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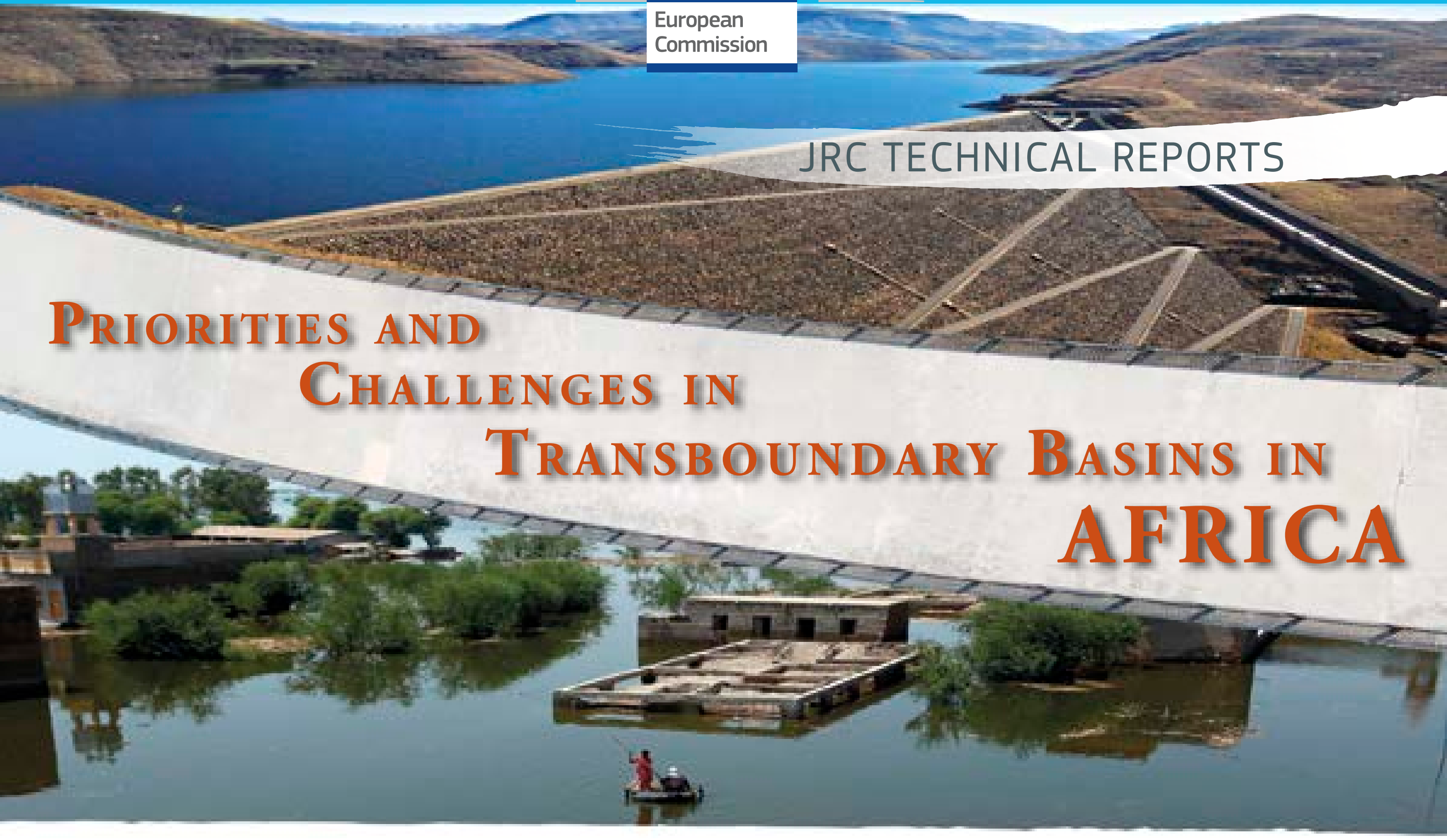

Priorities and Challenges in Transboundary Basins in AFRICA

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Coordinated by: European Commission

Every drop counts · Count every drop · AMCOW · African Ministers' Council on Water

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Executive summary

African ambitions for growth and transformation, as envisioned in the African Union Agenda 2063, depend largely on ensuring water security due to the influence of water access and use on the overall economic output. Besides, the Africa Water Vision 2025 recognizes the necessity of improving water wisdom to fulfil the aspiration of a prosperous Africa, based on inclusive growth and sustainable development Policy context.

In addition, water and natural resource management is under increasing pressure, due to a number of factors including climate change, population and economic growth, political instability and increased competition for increasingly limited resources in a context of global economy. Where resources are shared by several countries, as in the case of transboundary rivers, the management of these risks poses additional challenges, and the likelihood of a non-optimal or poor management is likely to critically affect the socio-economic conditions of the actors and countries involved. This could even lead to intra-basin tensions, jeopardising transboundary and inter-sectoral cooperation. In this respect, sub-optimal or poor management is likely to critically affect the socio-economic conditions of the actors and countries involved. This could even lead to intra-basin conflicts. Identifying appropriate and timely adaptation measures in this changing environment is one of the greatest challenges for development and cooperation.

The European Union, through the activities implemented by DG INTPA and JRC, in collaboration with its African partners (AMCOW, AMCOST, AUDA-NEPAD Centres of Excellence in Water Sciences, Regional Economic Committees and African River Basin Organisations) and Member States, has demonstrated to the international scientific and policy communities the importance of establishing forums for dialogue. They provide an opportunity to discuss and address the main regional threats, the identification of priority strategies and opportunities for current and future cooperation, as well as the need to develop pertinent and adapted human capacity programmes, develop and analyse data and information to support integrated management and policy decisions, particularly in transboundary basins, and to address the importance of sharing and maintaining information that affects the riparian countries.

To this scope, this preliminary report aims to provide a first-level assessment based on currently available knowledge, data and information for a selected set of African transboundary river basins (selected by DG INTPA). The focus is on water resources, not because of its dominance over other sectors, but because it is a cross-cutting resource shared by different sectors and a key driver of development in Africa. It should be clear that for this assessment, it is essential to develop a common and agreed knowledge base supported by objective and open data and information, in order to facilitate agreement and convergence of different sectoral policies.

Methodology and key findings

The preliminary analysis of key issues and priorities in diverse regions and contexts across the African continent has highlighted some common points of interest for the development and continuation of this assessment. As expected, some key factors have a clear and cross-cutting impact on all river basins, regardless of their specificities or levels of development. Amongst these, a self-evident but definite example is Climate Change and Climate Variability issues which have a direct impact on natural resources and people. These, and specifically Climate Variability in the short to medium term, must be taken into account (research and assessment at local scale) in future cooperation and development, as they are essential to consider in the identification and implementation of water management strategies. Other common drivers particularly challenging for all the African river basins analysed here are the increasing water demand (resulting from population and economic growth) and political instability that may result from the competition for limited resources and their unequal geospatial distribution and access.

This analysis of the most updated and relevant scientific and open access reports and publications supports the identification of key issues and priorities, as the capability to determine the root causes of the problems in a transboundary basin (knowledge of processes and ability to assess causes and effects of external factors and management) is key to facilitate and stimulate dialogue between decision-makers from different sectors and countries to improve agreements: data, monitoring and scientific evidence can be used as a basis for simulations to adjust and adapt policies and regulations which may differ between countries and areas of expertise. Scientific literature analysis should be also complemented with the involvement of local and thematic experts in order to take advantage of lesson and experience from history.

The analysis has been subsequently compared, contrasted and integrated (where appropriate) with programming literature and other sources (grey literature - information produced outside the traditional channels of rigorous publication and distribution). The latter deserve more rigorous analysis. Indeed, a common issue identified in several river basin is the dominance of specific sectors in the number of publications and research available (probably subject to the availability of data and the specific expectations and interest).

One criticism highlighted in the assessment is that many planning and reference documents (river basin authority strategy papers, project summary reports, policy reports, national reference documents) do not include the methodology and data used in most cases to identify the key issues for each river basin. This can introduce uncertainties and difficulties and is particularly important for joint and cross-sectoral analysis of problems: for example, to analyse and compare two or more river basins belonging to the same region and for which it would be interesting to carry out a joint analysis. It would be important for donors to have a common base of data and methods, in order to limit unexpected differences and, furthermore, to ensure the acceptance of alternative results by the different stakeholders.

In this study, a collection of scientific articles, technical literature and data supporting this continuous and ongoing process has been developed. However, it should be noted that in some cases, especially for specific regions within river basins, open data and scientific documents are not easily accessible or not available at all. This can only be addressed and completed through consultations with regional and local experts, grey literature and programme documents. In addition, a key requirement is the development of a database of past and ongoing projects in order to learn lessons, avoid overlaps and do more rigorous knowledge management that will benefit the identification and implementation of future projects.

Transboundary River Basin Issues and Relevant STI areas

Food security: In all Sub-Saharan Africa River basins a high level of food insecurity is still a major issue affecting almost 30% of the population. Food insecurity is still a key issue also in the more developed basins, especially in rural and remote areas (see for example the Kwando sub basin in the Zambezi and most of the countries (except SAF) in the Orange). Food issue is associated with: i) <u>Low agriculture productivity level</u>, scarce soil fertility management and volatile and unstable production because of Climate Change (CC) and Climate Variability (CV); ii) <u>Fish stocking management</u>: overfishing, not regulated (and illegal) catch, missing monitoring and control data, conflict among countries, alien species, etc.; iii) <u>Livestock management, pasture and transhumant movements</u>: identified issues are linked with limitation to mobility, degradation of rangelands and pasture productivity.

- <u>Actions and STI areas for development</u>: i) Strategies for improving soil fertility management to increase the resilience of traditional and rainfed system to CC and CV; ii) Assessment of irrigation cropping systems for the identification of causes of limited production below expectation and identified potential; iii) enhance the assessment and data collection to assess the link and nexus between pastoralism and agriculture; iv) assessment and data to ensure forage production and protect local species (see for example *Kuri* cow in the Lake Chad).

Management of flow regime, floods, droughts and CC: An important element arising out of these analyses is the existence of a <u>knowledge gap</u>, and above all the existence of a <u>controversial discussion</u> among the main causes of <u>land degradation and water balance</u> at river basin scales. Groundwater (GW) and aquifer system monitoring and knowledge is often reported as a priority but missing data and information are evidenced in most of the River Basins: indeed, GW exploitation is sometimes reported as low other times as very high, but regularly pointing out very poor knowledge (e.g. reported evidence of depletion but with high uncertainty as limited data and modelling capacity available). Impact of CC always identified as a key issue even if the specific impact on different sectors is still controversial and requires documented regional assessment (to take into consideration regional specific elements, downscaling of CC scenarios and specific impact of local CV impacts on the short term).

- **Actions and STI areas for development:** i) a key action identified and shared by all the stakeholders is the need for the development of agreed and shared data, knowledge and human capacity development across the riparian countries; ii) development and enhancement of scientific, objective and open data, models and monitoring that contribute to further understand the phenomena and the potential mitigation and adaptation solutions; iii) optimal water level and release quantification and management in the reservoirs and lakes; agreed identification of dominant causes impacting floods (specifically in the Niger), assessment and resolution of competition between sectors (tourism, hydropower, agriculture, environment, etc.); definition and agreement (among countries and users) for river environmental flow (spec. in the Orange); improve scarce monitoring and knowledge of water balance data (see the Okavango); clarify the ongoing debate on land-use changes and impact on soil water holding capacity in the Senegal.

Management of increasing water demand: In general, a very high increase is expected for agriculture and hydropower sectors in most of the river basins. Specifically an increasing and stronger competition between hydropower, irrigation, navigation and natural flow is clearly expected: in the White Nile (Lake Victoria) this is particularly evident for navigation and because of pressure on wetland; in the Niger the figure is quite complex and irregular across the river basin (development of new dams upstream, impact on the Inner delta, navigability in the middle Niger, erosion issues in some regions, not efficient use of water release by irrigation systems, exploitation pressure already very high during dry seasons, relative small capacity for GW exploitation etc.); in the Zambezi large water transfer systems are under discussion and would need a more equitable water allocation among riparian countries. In the Lake Chad high GW exploitation level for drinking water is already identified. In the Orange water demand and resource sharing is specifically under discussion for Namibia and South Africa.

- **Actions and STI areas for development**: i) Enhance Basin-Wide Water management plan and assessment specifically important to identify optimal and agreed water allocation among the countries. ii) Even if the trade-offs between sectors users and water demand have been someway already identified and assessed (see Senegal RB), still uncertainty remain specifically for traditional food production systems that as water user are much more sensitive to hydro-climatic condition and external factors which should ensure traditional system water demand allocation; iii) increase data and knowledge for the quantification of growing demand from all different sectors and the assessment of their cross-sectoral links. vi) Raising awareness of the need of a new management approach: shift from looking into ways to increase water supply to looking into ways to improve management of the water available. v) Dissemination of strategies and best practises for: increase the use of recycled water, more efficient irrigation system (drip vs flood), improve water accounting systems, and improve cropping system water productivity. vi) Research and strategies for the identification of more equitable water allocation among users, regions and countries.

Addressing water quality issues and health related diseases. Biological water quality is a key issue in all river basins, whereas anthropogenic chemical pollution of the environment is not, given the degree of its development, a priority problem for human health and the environment. Indeed, in some cases, chemical pollution is identified as a key problem in several areas and programmes, but it should be noted that most of these problems are usually very local in nature and are well localised, e.g., near large cities, extensive industrial agriculture, mining, etc. They are also specifically related to occupational risks and hazards. In contrast to the European context, pesticides are not currently a generalised environmental risk in river basins, but rather a risk to workers' health, due to poor management of domestic and industrial processes and waste. Diarrheal, Bacteria and water borne diseases (such as Malaria, Schistosomiasis, Filariasis, Dengue, Yellow Fever) are mostly associated with urbanisation and alteration of ecological systems. These diseases are a key issue for all river basins analysed. Other important issues captured in several case studies are: Mercury issues in the area of gold mining (White Nile, Mali and Guinea in the Niger RB, Orange RB, and Senegal RB) and other mining related contamination problems. Pollution with agrochemicals, eutrophication and industrial impact is mainly due to untreated urban effluents, domestic, industrial and livestock waste. Pesticides normally are below law limits, but some local specific issues persist: for example, for cocoa plantations. Micro and small macro plastic issues in water are also detected (specifically in the Lake Victoria (Nile) and in the Delta of Niger RB). Land degradation with loss of biodiversity, deforestation, landuse and landcover changes, proliferation of invasive species, desertification and bush fires, and indoor air pollution.

- **Actions and STI areas for development**: i) Assessing and mapping the risks related to biological water quality and water-borne diseases that should be flagged with greater urgency and included as a negative impact in the development and assessment of new dam and irrigation infrastructure projects. Explore non-invasive solutions such as those proposed in the Senegal RB; ii) Improved research and monitoring: Basin-wide monitoring and mapping of bacteriological water quality and waterborne diseases, specifically for all new dam/irrigation projects. Specific environmental impact assessment and mapping of mining and oil projects; iii) Establishment of a groundwater monitoring network; iv) Mitigation: Improving wastewater treatment and waste management, awareness raising and technology transfer are needed in the area of waste management and recycling; v) Evaluation of wetland restoration and erosion control programmes.

Management of water-energy sector: In this assessment, the focus is on the analysis of issues related to hydropower, mainly highlighting the current hydropower production in the river basins and the expected potential for the coming years. Hydropower is dominant in Lake Victoria (White Nile) basin, but with evidence of water shortage issues (Burundi). In some river basins, it is reported that hydropower potential is not yet highly exploited (e.g. in the Niger RB where it is argued that only 1/3 of the potential is exploited). The need for a more complete assessment of the conflict and impact on other sectors has been often identified as a priority (see competition with navigation services and natural flow requirements in the Lake Victoria, flooding impact evidenced in the Niger RB, Senegal, and Zambezi). In the Senegal RB, dams are currently satisfying about 18% of the energy demand but impact on other sectors are already an argument of stress, conflicts and tension between different users. Inefficiencies inherent in large dams have been identified (evapotranspiration losses, impact on local ecosystems, maintenance problems, etc.). A frequent issue identified is the need to reduce fuel wood and charcoal demand that is still dominant in most of the basins. Limited connection to existing grid (low electrification rate) is often an issue for most of the rural areas: even RBs with high hydropower and energy production would need an improvement of transmission network to ensure an equal and fair redistribution and allocation of energy.

- **Actions and STI areas for development**: i) explore the potential of small hydropower plant to support rural electrification and the synergies with other sources (biogas, residues valorisation, PV, Floating-PV and Solar) ii) support multi-purpose infrastructure and cost benefit analysis iii) solve transboundary water disagreement (see e.g., South Africa and Namibia in the Orange, upstream and downstream countries in the Nile) and move to equitable (energy and water) resource allocation. iv) Explore alternative solutions to mitigate reservoir management inefficiencies by implementing, for example, floating PV system limiting evaporation loss; ii) research for the identification of alternative energy production to reduce fuel wood and charcoal dependency (e.g., improved stoves).

Related and future work

Some important steps and actions to integrate and further develop the assessment and the come to final key priorities and STI activities are:

- Identification of cross-cutting issues for the river basin belonging to common regional areas.
- Identification of potential adaptation solutions identified for some river basin that can potentially be applied and transferred to others.
- Identification of key data gaps and areas where intervention is more urgent (see for example the general and shared issue of groundwater monitoring and assessment, that is reported in most of the regions and which has so far received little attention, perhaps giving more importance to the analysis of surface water resources, but which is now identified as one of the most important priorities in the light of the CC and the increase in pressure and demand.
- Mapping of key issues: mapping of key layers and data would be implemented in a WebGis system to facilitate the interaction with local experts and stakeholder.
- Identification of capacity building needs at technical, scientific and management levels. It is important to identify capacity building needs (scientific, technical and management) on the basis of the identified priorities, given the great heterogeneity of both cross-cutting and transboundary basin issues.
- Mapping of risk and potential tensions areas related to competition between sectors but also between riparian countries and local populations for natural resources which are under strong pressure due to CC and CV as well as high population growth in Africa.

Quick guide to read the short report

This preliminary report provides a brief overview of the selected river basins, focusing on the identification of the main challenges and potential priorities as well as the Science, Technology and Innovation (STI) issues that should be developed based on current knowledge. The list is not intended to be exhaustive, but a first mapping of concrete key challenges, objectively selected and identified on the basis of current scientific and technical data and knowledge, with the objective to feed the discussion, criticism and final choice (and ranking) thanks to the involvement of stakeholders and managers (from AUDA-NEPAD Centres of Excellence in Water Sciences, Universities, EU Delegations, River Basin Organisations, AU institutions as AUDA-NEPAD, AMCOW and AMCOST).

In order to provide a common logical framework, the preliminary results of the assessment are presented by specific thematic box (see Figure 1 for list). The key priorities and issues have been summarized at two levels: 1) first at the thematic level, with a summary list (see boxes); and, 2) at the watershed level.

All these detailed questions and factual information are finally necessary to obtain a more synthetic (and ranked) list of key priorities for the river basin and riparian countries. Indeed, at the end, a chapter containing a preliminary summary list of key challenges is presented. A summary map aiming to display the key layers and spatial data related to water and the different WEFE NEXUS sectors (Water, Energy, Food Security, Environment) in the transboundary basin is also presented; This map will also be shared (in a second phase) through a WebGis portal (AQUAKNOW) to facilitate discussions and consensus with local experts, managers and stakeholders who will participate in the spatial analysis of the identified problems.

Figure 1. Thematic specific topics.

1 Introduction

1.1 Not only science, but also Human Capacity Development

African ambitions for growth and transformation, as envisioned in the African Union Agenda 2063, depend on ensuring water security due to the influence of water access and use on the overall economic output. Besides, the Africa Water Vision 2025 recognizes the necessity of improving water wisdom to fulfil the aspiration of a prosperous Africa, based on inclusive growth and sustainable development. However, the current situation regarding Human Capacity Development (HCD) in Africa is worrisome: according to the African Development Bank, the continent has only 35 scientists and engineers per million inhabitants, in comparison to 2,457 for Europe and 4,103 for the United States. Hence, Africa needs to foster its progress in science, technology and innovation, but African students generally show preference for social and economics subjects and the presence of capacity constraints in the water sector threatens the achievement of Africa's development agenda. Besides, the low investment in research and development constitutes a barrier to the global competitiveness and productivity of the continent.

In order to add value, HCD programs in the water sector must reflect national circumstances, be informed by appropriate institutional schemas and integrate sectorial and national development aspirations. Therefore, they should be designed to overcome several challenges already detected through previous experiences, such as the lack of clarity about the focus of HCD programs aimed at junior water professionals and technicians, the inadequate connectivity and collaboration between key institutions, the performance of non demand-responsive HCD assessments (whose outcomes were generally neither institutionalized nor sustained), the existence of academic and Technical and Vocational Education and Training (TVET) programs unable to properly address the sectorial needs (and which trigger a negative perception of the industry towards the new graduates) or the absence or inadequacy of specific internship or mentorship initiatives for students.

In this context, the education and training sector in Africa is currently undergoing strategic reforms, which could offer a suitable framework to identify and implement the main HCD priorities for the water sector. Concretely, these priorities could be divided into four broad categories (JRC-ACEWATER II Technical Report - Mbaziira, 2020a):

1. Building critical skills: particularly, in the fields of sustainable development and the management and use of water and related resources. The main goal is to foster economic growth and social transformation, through the encouragement of technological empowerment, e-education and adaptive learning.
2. Fostering transformation in the TVET sector: in order to integrate flexibility, adaptability and continuous learning in the education and training supply.
3. Supporting space science and astronomy research, teaching and outreach: the application of space science and technology to effectively manage resources such as water, land, forests, and marine ecosystems offers multiple opportunities that are currently unleveraged. The use of space technology is also of key relevance in the generation of acutely needed information to support decision making for the sustainable utilisation of the resources.
4. Recognition of competences from non-formal and informal education and training (NFET): this significant goal is twofold. First, to ensure the access to existing technological preferences, cultural practices, local values and traditions of community learning to impart life skills. And, secondly, to contribute to the integration of mainstreaming indigenous water and pollution management knowledge into lifelong learning systems.

1.2 The EC response

In this context, the EU is actively cooperating with the AU in several policy initiatives framing the demand for the WEFE nexus approach to water development in Africa. Concretely, the Water, Energy, Food and Ecosystems for Development (WEFE4Dev) work programme of the JRC Water and Marine Resources Unit implements initiatives in collaboration with the directorates of International Partnerships (DG INTPA) and Environment (DG ENV) on WEFE Nexus assessment in relevant river basins in Africa. The integrated multi-sectoral approach to water management at the river basin level is combined with proactive and all-inclusive cooperative dialogues. The dialogues draw participation from the policy organs and decision makers of such African institutional partners as River Basin Organisations (RBOs); Regional Economic Communities (RECs); and research and academic institutions – including the AU-NEPAD Water Centres of Excellence.

With regards to the human capacity development activities, the JRC, in collaboration with the UNESCO-IHP, is supporting and coordinating the implementation of the African Networks of Centres of Excellence on Water Sciences (ACE WATER) project. Its second phase (ACE WATER-II) aims to foster sustainable capacity development in the water sector at the scientific, technical and institutional levels. A key aspect of the project is the alignment of the identified

HCD priorities with the current implementation of the strategic and operational plans of the NEPAD Centres of Excellence (CoEs). Therefore, the project aims to build synergies and complementarities and to avoid the duplication of efforts, maximizing results and impacts through the optimal use of available resources. Hence, the role of monitoring and evaluation (M&E) should be highlighted, in terms of relevance, efficiency and effectiveness.

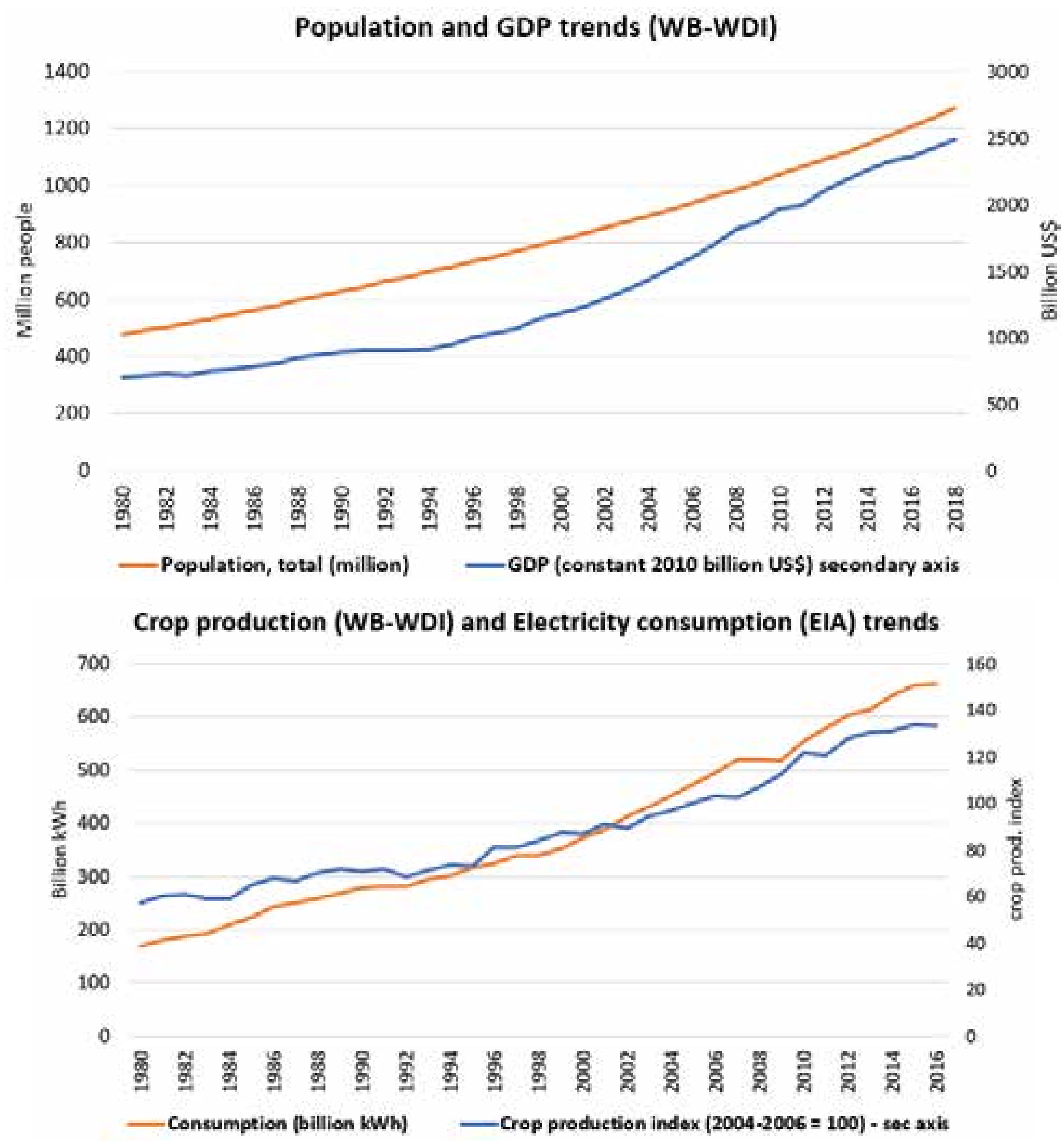
Concretely, activities conducted within the project framework include the celebration of regional consultative workshops and national dialogues with the main stakeholders, aiming to assess HCD needs in the water sector at different scales, to identify potential links to other relevant initiatives, to validate the outputs of the process and to inform its implementation. Pilot training courses were also a key part of the project and a difficult one due to the COVID-19 pandemic: it was necessary to perform a risk mapping and e-readiness assessment, in order to realign the planned courses and implement them online. Finally, M&E was carefully tackled through a specific developed tool, along with impact studies to assess the real significance of the project. In this regard, it should be highlighted that the role and visibility of the EC/JRC in the water sector in Africa has improved strongly thanks to the relationships established with the CoE and with their partner institutions in the water sector.

2 Past and current state of the WEFE nexus in the African continent

2.1 State of the art knowledge on WEFE nexus in the continent

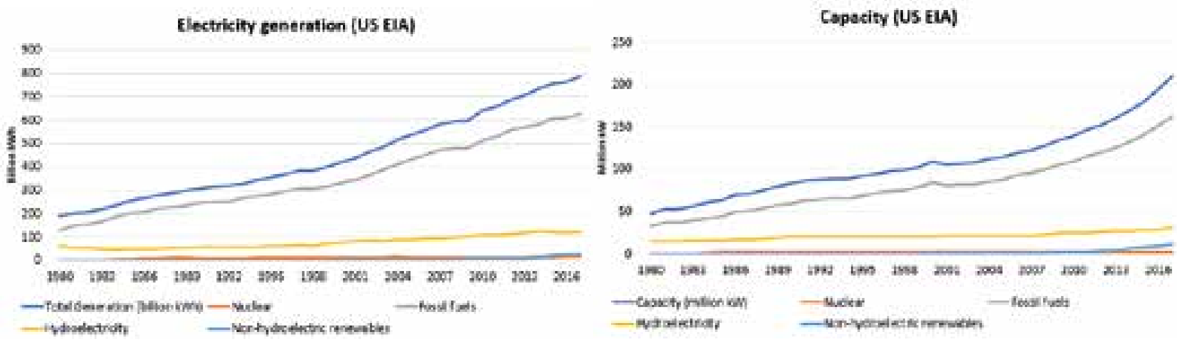
The African continent is today the house of about 1.27 billion people, corresponding to roughly 16% of the world's population. In the past decades, demand for energy and food increased along with the population and economic growth. Crop production rose by more than 35% between 2006 and 2016, while demand for electricity increased by more than 20% in the same period. Current agricultural production is mainly rainfed. Irrigation is highly developed in arid areas along the main rivers in Sudan, Egypt, Mali, Niger, Nigeria, Senegal, Namibia, and Zimbabwe. Only a minor fraction (about 5%) of the poorly available water resources are currently withdrawn, primarily in the Northern portion of the continent and mainly used for agriculture. Large investments in new irrigation facilities are foreseen in the coming years (FAO website accessed on 2020).

Figure 2. a) Population and GDP trends in the African continent 1980 – 2018 (World Bank, n.d.); b) crop production index (2004-2006 = 100) and electricity consumption trends1980 - 2016 (US EIA, n.d.; World Bank, n.d.).



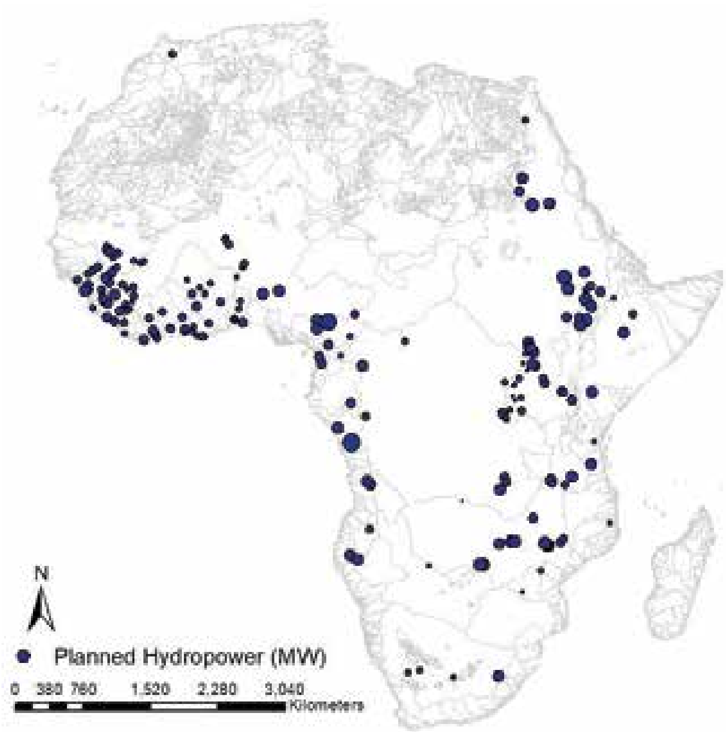
Majority of the electricity is produced in the continent in a network organized in 5 power pools which are slowly getting more integrated (IRENA). Hydropower represents the main renewable electricity production source in the continent and the second after fossil fuel powered thermal production (Gonzalez Sanchez et al., 2020a; US EIA, n.d.).

Figure 3. Electricity generation (billion kWh) and installed capacity trends (million kW) in the African continent (US EIA, n.d.).



Large investments directed towards the expansion of hydropower capacity are foreseen for the coming years, which will be translated into more than 200 new facilities according to Zarfl et al (2015). The majority of these new installations are planned to be implemented in the most water abundant basins and the wettest areas of the continent.

Figure 4. Planned hydropower projects in the African continent (Zarfl et al., 2015).



In addition to the hydropower development, several ambitious water transfer projects are being considered in the main basins of the continent. Some of them are in an advanced stage of development, as the “Lesotho Highlands Water Project” between Lesotho and South Africa, or the “Mzimvubu” and the “Mokolo and Crocodile River Water Augmentation” projects in South Africa. Other are in a less mature state of implementation, as the “New Nile” and the “Transaqua” projects, which plan to diverge water from the Congo basin to the Nile and towards Lake Chad respectively (Shumilova et al., 2018). Additional water transfer schemes were designed for the Zambezi basin, between Zambia, Namibia, Botswana, and Zimbabwe.

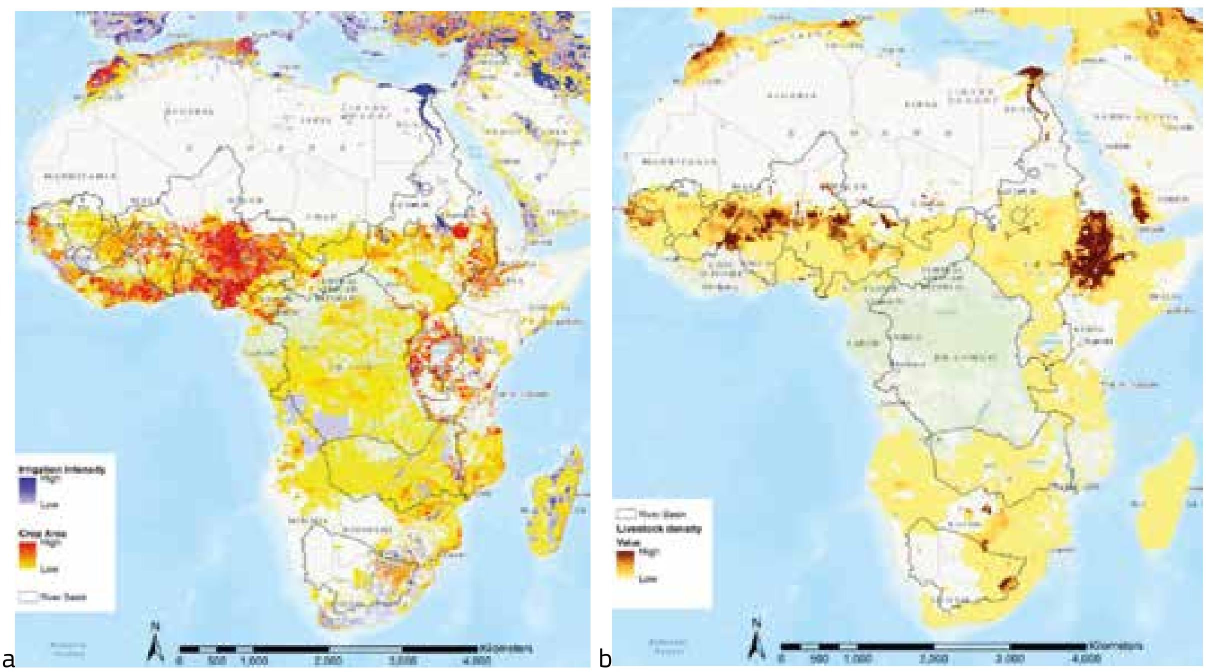
2.2 Water and Agricultural sector

The increasing demand for crops and other agricultural products is projected to increase following the population growth in the continent. According to a recent outlook (OECD/FAO 2020), population in the continent is expected to expand by more than 300 million people in 2030, boosting the demand for agricultural products and increasing the production by about 21% in terms of net value added (about 16% represented by crop production, 5% livestock and fish farming). Main outputs are expected to be represented by roots and tubers, grains, and cotton. The increased agricultural production is projected to be mainly the result of cropping intensification and increased production efficiency, but it will also soar the demand for agricultural land, with the harvested area expected to expand by about 4 Mha.

Demand for animal proteins, as bovine and ovine meat and poultry, is projected to grow steadily in the coming decade. The derived production growth will be mainly allowed by a modernization of the farming supply chain and techniques, but it will also cause an estimated 18% increase in GHG emission from the agricultural sector. Population growth remains the main factor determining the expansion of the overall agricultural sector, but also per capita consumption is expected to increase by 75 Kcal/day, reaching about 2510 Kcal/day. This value, despite being the world's lowest one, brings the African per capita consumption figures to about 80% of the world average (OECD/FAO 2020).

The continental agricultural market is expected to largely benefit from the implementation of the African Continental Free Trade Agreement signed in 2019, ensuring a reduction of the transaction costs for more than 90%. The main constraints to the agricultural development are represented by the limited access to technology, lack of infrastructure, fragmentation of the suitable arable areas, limited water resources and large climate variability, and limited access to irrigation techniques in the areas where arable land is mostly available (OECD/FAO 2020).

Figure 5. left) Crop and irrigated areas; right) livestock distribution. (JRC Technical Report. Water Atals - Farinosi et al 2018b, Malagó and Bouraoui, 2021; You et al., 2005 on MapSpam data). The figure reports also the boundaries of the main African Transboundary River Basins.



2.3 Water and Energy Nexus

In most African energy systems hydropower is the dominant renewable energy source and, according to the World Bank, electricity and water demands are projected to grow significantly up to 2050 in the continent, by 700% and 500% respectively, with respect to 2012 (Rodriguez et al., 2013). Other salient characteristics of these systems are their low electrification rates, small sizes, high shares of oil in the power generation mix, and the lack of significant power and gas interconnections.

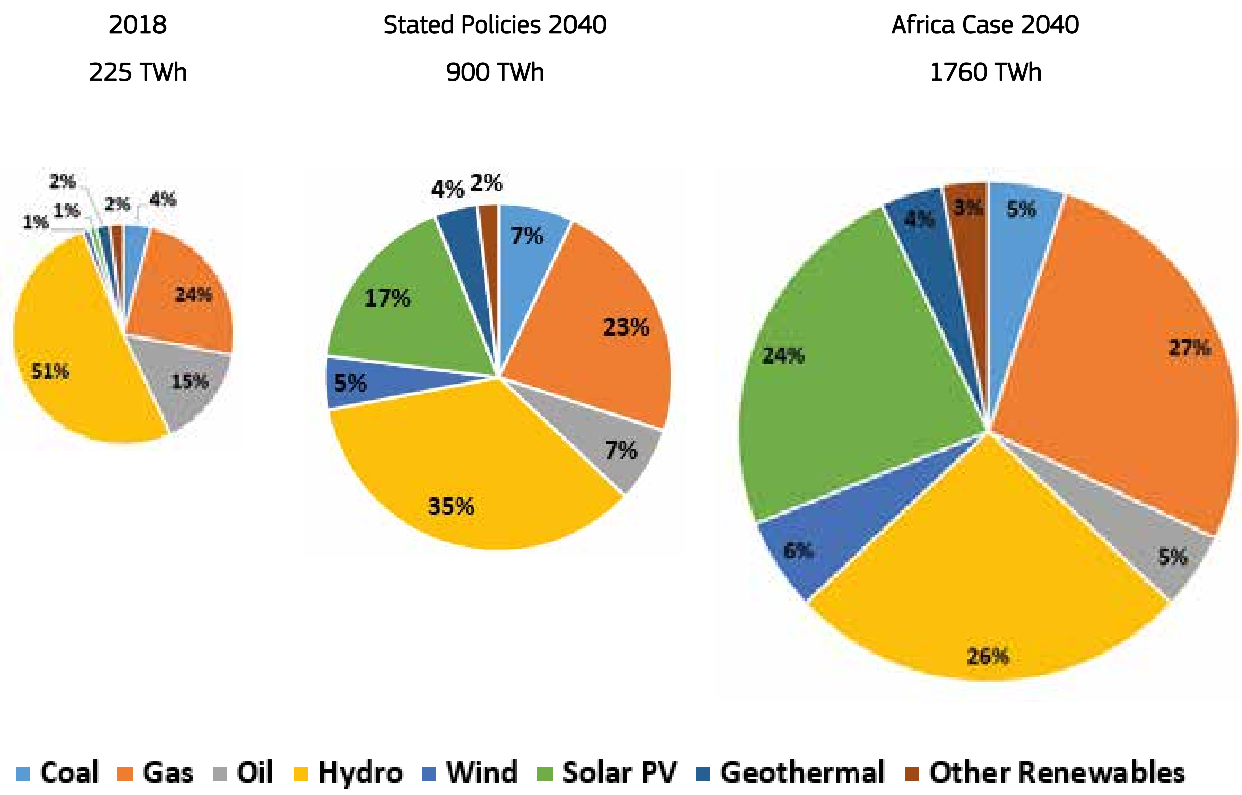
Power systems are constrained both by the availability and temperature of water resources, as thermal power plants need water for cooling and hydropower generation relies on water to operate. Therefore, climate variability has a strong impact on African energy systems (where hydropower is the dominant renewable energy source), affecting their energy mix, operational costs, CO_2 emissions and water consumption for energy generation. For example, in the North, Eastern and Central African Power Pools, differences between dry and wet years could vary the share of electricity coming from hydro units up to 5.2%, introduce changes in the operational costs around 1.4 billion € (or 3.28 €/MWh) and induce oscillations in CO_2 emissions up to 15 millions tons per year. Besides, power systems may impact in the quantity and quality of the water resources. For example, water losses due to hydropower generation in Africa cannot be ignored: 42 billion cubic meters in 2016 (when the correspondent to all the other fuel types combined were estimated at 1.2 billion cubic meters). In this context, the use of non-hydro renewable energies instead of fossil fuels can contribute substantially to reduce water use while meeting the increasing energy needs of the continent (Gonzalez Sanchez et al, 2020a). Moreover, grid interconnections could play a significant role, reducing water withdrawals and consumption for energy generation in comparison to the existing system configurations, as well as the average electricity price.

The energy mix in Africa is expected to undergo significant changes in the next decades. Fossil fuels (gas, carbon, oil) will continue to contribute a significant share of the energy production, still with oil expected to significatively shrink. On the other hand, from the renewables perspective, the share of hydropower production is expected to decrease as well, with most of the investments being drained by Solar PV and wind industry.

In this complex framework, the geothermal energy, that currently accounts for a marginal share (2% of electricity generation in Sub-Saharan countries, excluding South Africa), will anyway experience a large increment of generated energy and then of installed power, up to estimated 4% in 2040. Among the main advantages of this energy source are its low environmental impact and greenhouse emissions when compared to energy generated using fossil fuels; a quite constant generation output independent from weather conditions (which makes it particularly suitable for base load electric generation); a competitive levelized cost of electricity generation (LCOE) and; less proneness to the instability of the international Oil and Gas (O&G) market. In this context, the East African Rift System (EARS) geodynamic context creates highly favourable conditions for the existence of geothermal systems at economically and technically drillable depths (less than 4,000 m), with a global potential estimated at 15,000-20,000 MW. However, currently only Kenya has exploited a small part of its geothermal resources, because the development of this energy source in Africa is still hampered by the absence of clear and coherent legislative frameworks; the lack of local technical and managerial skills; the remoteness of many geothermal areas in relation to O&G regions (where most of the drilling contractors and service providers are based); the inadequate financing at the early stages of the projects; the competition from other energy sources and; the issue of the remunerative price for the generated electric power in still poor developed national electric markets (JRC Technical Report – ACEWATER II Project - Battistelli et al., 2020).

Despite the apparently limited relevance of the geothermal energy, it is worth to note that few countries retain most of the potential, and particularly few small countries could largely cover most of their electrical energy needs (e.g. Djibouti, Comores).

Figure 6. Electricity supply by type, source and scenario in sub-Saharan Africa (excluding South Africa). Source: IEA. Africa Energy Outlook 2019. World Energy Outlook Special report.

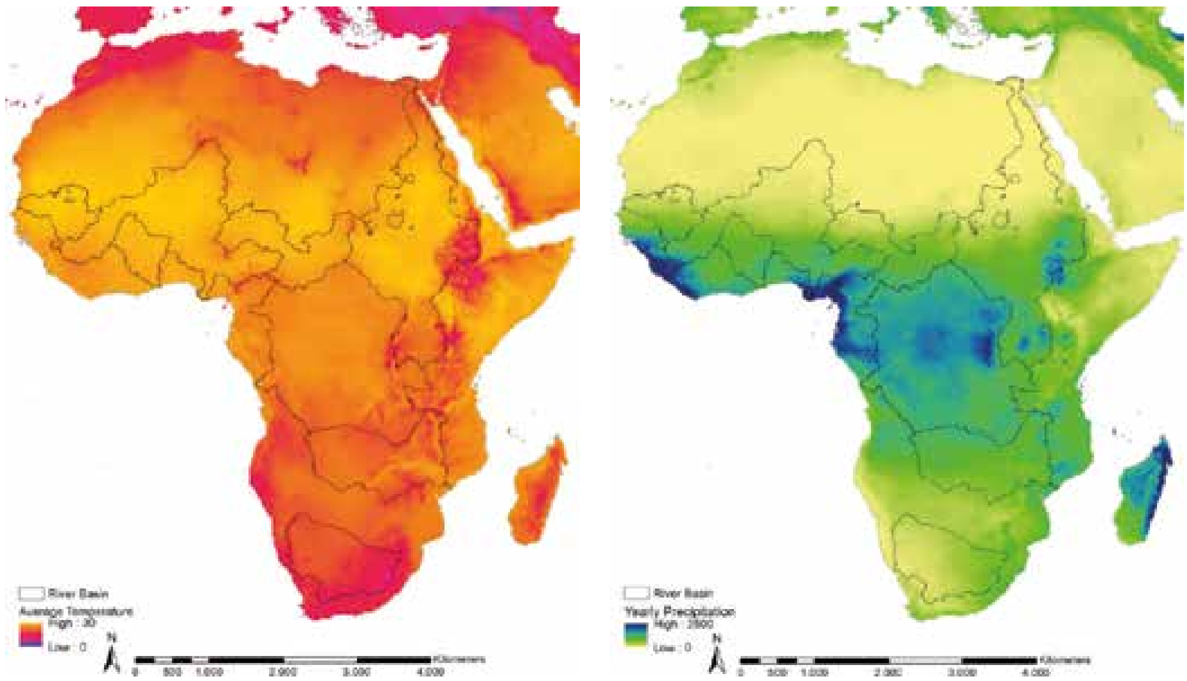


3 Future challenges 1 - Climate analysis current vs future

3.1 Climatic characterization of the continent

The continent is characterized by particularly scarce precipitations unevenly distributed over space and time (JRC Policy Report – Neuville ET AL., 2017). Areas characterized by a relatively more abundant precipitation are localized in the Western African coastal area, in the Gulf of Guinea, Equatorial Congo, Lake Victoria area (Figure 7).

Figure 7. (left) Average Temperature (°C) and (right) yearly total precipitation (mm) in the study domain in the period 1997-2012 (Farinosi et al. 2018b based on Beck et al., 2017 data).

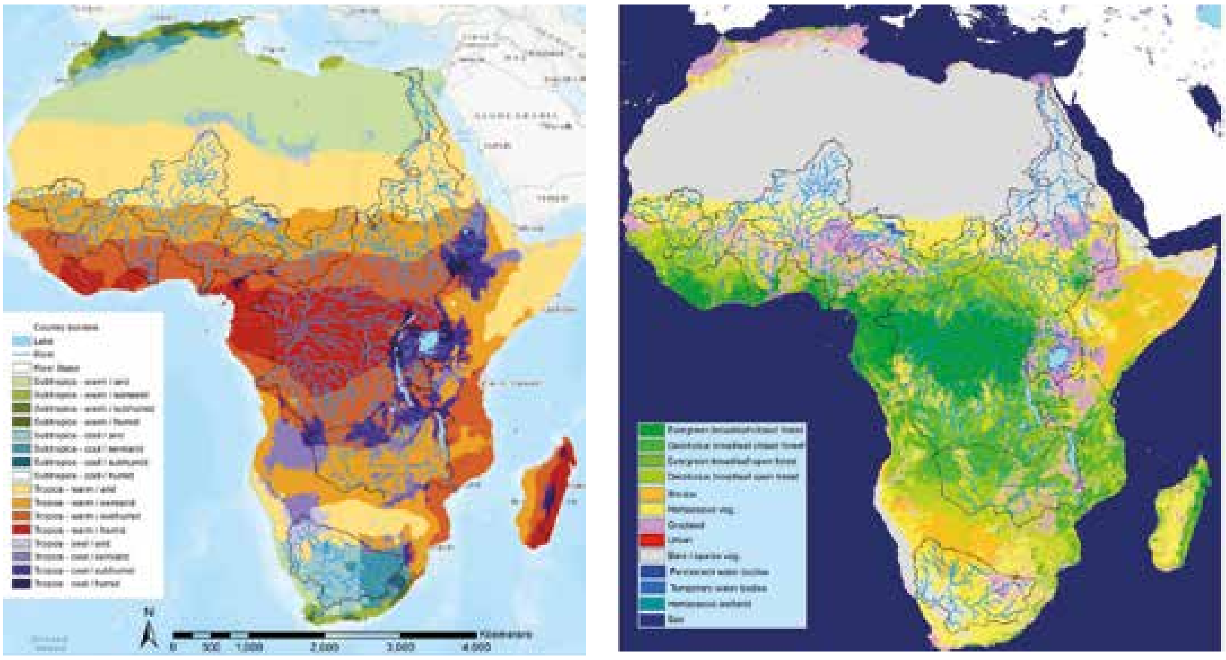


Excluding the most arid areas, precipitation patterns are characterized by a strong seasonality. Intra- and inter- annual climate variabilities are extremely high and cause a large uncertainty with regard to the management of natural resources in the most water intensive anthropological activities, as agriculture (Nicholson et al., 2018).

The Sahelian region has a pretty uniform precipitation pattern: after the 1960s, the precipitation heavily declined in relation to the relatively more abundant first part of the XX century, slightly going back toward an increase after the 1980s (Nicholson et al., 2018). Precipitation anomalies are heavily affected by the oceanic oscillations in sea surface temperature. Looking at the precipitation records, a decadal variability is apparent in the precipitation records after the 1930s; the Western and the Northern part of the continent experienced a significant downward precipitation trend in the past decades, with conditions radically changing after 1968 (Nicholson et al., 2018). The downward trends extended to a large part of the continent following the 1977/1978 La Nina driven shift in the Pacific equatorial area.

Figure 8. a) Agro-ecological zones (Farinosi et al 2018b based on Sebastian, 2009 data); b) Land cover map (JRC Technical Report - Farinosi et al 2018b based on Copernicus Service Information, 2017 data).

a b



The increasingly dry conditions heavily affected the already precarious food security position of the sub-Saharan African growing population. Looking at the projected precipitation trends for the coming decades, the situation does not seem to change towards more favourable circumstances (Dosio et al., 2019). Over the Northern portion of the continent, the precipitation regimes are not projected to change considerably. Besides, models do not agree on the possible changes in mean precipitation over Western Africa: some models projected slightly wetter, other dryer conditions. Most of them agree, however, in a reduction of the precipitation frequency and an increase of the dry spells over the region. Eastern Africa is projected to experience a slight increase in the mean annual precipitation, but in combination with an increased intra-annual variability, with more precipitation in the wet season and increasing dry spells in the dry one. Central and, in particular, Southern Africa are expected to undergo a major decline in the precipitation trends, both in terms of annual average and wet spells (Dosio et al., 2019). Dry spells, heatwaves, and drought conditions are likely to be more frequent and intense in the coming decades (Dosio, 2017; Dosio et al., 2018; Naumann et al., 2017; Spinoni et al., 2019), while more frequent floods are likely to hit the wetter portions of the continent (Alfieri et al., 2017).

The combination of the main hydro-meteorological hazards are expected to generally increase, especially in the regions where population change is projected to be more significant (JRC Technical Report - Farinosi et al., 2019; Migali et al., 2018).

4 Future challenges 2 -Socio-economic drivers determining water use in the continent

4.1 Trends in climate extremes under different global warming scenarios

According to the most recent socio economic projections, the African continent is expected to witness a considerable increase in the population figures (which are estimated to pass from 1.27 to 2 billion people in the coming decades, up to 2050; JRC Policy Report – Neuville et al., 2017; Riahi et al., 2017). The different combinations of evolution, socio economic development and migration scenarios, are likely to change considerably the demographic variables in terms of fertility, mortality, age distribution, literacy, employment, and distribution of the economic resources (Riahi et al., 2017).

Climate change is expected to strongly impact the African continent and in particular the already stressed water resources (Farinosi et al., 2019). The evolution of the climate related dynamics is particularly impactful when combined with the socio-economic progression of the continent. The largest population change and a large part of the economic development worldwide, in fact, are expected to take place in the African continent in the next decades. Here it is presented a preliminary analysis of the potential exposure of population to future changes, with regard to the most impactful hydro-meteorological events in Africa under three Global Warming Level (GWL) scenarios.

Taking stock from the work conducted at the JRC in the specific fields (Alfieri et al., 2017; Dosio et al., 2018; Naumann et al., 2018), this analysis assessed the exposure of current and future African population to the increasing magnitude and frequency of collocated hydro-meteorological multiple hazards (drought, heatwave, and flood) under the Paris targets, respectively implying, 1.5 and 2 °C increases in Global Mean Surface Temperature (GMST) over pre-industrial levels (Frieler et al., 2017; Hoegh-Guldberg et al., 2018). In order to assess also the possible consequences of the inability to meet those targets, we considered an additional scenario which portraits a Global Warming Level (GWL) of 3°C, beyond the Paris targets (Raftery et al., 2017). The projections in climate extremes were combined with projections in population growth from the Shared Socio-Economic Pathways 3 (SSP3) (Riahi et al., 2017). The evolution of the hazards was studied both separately and conjointly, in order to better understand how the synergies between multiple hazards, expected to reinforce one another, could threaten the future population in the continent. In particular, the analysis of the multi-hazard combination was conducted through the analysis of the distribution of the population share exposed to the overall hazard, and the analysis of the specific dynamics of the three combinations.

Taking West Africa as an example (and considering a normalized scale where 0 represents the lowest multi-hazard magnitude and 300 the highest one), in the baseline scenario 100% of the population (~300 million people) is expected to be on average exposed to a multi-hazard magnitude larger than 25 (interquartile range 0-40), while the most exposed 10% (~30 million people) could face up a value above 100 (75-135). In a 3°C GWL scenario, 100% of the population (projected to increase from ~300 to ~790 million) would be exposed to a multi-hazard average magnitude greater than 50 (15-70), while the most exposed 10% (~79 million people) would deal with a magnitude of about 200 (165-250). More in general, the increase of the multi-hazard exposure between 2°C and 3°C is considerably higher than between 1.5°C and 2°C scenarios.

The rise in multi-hazard exposure over the Mediterranean Region (+120% in a 1.5°C, +200% in a 2°C, +400% in a 3°C with respect to the reference scenario), North-East and West Africa (with similar increases of about +200%, +300%, +700% respectively) results from the combination of changes in both the hazards frequency and population exposed.

Figure 9. Spatial distribution of drought (SPEI – standardized precipitation and evaporation index) and heat wave (HWMId – Heat Wave Magnitude Index) at global level (Farinosi et al., 2019).

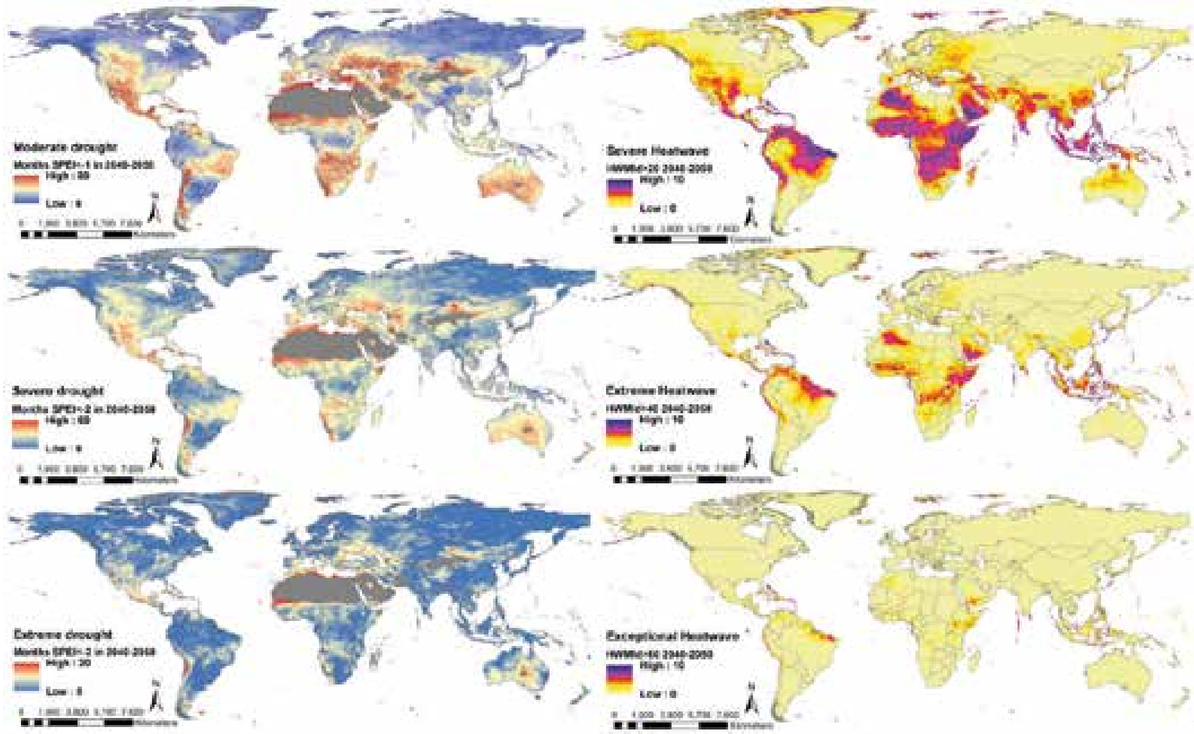
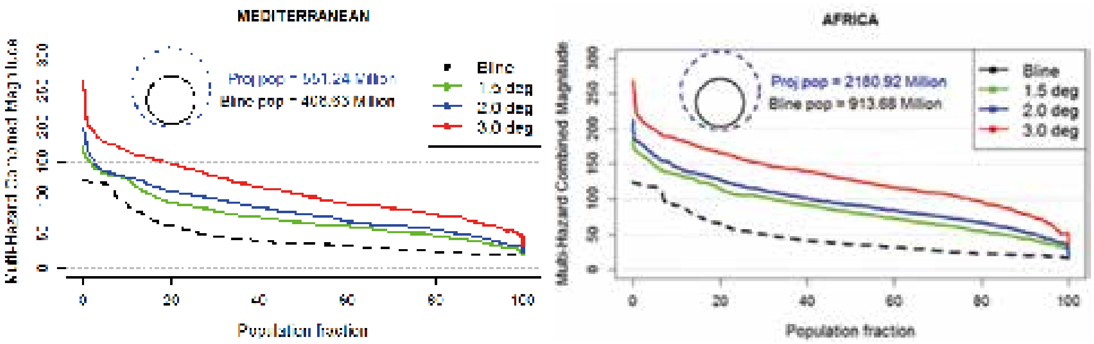
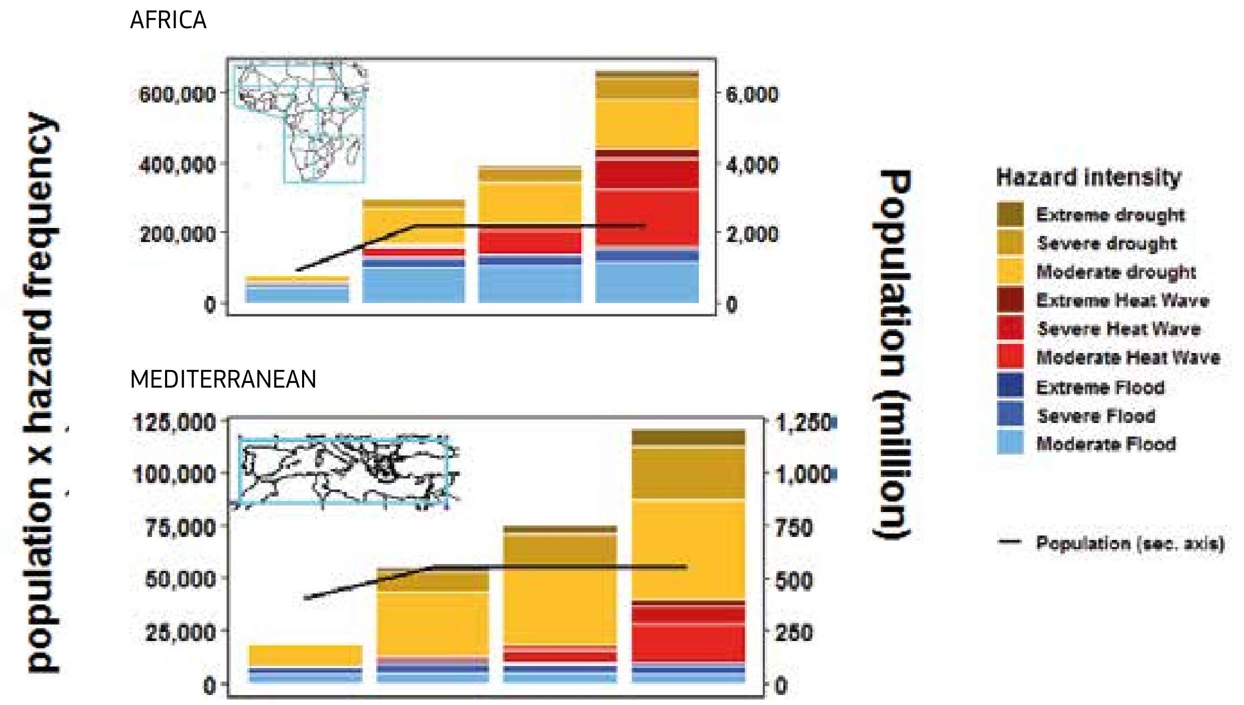


Figure 10. a) Share of the population exposed to the multi-hazard situation (combined magnitude normalized to a 0-300 scale) for the reference and global warming levels by continent; b) Continental level, population exposure to the three degrees of the intensity (moderate to extreme corresponding to lighter to darker colours) of the three hazards (flood-blues, heat waves-reds, and drought-browns) for the three warming levels (Baseline, 1.5, 2, and 3 degrees increase in GMST). The black lines show the population (in million on the right axis) between 2010 (baseline) and 2050 (projection). Left axis represents the exposure level, here defined as Exp=Pop*Haz (population times hazard frequency) (Farinosi et al., 2020, 2019).

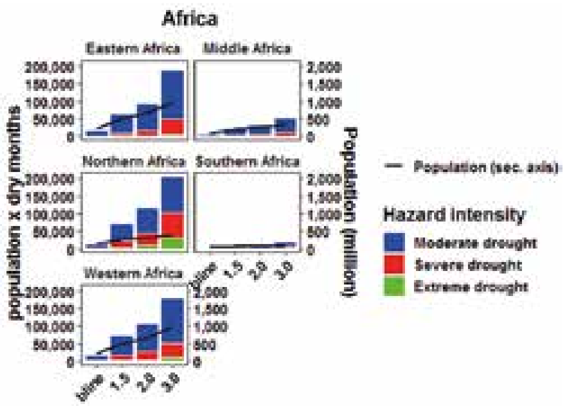




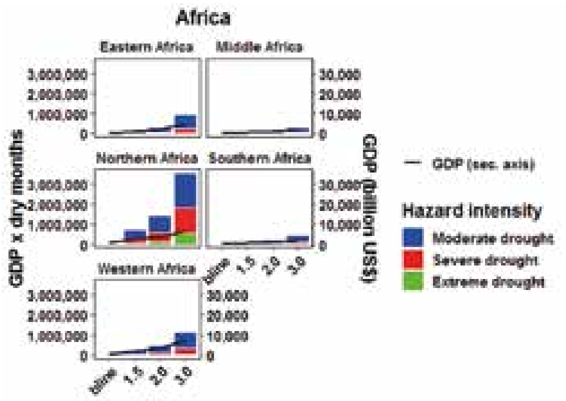
Breaking down the exposure of population and GDP to the different classes of the three hazards, the increase with the GWL is evident in all the cases for each of the African regions.

Figure 11. Exposure of population and GDP to the hazards considered in the African Regions (Farinosi et al., 2019, 2020).

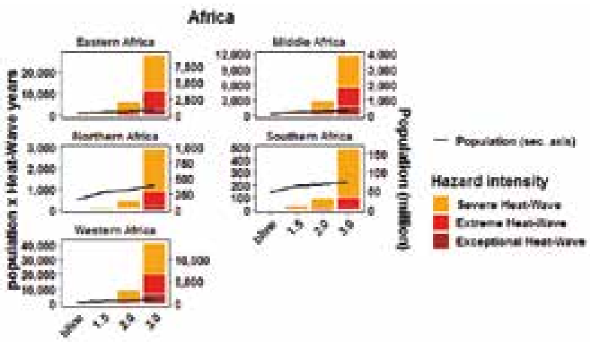
Population and Drought



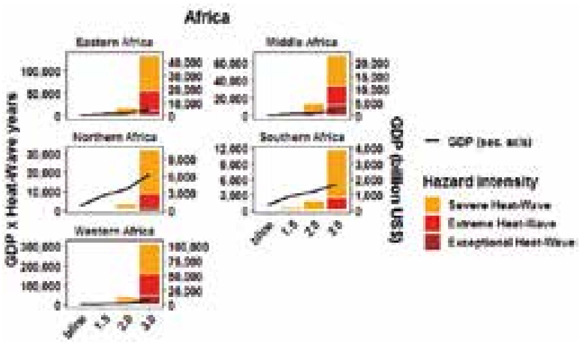
GDP and Drought



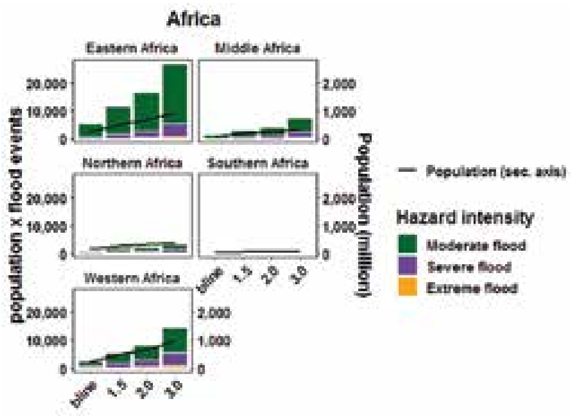
Population and Heat Wave



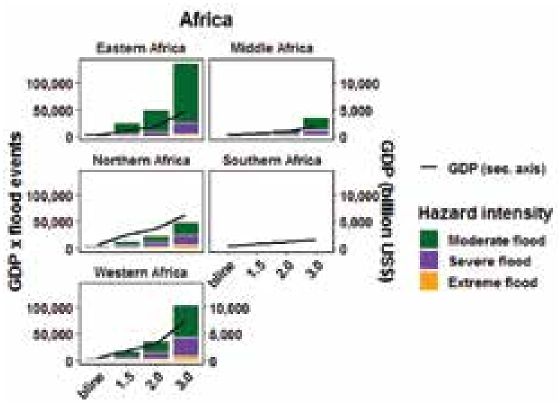
GDP and Heat Wave



Population and Flood



GDP and Flood



Limiting global warming to 1.5°C and 2°C, as for the Paris Agreement temperature targets, would substantially decrease the share of the African population exposed to three widespread hydro-meteorological hazards – droughts, heatwaves, and floods – against a 3°C warming scenario. Concretely, we found that keeping temperature increase below 2°C would reduce the share of population exposed to the combined extreme hydro-meteorological events by more than 50%, in Africa. Additional efforts to limit it to 1.5°C would further reduce the exposure by about an additional 10 to 30%. The high exposure of the African population to extreme hydro-meteorological events could exacerbate the issues related to water management in the African regions (Farinosi et al., 2020, 2019, 2018a, 2018b).

4.2 Climate and socioeconomic drivers in critical water management

The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The types of information collected include details about date, actors involved, type of violence, location and fatalities, accompanied by a brief description of each of these events. The ACLED database was not specifically designed to collect records of episodes of violence related to the water resources use and management. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. A selection of keywords were singled out and used to highlight violence events potentially related to the water resources management. The selected keywords are related to several aspects of the broader water management topic, such as: water management, water price, water availability and uses, water supply and sanitation, wastewater treatment, agriculture, irrigation, food production, natural hydro-meteorological hazards and disasters. Particular attention was used to avoid including events in which water was used to sedate the protest, as for instance in the case of water cannons usage, or in the case of the territorial disputes over marine areas.

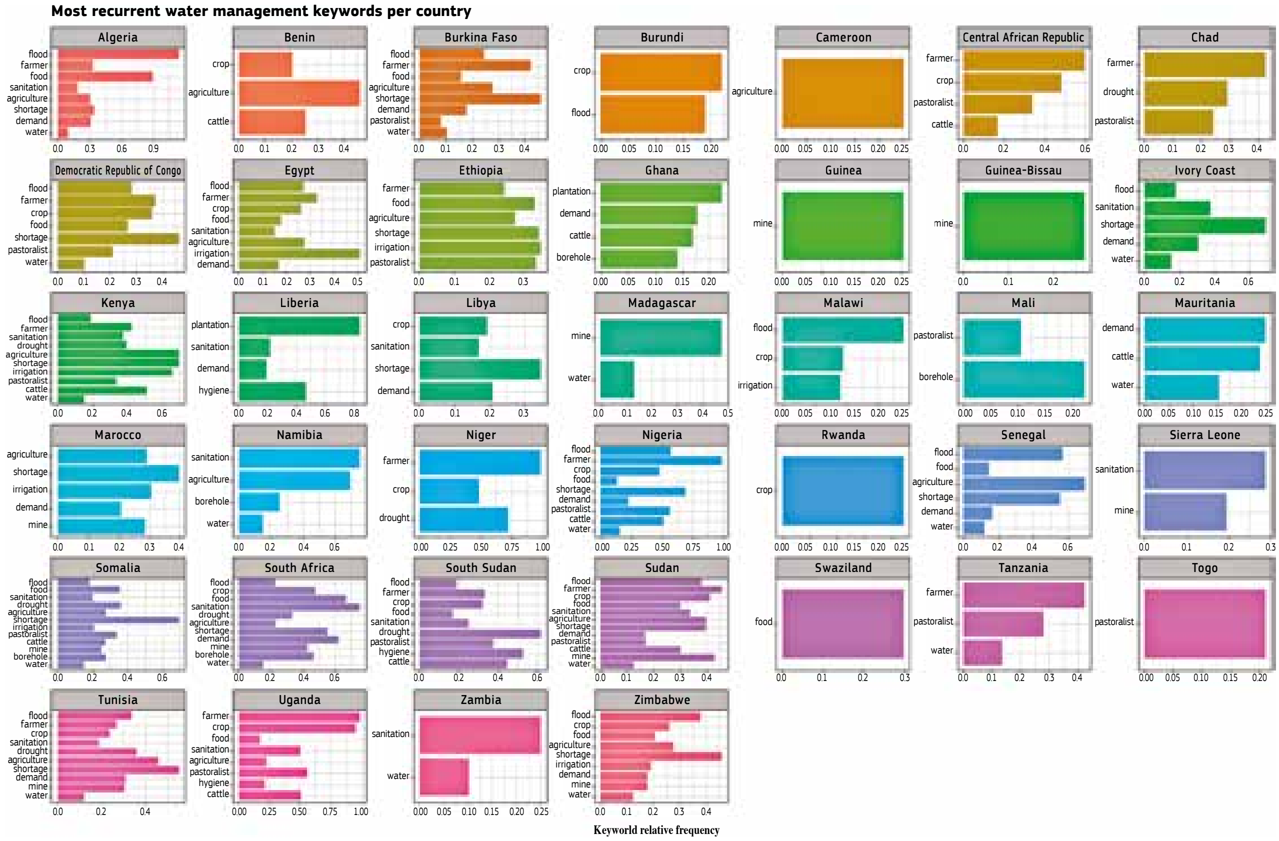
Therefore, the water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The spatial distribution of the events has a noticeable variation across time, but a series of spatial clusters could be identified. The most significant hotspots of water related violent episodes could be highlighted in the following areas (HD = High Density, LD = Low Density):

- North Africa
  - Coastal areas of Tunisia and Algeria (HD);
  - Nile Delta (HD);
- West Africa
  - Senegal Basin (LD);
  - Niger and Volta Basins (LD);
  - Niger Delta and Nigeria (HD);
- Central Sahel
  - Chad basin and Eastern Nigeria (LD);
- Eastern Africa
  - Central and Upper Nile (HD);
  - Lake Victoria basin (HD);
  - Horn of Africa (HD);
- Southern Africa

- Lowed Zambezi (LD);
- Limpopo (HD);
- Upper Orange (HD);
- Lower Orange (LD);
- Coastal South Africa (HD).

The nature of these issues is not always homogeneous among the countries. The most recurrent words in the events characterizing a specific country or portions of it might vary considerably, but in the large majority of the cases they are representative of a handful of topics (including: water supply, hygiene and sanitation; agricultural and farming use of water resources; natural hazards; mining and other water intensive economic activities). The essence of the water related violence episodes is also generally different between urban and rural areas, being the first ones mainly represented by water supply and sanitation, water price, and access to the resource, while in the rural areas issues related to agricultural use stand out.

Figure 12. Most recurrent water related keywords per country in selected transboundary river basins (JRC Technical Report - Farinosi et al 2018b).



5 Integrated Green Transition in Transboundary basins in Africa

5.1 Introduction

Water and natural resource management is under increasing pressure, particularly in Africa, due to a number of factors including climate change, population and economic growth, political instability and increased competition for increasingly limited resources. Where resources are shared by several countries, as in the case of transboundary rivers, the management of these issues poses additional challenges. In this context, non-optimal or poor management decisions may critically affect the socio-economic conditions of the actors and countries involved, even leading to intra-basin tensions and jeopardising transboundary and inter-sectoral cooperation. These dynamics are increasingly likely to have a significant impact on countries in the developing world, which are already facing major challenges in managing shared resources. Thus, identifying appropriate and timely adaptation measures in this changing environment is one of the greatest challenges for development and cooperation. The European Union, through the activities implemented by DG INTPA and JRC, in collaboration with its African partners (AMCOW, AMCOST, AUDA-NEPAD Centres of Excellence in Water Sciences, RECs and African River Basin Organisations) and Member States, has already demonstrated to the international scientific and policy communities the importance of establishing forums for dialogue to discuss and address the main regional threats. Key aspects of these initiatives are the identification of priority strategies and opportunities for future cooperation, as well as the need to develop the human capacity, data and information necessary to support integrated management and policy decisions, particularly in transboundary basins. Concretely, this section aims to provide insights on these aspects in summary form for a selected number of transboundary basins in Africa (Table 1 and Figure 13). Besides, it addresses local and transboundary issues from the perspective of decision-makers, challenges, (lack of) infrastructure development, inefficient water allocation, uninformed decision-making processes, data and information sharing policies and processes, opportunities for the private sector and the selection of case studies for further analysis. The results obtained in this first stage will lay the foundation for the preparation of dialogues and coordination meetings and workshops that will be organised in the framework of a second phase of this project and support the implementation of the AU-EU partnership and the Team Europe Initiative (TEI) on transboundary water management.

Table 1. List of identified Transboundary River Basins.

Major Transboundary River Basins				
ID	**NAME**	**SURFACE**	**REGION**	**SPECIFIC FOCUS**
1	***NILE***	2,956,000	North-Central Africa	White Nile - Lake Victoria
2	***NIGER***	2,111,000	Western Africa	
3	***ZAMBEZI***	1,373,000	Southern Africa	
4	***LAKE CHAD***	976,000	Central Africa	
5	***ORANGE***	965,000	Southern Africa	
6	***OKAVANGO***	646,000	Southern Africa	
7	***SENEGAL***	445,000	Western Africa	
8	***LIMPOPO***	406,000	Southern Africa	
9	***TANGANYIKA***	245,000	Central Africa	
10	***CHOBE (Sub-basin of Zambezi)***	100,200	Southern Africa	

Figure 13. Major transboundary river basins identified for the assessment (Nile and Congo mapped as linked with Lake Victoria and Lake Tanganyika sub basins).

5.2 Methodology

This section provides a short overview of each selected river basin, with emphasis on the identification of potential key challenges and priorities. The list is not intended to be exhaustive, but a first mapping of concrete issues, objectively selected and identified on the basis of current scientific and technical data and knowledge, in order to feed the discussion, criticism and final choice thanks to the involvement of local stakeholders, managers and experts.

To provide a common logical framework, we have split the assessment into different topics:

- Introduction
- Hydrology
- Water, agriculture and food security issues
- Water and socioeconomic issues
- Water demand, water availability and management
- Water, climate change and variability
- Water quality, health and ecosystems
- Water and energy

Strategic development documents, scientific and technical literature in the context of the selected river basins and some of the riparian countries have been used and duly referenced in the report. The objective is also to identify existing information on priorities, data and knowledge sharing policies between institutions and countries. If any, specific data collection problems and challenges (particularly data and analysis gaps, but also potential gaps in the skills and competences of institutions involved in transboundary river basin management) will be finally evidenced. A specific focus will be devoted to data and information associated to water management and in general on water resources, water related issues and water demands and withdrawals (water balance) in the selected river basins and related aquifers, to characterise both surface and ground water availability and water allocations (for different sectors, such as domestic, agriculture, livestock, energy and industrial).

5.2.1 Summary and thematic specific key issues and challenges

For each thematic paragraph a "Synthesis Box" has been included. This highlights key issues and challenges and relevant information (e.g. missing data, need for modelling, knowledge gaps,) specific to the thematic (hydrology, food security, etc.). All these detailed issues and evidenced information are finally needed to derive a more synthetic list of key priorities for each river basin.

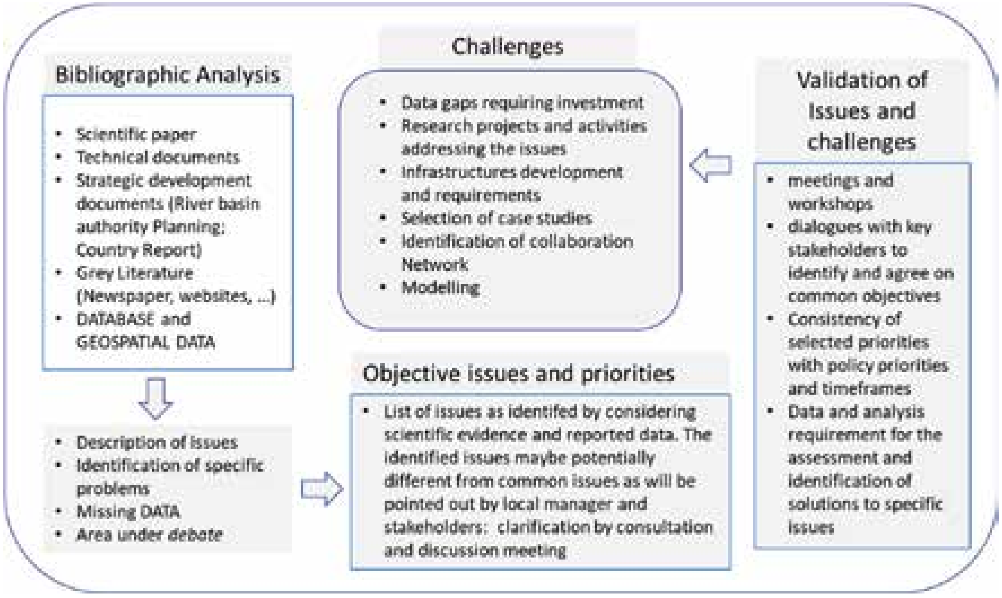
Indeed, at the end of each river basin chapter a summary preliminary list of key challenges is presented: it must be considered that the objective is to identify those aspects and issues linked with water resources and their management, so other important challenges currently faced by the river basin may be not listed here. Indeed, we have also to observe that an assessment at the scale of a transboundary river basin, e.g., focusing on a hydrographic basin, is going to be implicitly centred on the water sector.

Figure 14. Example of thematic Synthesis Box.

Thematic issues and challanges
• *Monitoring, assessment and knowledge of fishing stock is required* • *Ensure water balance assessment as the catchment has a key hydrological rule acting as a constant source of water downstream and specifically during dry period* • …………………………………

We have also included a summary map which is aimed to display some key layers and spatial data linked to water and the other three components of the WEFE Nexus approach (Food, Agriculture, Environment and Energy) for each river basin. Concretely, these maps will be also presented in a Web GIS format to facilitate experts, managers and stakeholders the performance of spatial analysis on the identified issues. The maps are currently in draft form and rely on an initial selection of common layers for all the river basins. In a second phase, each river basin would be potentially associated with specific layers (when available), useful for the identification and description of particular issues. Layers used for geographical mapping in the current version are: Designated Protected Areas and Parks; Ramsar Sites; cropland intensity and distribution; main cites and urban centers, major rivers; major dams and reservoirs with also information on type of use and water loss by evaporation analysis, major mining activities; contaminated region hotspots; population density; livestock and irrigation water demand and distribution, climatic characterization (annual precipitation) and others. For a complete list of layers used and sources a synthesis table is provided in the Annex.

Figure 15. Schema of the methodological approach.



5.2.1.1 Involvement of Delegation of the European Union and African Centres of Excellence (CoEs)

The key issues and priorities identified and described in the previous chapters have been mainly selected as based on data, knowledge and information derived by open access literature, grey literature and documentation from river basin authorities. It has to be stressed that such assessment requires the development of a shared and agreed knowledge base supported by objective and open data and information, that is essential to ensure agreement and convergence of all different sectoral policies and authorities involved in the management and regulation of resources.

In order to ensure and facilitate the discussion, criticism and final choice (and ranking) of the key issues, even if preliminary, the selection has been shared with stakeholders and managers (from AUDA-NEPAD Centres of Excellence in Water Sciences, Universities, EU Delegations, River Basin Organisations, AU institutions as AUDA-NEPAD, AMCOW and AMCOST). The river basin specific chapters and priorities list have been shared to be reviewed and integrated when required and in addition, a ranking score have been asked to all stakeholder involved.

More specifically 30 Delegations of the European Union have been consulted (see Figure 16). Among these 9 have actively answered and contributed to the reporting and to the identification of priorities, while few others just highlighted their interest to be informed and involved in the future development and assessment.

Figure 16. EEAS Delegation of the European Union invited to review, integrate and rank the list of priorities and key issues for the selected river basins.

The 9 EU Delegations that provided a direct feedback are EEAS-Bujumbura (Burundi), EEAS-Gaborone (Botswana), EEAS-Kampala (Uganda), EEAS-Maseru (Lesotho), EEAS-Niamey (Niger), EEAS-Kinshasa (Democratic Republic of Congo), EEAS-Lilongwe (Malawi), EEAS-Maputo (Mozambique), EEAS-Pretoria (South Africa). The basins interested of their feedback are so: Chobe (Zambezi), Lake Chad, Lake Tanganyika, Lake Victoria, Limpopo, Niger, Orange, Okavango, and Zambezi.

In addition a quite numerous number of experts and representatives of the Centre of Excellence networking have been consulted. Currently only 6 gave already a contribution, which could be included in this report, while many others expressed their interest for such type of analysis and study, but because of time constraints and other commitments were not yet able to provide a direct feedback. Nevertheless the exchange of information with all EU Delegations will continue to ensure a common and agreed further development.

The feedback provided from experts (Figure 17) are from: Kwane Nkrumah University of Science and Technology (Prof. G. Anornu); Stellenbosch University (Dr. N. Elema); IGAD Climate Prediction and Application Centre (M.A. Hassan), NEPAD Centres of Excellence on Water Science and Technology (Prof. A. Kane), University of Malawi (Prof. C. Ngongondo) and Council for Scientific and Industrial Research – CSIR (A. Seetal).

Figure 17. Centres of Excellence and External Organisation invited to review, integrate and rank the list of priorities and key issues for the selected river basins.

In addition also other external organisations, solicited by EEAS on the issue, have provided important feedbacks and suggestions: among these specific feedback have been received by GIZ (German Society for International Cooperation), OKAKOM (The Permanent Okavango River Basin Water Commission), ORASECOM (The Orange-Senqu River Commission) and LHWC (The Lesotho Highlands Water Commission). The basins involved by the feedback of CoEs and other external organisations are: Lake Chad, Lake Victoria, Lake Tanganyika, Limpopo, Niger, Orange, Okavango, Senegal, and Zambezi.

RIVER BASIN 1
NILE (SPECIAL FOCUS ON LAKE VICTORIA AND LAKE ALBERT)

RIVER BASIN 2
NIGER

RIVER BASIN 3
ZAMBEZI

RIVER BASIN 4
LAKE CHAD

RIVER BASIN 5
ORANGE

RIVER BASIN 6
OKAVANGO

RIVER BASIN 7
SENEGAL

RIVER BASIN 8
LIMPOPO

RIVER BASIN 9
TANGANYIKA

RIVER BASIN 10
CHOBE-KWANDO (ZAMBEZI)

RIVER BASIN 1

NILE (SPECIAL FOCUS ON LAKE VICTORIA AND LAKE ALBERT)

5.3 River Basin 1 – Nile (Special Focus on Lake Victoria and Lake Albert)

5.3.1 Introduction

Nile is the world's longest river, draining about 10% of the landmass of the African continent. It originates from the wet tropical areas in the eastern part of the continent and from the highlands in the Horn of Africa. It flows northward through several climatic zones, ranging from tropical to arid, and crossing the border of 11 countries before ending in the Mediterranean Sea. The broad catchment area, spanning more than 3 million squared kilometres, is distributed among the following countries (percentage of the territory and hydrological balance: [+] water producer; [-] water consumer; [º] neutral): Burundi (0.4% [+]); Rwanda (0.7% [+]); Tanzania (3.7% [+]); Kenya (1.6% [+]); Democratic Republic of Congo (DRC) (0.7% [+]); Uganda (7.5% [+]); Ethiopia (11.5% [+]); Eritrea (0.8% [+]); South Sudan (19.5% [º]); Sudan (44% [-]); Egypt (9.6% [-]).

Figure 18. The Nile river basin.

This area is home to more than 250 million people, heavily dependent on the surface and subsurface water resources connected to this hydrological system for their survival. The Blue Nile basin and the White Nile are the main water sources for the downstream Nile. Hence upon their strategic management depends the health of the entire basin. Conscious about the challenge that managing this basin poses, 10 of the 11 riparian countries (Eritrea participates as an observer) joined their forces in the establishment of the Nile Basin Initiative (NBI), created in 1999 to manage the transboundary resources (NBI, 2016; Wolman and Giegengack, 2007).

5.3.1.1 Lake Victoria and Lake Albert

Lake Victoria is the second largest lake in the world in terms of surface area (68,800 km^2), with an average depth 40 m, a maximum depth 80 m, and an average volume of 2760 km^3). Headwaters of the White Nile River, its catchment covers an area of 194,200 km^2 across five different countries: Burundi (7% of the drainage area), Kenya (22%), Rwanda (11%), Tanzania (44%) and Uganda (16%). However, only Kenya, Uganda and Tanzania are riparian countries (sharing the lake's shoreline; LVBC and GRID-Arendal, 2017). The Lake Victoria Basin (LVB) is one of the most densely populated regions in Africa (300 people per km^2, while the Africa's average is 36) and the basin is home to around 45 million people. Main cities in the LVB include Kampala, Mwanza, Kisumu or Entebbe, among others, and they are experiencing a rapid growth, along with industrial development. Poverty is a key issue in the basin and puts additional pressure on natural resources, as degraded lands support a large number of rural poor households, especially in the upper basin (Burundi, Rwanda and the Kenya highlands). Agricultural activities and livestock rearing provide livelihoods to over 80% of the basin's population and 200,000 fishermen and their families subsist on daily fish catches. Rainfed agriculture accounts for 30-40% of the regional GDP and sustains around 60% of the population in LVB (World Bank, 2018).

The water balance of the lake is maintained primarily through rainfall and evaporation, rather than inflows and outflows, and residence time of water in the lake is about 23 years. Lake Victoria receives inflow from 17 tributaries (being the Kagera river the largest one), but they only supply near 20% of the total water input (direct rainfall over the lake accounts for 80%). The LVB provides 14% of the total Nile flow through the White Nile River (only river that flows out of the lake and then goes through both Kyoga and Albert lakes before entering Sudan). Therefore, the fluctuations of these lakes, particularly Victoria, regulate the Nile flows (Yin and Nicholson, 1999). It has one of the richest freshwater ecosystems in the world, with over 2000 species, 500 of them not found anywhere else on earth. Around 25% of the basin area is protected and include main wildlife attractions, such as the Serengeti and Volcanoes National Parks (World Bank, 2018).

Lake Albert is the seventh largest lake of Africa and it is shared between Uganda (54%) and DRC (46%). Its main tributaries are the Victoria Nile (coming from the Lake Victoria in the southeast) and the Semliki River (from Lake

Edward in the southwest). Between Lake Victoria and Lake Albert stands Lake Kyoga, a relatively shallow lake which receives its main inflows from Lake Victoria (although local tributaries drain an area of about 57,000 km^2; Brown and Sutcliffe, 2013). Lake Edward is located on the border between Rwanda and DRC, bounded by the Ruwenzori mountains to the north and the Virunga volcanoes to the south. The lake has a surface of 2,325 km^2 and a catchment of 20,374 km^2, losing more than 50% of its water income to evaporation (Russell and Johnson, 2006). The Kazinga Channel (a paleo-river valley) connects Lake Edward to Lake George, a hypereutrophic lake of 3 m of maximum depth and much lower salinity levels than Lake Edward (because the later's salinity budget is dominated by alkaline inflows from the Virunga volcanoes) (Rusell et al., 2003). For the extended Lake Victoria basin (including not only Lake Victoria, but also Lake Albert, Lake Edward and Lake Kyoga), total population was estimated at 70 million people in 2010 (Tramberend et al., 2020).

5.3.2 Key challenges: Lake Victoria and Lake Albert

5.3.2.1 Hydrology

Lake Albert and Lake Victoria basins are complex and integrated water resource systems characterized by the presence of diversified aquatic ecosystems including important surface water resources such as wetlands, rivers systems, open lakes and groundwater. The analysis of precipitation distribution and variability is particularly important, as 80% of water inflow into the lake comes from direct precipitation over the lake itself. In this context, the amount of water in Lake Victoria is particularly sensitive to climate variability: in the last decades, the long rain season (March-May) has experienced a series of dry anomalies (Thiery et al., 2016), which is at odds with the rainfall increase that climate change scenarios for East Africa suggest. Neither should be overlooked the downstream implications, as Lake Victoria catchment provides about 14% of the total Nile flow.

The basin has an important hydrological role, acting as a buffer zone that allows interannual water storage and influences downstream variability. Fluctuations of the lake have been observed even if the lake remained stable over the average since early 1960s (Awange, 2013). Concretely, an area of about 69,200 km^2 was reported in 2018, pointing out just a limited declining rate of 200 km^2 between 1984 and 2018. Further analysis on this issue could be integrated with the Global Surface Water Explorer dataset developed by the JRC, which provides the location and temporal distribution of water surfaces at the global scale over the past 32 years.

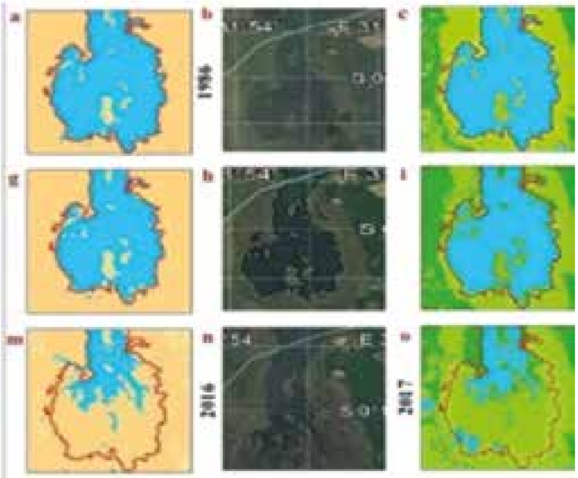
The outflow of the Lake Victoria is regulated and impacted by the management of 2 hydropower plants (Nalubaale and Kiira), both in the Janja region. Since 1954, Lake Victoria has been regulated by the Nalubaale hydropower dam, providing about 90% of Uganda's hydropower, and added energy input for Burundi and Rwanda too (Getirana et al., 2020). A steep water elevation decline has been reported (Getirana, 2020) between 1998 and 2007 for a total -2.5 meter, while starting from 2007, the Lake Victoria has experienced a replenishment till levels similar to the late 90s. These changes and different dynamics have been mainly associated to precipitation changes and trends and to dam management at the lake outlet, but specific analysis on the influence and importance of the two factors still need an in-depth study. The monitoring and knowledge of lake water levels and extension, of its annual and intra annual variability and its dependence on climatic and water management practices are key priority areas where further research is deemed necessary. Recent studies indicate that the length and width of the lake did not undergo dramatic changes during the period 1984-2018 (reported values for year 2018 were 388 km and 363 km, respectively). Even

Hydrology - challenges

- Lake Victoria and Albert play a key role influencing water inflow in the Nile, providing about 14% of the total Nile flow, and contributing till 80% during Blue Nile's dry season.
- The catchment has an important hydrological role acting as a constant source of water.
- Water releases from the lake and the impact of current and new hydropower plants still require an agreed quantification at river basin level: currently only an agreed release curve is available and not clear transboundary rules and agreements are in place.
- Different management scenarios have been tested resulting in a clear contradiction and competition between hydropower requirements, navigation and natural flows; the agreed management curve has resulted in very high fluctuations of the lake level.
- Groundwater quantity is generally not an issue except at local scale and water quality is generally good, except for microbial contamination in shallow aquifers underlying urban settlements and iron, manganese and fluoride mainly due to natural origin.
- Groundwater accounts for the largest percentage of water use for human supply.

if no dramatic change has been observed at global scale, important variations have been reported for specific regions (such as Birinzi, Winam, Emin Pasha and Mwanza gulfs).

Figure 19. Lake extent over different periods. Source: elaborated from Awange et al., 2019.



Wetland ecosystems are of great importance in the context of the Lake Victoria and Lake Albert basins. These transitional ecosystems between terrestrial and aquatic environments provide a variety of goods, services and benefits contributing to people livelihoods and country economy (water purification, flood control, ecosystem habitats for fauna and plants, fishing, fuelwood, medicine, pasture and agriculture linkage, tourism, etc.). Clearly the functionality of wetlands is also dependent on their health and a good management. In this sense, it is not only their extension to be considered when performing analysis and assessment of wetlands. Nevertheless, it is important to point out that several studies report a decline of wetlands in the region: in Uganda a decline of about -40% was observed from 1994 to 2008, reaching now a coverage of about 11% of land (MWE, 2015, Uganda Wetland Atlas). Hydrology of wetlands is always associated with the presence of flooding, with different level of permeance and duration. During 1995-2010 about 9,000 ha of wetlands were infilled and converted to drylands.

Groundwater quantity is generally not an issue except at local scale and water quality is predominantly good, except for microbial contamination in shallow aquifers underlying urban settlements and iron, manganese and fluoride mainly due to natural origin. Transboundary aquifers exist in the region (e.g., Uganda sharing the aquifers of the Nile and the Lake Victoria basins) but in general terms the building and strengthening of governance and regulatory structures, as well as the promotion of equitable and reasonable utilization, are still at an early stage of development for many Nile countries (Awulachew et al., 2012).

5.3.2.2 Agriculture and food security

The agricultural sector, mainly consisting of rainfed agriculture, employs about 80 percent of the rural population. The sector contributes significantly to foreign exchange earnings and provides raw materials for agro-based industries. The sector accounts for about 34 percent of the gross domestic product (GDP) in Burundi, 29 percent in Kenya, 32 percent in Rwanda, 25 percent in Tanzania and 23 percent in Uganda (USAID, 2018). Major food crops include maize, rice, potatoes, bananas, cassava, beans, vegetables, wheat, sorghum, millet, and pulses, some of which contribute to cash crops. Other cash crops include tea, cotton, coffee, pyrethrum, sugarcane, sisal, horticultural crops, oil crops, cloves, tobacco, coconut, and cashew nuts. At basin scale, agriculture is also the main economic sector (85% of the LVB population depends on it for food security, income generation and employment). Arable land accounts for 33% of the basin area and three different cultivation systems can be found in the basin: mixed lowland smallholder subsistence rainfed cultivation (10.4 million ha); mixed highland smallholder cultivation (3.3 million ha) and; large-scale cultivation systems (0.2 million ha). The first type is characterised by small plots (<1 ha), operated by single households (which also maintain a small herd of livestock and cultivate mainly by hand) and only one growing season. The second type takes place about 1,700 m above sea level, average plot size ranges between 2-10 ha, cultivation by hand is combined with some mechanisation, farming system is semi-commercial (prevalence of cash crops in addition to food crops) and has two growing seasons per year. Regarding large-scale cultivation, generally is performed in large household landholdings, company-owned or government-owned states (tens of thousands of ha), using mechanised equipment and agricultural inputs (fertilisers, pesticides) and producing mostly cash crops (coffee, tea, cotton, flowers, sugarcane, etc.). Some informal irrigation (40,000 ha) is practised under the mixed highland smallholder cultivation (e.g., marshland irrigation in the Kagera sub-basin), while large-scale systems use formal irrigation schemes (around 60,000 ha) (GRID-Arendal, 2017). After maize and wheat, rice is the most cultivated cereal in the LVB and the basin has potential to meet rice demand in East and Central Africa. However, its current yields are low in comparison to the global average (they range from 1.5 to 2.5 MT/ha).

In this context, sustainable intensification would be preferable to cultivated land expansion and potential yield gains could be obtained by irrigation (around 410 kg/ha), use of agricultural inputs (1,400 kg/ha) or both (2,070 kg/ha); Amankwah-Minkah, 2020). Livestock in the LVB play an important role in food security, livelihoods, income, and GDP. With growing populations and incomes in much of this region, there is an increasing demand for livestock products that is pushing sector growth. Unguided, this growth could increase livestock sector emissions and the number of livestock at-risk from climate change impacts (Ashley, 2019).

At country scale, more than 80% of the households in Uganda depend on natural resources for their livelihoods, although natural resource-based sectors contribute to around 25% of GDP. However, poor natural resources management is negatively impacting Uganda's economy and poverty levels, as degradation affects about 41% of the country's land. In this regard, costs of soil erosion and land degradation were estimated at 17% of GDP in 2019 and maize productivity losses per year due to soil erosion could have reached 190 kg/ha. Besides, the country has one of the highest rates of forest loss worldwide (2.6% every year) and related economic losses amounted to USD 1.2 billion between 1990 and 2015. Climate risks are expected to further worsen this situation, and economic costs across sectors such as the agricultural one could be between 2.3 to 4.2 billion dollars by 2025 (World Bank, 2021). In Kenya, the agricultural sector has a share of more than 50% of GDP (26% directly and 25% indirectly through the links with other sectors), it is responsible for most of the country's exports, for about 56% of the employment and for one third of poverty reduction among rural households. Maize and beans are the predominant crops in the country, accounting for 85% of Kenya's cultivated land in 2015/16. However, agricultural productivity in Kenya is low and volatile due to several factors, such as lack of quality inputs, distorted markets, minimal modernisation, high incidence of pests and diseases, poor soil health or low investment in infrastructures. Besides, climate variability and change pose a large threat to the attainment of Big 4 agenda's food security objective (100% of nutritional and food security for all Kenyans in 2022), as the country has been ranked 13th out of 233 countries for "direct risks" arising from "extreme weather" (World Bank, 2019). In Rwanda, the agricultural sector contributes to a third of GDP and employs 70% of the population. Despite the increase of agricultural productivity, about 70% of all the food consumed in Rwanda is accessed through markets (instead of self-production) and malnutrition is still a prevalent issue. In this regard, the National Strategy for Transformation (NST1) aims to increase average productivity of key crops by 2024: doubling maize, Irish potato, beans and fruits yields; increasing at least 30% the yields of rice, wheat, cassava, sweet potatoes, soybean and vegetables and; targeting increases in the quantity of meat and dairy products (FAO, 2018). Burundi's economy is based on the agricultural sector, which has a share of 44% of GDP, employs 90% of the population and provides 95% of food supply. However, Burundi is one of the poorest countries in the world (placed 152nd out of 189 economies in 2015) and highly dependent on official development aid (more than 50% of the annual government budget). Besides, the country has one of the highest rates of malnutrition in the world and 75% of the population is food insecure (IFAD, 2016). Agriculture in Tanzania accounts for 27% of its GDP, 67% of the jobs and it provides livelihoods for the most vulnerable people (80-90% of agricultural is held by smallholders). However, climate-related factors threaten the future of the sector, as they could decrease food production by 8-13% by 2050 and a value-loss of agricultural production of USD 27 billion (GCF, 2021).

Agriculture and food - challenges

- The agriculture sector, mainly consisting of rainfed agriculture, employs about 80 percent of the rural population; arable land accounts for 33% of the total area.
- Productivity is low and volatile due to several factors, such as lack of quality inputs, distorted markets, minimal modernisation, high incidence of pests and diseases, poor soil health or low investment in infrastructures.
- The basin has potential to meet the rice demand in East and Central Africa.
- Climate variability and change pose a large threat to the attainment of development goals (e.g., 100% of nutritional and food security for all Kenyans in 2022). Strategies to identify adapted and resilient agrosystems are in place, but a constant focus need to be fixed on soil fertility management and in the sustainable intensification of current cropland.
- Lake Victoria is the most important source of affordable animal protein (fish) in East Africa.
- Food security should be increased with enhanced self-sufficiency strategies, thus reducing food dependency on markets.
- Support adaptation in extensive livestock systems, including attention to mobility, protecting rangelands from degradation, and improving feeding in pastoral production.

5.3.2.3 Socioeconomic

The socioeconomic importance of Lake Victoria to East Africa is associated with the fact that it is the largest inland water fishing sanctuary; a major inland water transport link for the East African Community (EAC) Partner States; a source of water for domestic, industrial, and commercial purposes; a major reservoir for hydroelectric power generation; a major climate modulator; and a rich biodiversity sanctuary. Poverty is pervasive in the basin, at about 49 percent of the population of the LVB (2008 data). Most of the poor people in the basin rely on natural resources for their livelihoods; for example, the income generated from fisheries provided food security and supported the livelihoods of approximately 3 million people in 2009 (World Bank, 2018). The LVB is highly diverse regarding freshwater species (with high levels of endemic species, more than 78% in the case of fishes) and habitats, which provide a wide variety of ecosystems services. The lake provides significant commercial fishing. According to the LVEMP-II APL1 PAD

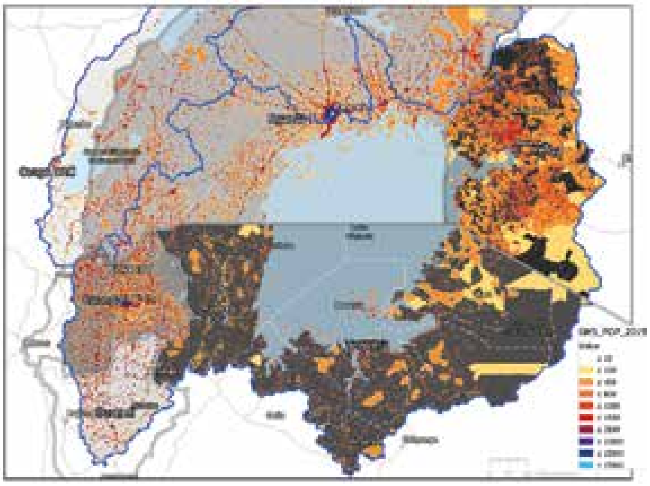
(Worldbank 2009), the fisheries industry provided employment for about 197,000 fishers and approximately 600,000 fish traders around the lakeshore towns and cities. Concretely, the introduction of the predatory Nile perch (Lates niloticus) and the development of related fisheries in the 1980s and 1990s caused an economic boom which attracted poor people from neighbouring countries, although it was highly detrimental for native species (such as cichlids, which dominated the former subsistence fishery in the lake). Currently, the Lake Victoria Nile perch is considered the most valuable freshwater fishery in Africa and, along with the Nile tilapia and dagaa, contribute to 90% of the biomass catch in the lake (total annual landed catch value of USD 500 million, USD 400 million in export revenues, GDP share of 0.5% in Kenya, 2.5% in Tanzania and 2.8% in Uganda; World Bank, 2018). In this context, the decline of fish catches mainly due to overfishing poses a large threat to the local economies and livelihoods of the riparian countries (Njiru et al., 2018). It has even been discussed that a feedback loop exists between conflict in Uganda and fisheries in the Lake Victoria (Glaser et al., 2019).Lake Victoria is a principal waterway for commercial traffic in the region, servicing both the central and northern corridors and a key factor for regional development. A significant number of commercial vessels operate for transportation of passengers and cargo, being the main ports for international transport routes. Traffic through the main public ports is estimated in 500,000 tons/year, but while local traffic has increased since 2005, the international transit has decreased. (NBI, 2016). Exports have a higher value than imports (some years, the value of imports is a quarter of the value of exports), highlighting the significance of the lake as an exporting hub (especially for fish exported to Europe). Main imports include petroleum products and household items (EAC/LVBC, 2011). However, Lake Victoria is one of the most dangerous waterways in the world, resulting in an estimated death toll of 5,000 people per year (mainly fishermen, due to drowning, pirates and accidents) and affecting the wellbeing of around 30,000 people annually (AfDB, 2016). Besides, it has been concluded that safe navigation cannot be guaranteed if the lake level goes below 11.33 m. In this regard, while maintaining lake levels between 11.5 and 12.5 m (higher than current values) would have positive effects for navigational activities in Kenya and Tanzania, it would be detrimental for hydropower production in Uganda (NBI, 2016). Currently, Egypt is championing an initiative to create a trade shipping route between Lake Victoria and the Mediterranean Sea (VICMED project). The project will have a high cost due to the large engineering problems that its development will entail: presence of dams, shallow lakes (such as Lake Kyoga) or swamps (such as the Sudd in South Sudan). Besides, its cost-benefit ratio is not clear, as some landlocked countries already have alternative trade routes (reaching maritime ports in other countries) which could be faster (and therefore more convenient when it comes to the transport of perishable goods, such as agricultural products).

Socio economic - challenges

- The socioeconomic importance of Lake Victoria to East Africa is associated with the fact that it is the largest inland water fishing sanctuary; a major inland water transport link for the EAC Partner States; a source of water for domestic, industrial, and commercial purposes; a major reservoir for hydroelectric power generation; a major climate modulator; and a rich biodiversity sanctuary.
- The LBV is highly diverse in freshwater species (with high levels of endemic species, more than 78% in the case of fishes) and habitats, which provide a wide variety of ecosystems services; Monitoring and quantification of biodiversity trend need to be assessed.
- The decline of fish catches, mainly due to overfishing, poses a large threat to the local economies and livelihoods of the riparian countries: current legislation enforcement seems quite ineffective, as it impacts more on official fisheries while illegal or uncontrolled activities still persist.
- Exports have a higher value than imports highlighting the significance of the lake as an exporting hub (especially for fish exported to Europe: can European markets boost a more sustainable fishing?).
- Navigation service and its requirements regard water level, and weed control need to be better included in multi sectorial analysis.
- Access to WASH services is higher in Kenya than in Uganda (62% vs. 45%), whereas the use of a protected water source for drinking water is less frequent in Kenya than in Uganda (30% vs. 51%). Almost half of the total surveyed households obtain water from the lake (47%).

Water hyacinth, an invasive aquatic weed, has a considerable socioeconomic impact in the region: it not only causes losses in transportation and fisheries (estimated approximately at US 350 million per annum, its impact on the fishing industry alone would be around USD 130 million), but also negative social impacts (reduced access to safe water, social conflict triggered by increasingly difficult access to open water points, migration due to lost livelihoods, blockage of irrigation infrastructures or tourism decrease). Weed infestation could be significantly reduced mainly through biological pest control (World Bank, 2018) and mechanical cleaning. In this regard, rather than the traditional approach towards eradication, it has been proposed to create water hyacinth-bioenergy systems, although it would be necessary to improve the efficiency of extraction and drying to make them energetically and commercially viable (Güereña et al., 2015).

Figure 20. Population density 2019. Source: JRC elaboration from GHSL - Global Human Settlement Layer.

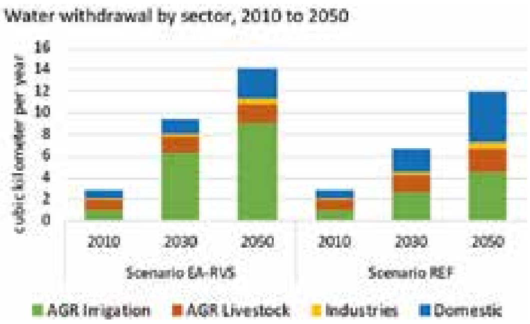


Many of the people have no access to clean water or improved sanitation facilities, resulting in high incidences of water-related diseases such as malaria, bilharzia, and cholera. The HIV prevalence (about 24 percent) is higher than national averages of ~5-7 % in other similar countries. Regarding access to water, sanitation and hygiene (WASH) services, a survey conducted in 1,800 households located in the LVB (Kenya and Uganda) showed that access to improved toilet facilities was higher in Kenya than in Uganda (62% vs. 45%), whereas the use of a protected water source for drinking water was less frequent in Kenya than in Uganda (30% vs. 51%). Besides, 47% of the total households obtained water from the lake (47%) and the proportion of round-trip times of more than 30 minutes to collect water was twice in Uganda with respect to Kenya (37% vs. 16%) (HoPE-LVB, 2018).

5.3.2.4 Water use and demands

While water withdrawals in the extended LVB (including not only Lake Victoria, but also Lake Albert, Lake Edward and Lake Kyoga) were estimated in 2.8 km³ in 2010, future scenarios predict a 4-5-fold increase by 2050, especially due to irrigation and domestic water needs. Concretely, total population is expected to increase from just over 70 million people in 2010 to 153-181 million by 2050 depending on the scenario, whereas irrigated areas could expand from approximately 500 km² in 2010 to 1,719-4,000 km² by 2050 (future irrigation withdrawal could range between 4.5-9 km³, while in 2010 it was about 1 km³) (Tramberend et al., 2020).

Figure 21. Annual water demand in the extended LVB. Source: Tramberend et al. (2020)



Lake Victoria is an important source of domestic, industrial and irrigation water supply and a source of drinking water to major urban centres. In 2017, approximately 5 million people living in the major cities and towns around the lake, such as Kampala, Entebbe, and Jinja (Uganda); Kisumu, Homa Bay, and Migori (Kenya); and Mwanza, Musoma, Bukoba, Shinyanga, and Kahama (Tanzania), depended on Lake Victoria for their domestic and industrial water supply. Regarding irrigation development, Tanzania has been portrayed as an "economic water scarce country", which means that water scarcity could be overcome if enough investments are made. In Tanzania, agriculture is the main economic activity and supports 80% of the rural poor communities, but only 2% of the cultivated area is irrigated (264,388 ha) while the National Irrigation Master Plan (NIMP) estimated the total irrigation potential in 29.4 million ha (2.3 million ha with high potential for irrigation). Concretely, five potential irrigation schemes were evaluated in the Tanzanian part of LVB: Bugwema (1,600 ha), Manonga (7,000 ha), Isanga (2,000 ha), Ngono (8,000 ha) and Mara Valley (3,000 ha). Using maize as reference crop, estimated average irrigation requirements ranged from 198 mm/year in Ngono to 532 mm/year in Manonga Valley (Droogers and Bastiaanssen, 2008). In Kenya, agriculture accounts for 24% of GDP and 65% of the total exporting earnings, with a sector annual projection of 5 to 6%. Kenya's irrigated areas within the LVB are Lake Victoria North (5,600 ha in 2010, total

Water demand - challenges

- Future scenarios predict a 4-5 fold increase of water demand by 2050, especially due to irrigation and domestic water needs.
- Lake Victoria is an important source of domestic industrial and irrigation water supply and a source of drinking water to major urban centres.
- In 2017, approximately 5 million people depended on Lake Victoria for their domestic and industrial water supply.
- The agricultural sector in Uganda (Irrigation and livestock) is the second largest water user (259 million m³, 41% of the total water withdrawal), after the domestic sector (328 million m³, 51%) and followed by the industry (50 million m³, 8%).
- The LVB in Rwanda provides 90% of the national waters and covers 67% of the country (the rest of the country is within the Congo basin).

projected area of 105,300 ha by 2030) and Lake Victoria South (17,965 ha in 2010, total projected area of 183,201 ha by 2030) (FAO/IFC, 2015). In comparison to Kenya and Tanzania, irrigation development in Uganda has been slow and the area equipped for irrigation is less than 3% of the national potential irrigated area (estimated at 567,000 ha). Existing irrigation schemes predominantly use surface water (96%) and they are mainly clustered around Lake Victoria and Lake Kyoga.

Irrigation and livestock in Uganda are the second largest water user (259 million m³, 41% of the total water withdrawal), after the domestic sector (328 million m³, 51%) and followed by the industry (50 million m³, 8%) (Wanyama et al., 2017). The LVB in Rwanda provides 90% of the national waters and covers 67% of the country (the rest of the country is within the Congo basin). According to the Rwanda Irrigation Master Plan (ICRAF, 2010), LVB sub-basins in Rwanda could irrigate up to 452,257 ha (30% from rivers, 25.4% from marshlands, 17.3% from lakes, 11.2% from dams, 9.9% from runoff to small reservoirs and 6.2% from groundwater).

5.3.2.5 Water quality, health and environmental issues

The LVB is among the poorest and most densely populated regions in Africa. Predominant health issues in the basin are linked to food insecurity, air pollution, unsafe water, and poor disposal of human waste (so called "traditional hazards"). Health statistics from the basin countries reveal that – together with the important issues of malnutrition, HIV, and indoor air quality problems - the biological water quality is a key human health issue in all riverine countries.

The main waterborne diseases in the Lake Victoria region, which are influenced by scarcity of clean water, include cholera, typhoid, dysentery, and certain intestinal parasites. The emergence and re-emergence of vector borne diseases (such as malaria, schistosomiasis, lymphatic filariasis, dengue yellow fever and others) go hand in hand with urbanisation-induced ecological changes in this densely populated region (uprooting and erosion, wetland destruction, dams, irrigation, alien species, global change, etc.).

Regarding modern hazards, anthropogenic chemical pollution of the environment is currently not a priority issue at basin scale, as suggested from statistics about land use and economic activities. However, although these types of pollution may not have had a significant impact on water quality at basin scale (as suggested by the few existing field data), they have caused problems in specific areas. Chemical pollution is generally observed locally due to occupational risks and the general mismanagement of domestic and industrial wastes.

In the southern part of the lake, where zones of artisanal gold mining are located, some upcoming mercury issues are reported. So far, water, fish, and sediment concentrations do not yet exceed existing quality standards, and biomass burnings and soil erosion still seem to be the major sources of mercury input into surface waters. However, artisanal gold miners and frequent skin-bleaching cream users are at risk of inorganic mercury poisoning, while the rest of the population, including fishermen is not. Since gold is the number one export good in all basin countries except of Kenya, and exploitation of other precious metals and oil takes place within the basin (in Kenya, Tanzania and Rwanda), emissions from mining activities, tailings and transport should be surveyed. Besides, in untreated urban effluents manganese, cadmium and lead exceeding drinking water standards have been observed.

Water quality, health and environment - challenges

- Together with the important issues of malnutrition, HIV, and indoor air quality problems - the biological water quality is a key human health issue in all riverine countries.
- The main waterborne diseases include cholera, typhoid, dysentery, and certain intestinal parasites.
- Emergence of vector borne diseases, such as malaria, schistosomiasis, lymphatic filariasis, dengue, yellow fever goes hand in hand with urbanisation-induced ecological changes.
- Anthropogenic chemical pollution of the environment is currently not a priority for human health and the environment at basin scale: problems occur locally due to occupational risks and the mismanagement of domestic and industrial wastes.
- In zones of artisanal gold mining, upcoming mercury issues are reported; whereas manganese, cadmium and lead concentrations exceeding drinking water standards were observed in untreated urban effluents. Hence emissions from mining activities, tailings and transport should be surveyed.
- Reported regional eutrophication issues are mainly attributed to untreated urban effluents, domestic and industrial waste and from soil erosion-induced nutrient runoff.
- Freshwater biodiversity is declining (almost 20% is threatened, and the percentage rises to 76% in the case of endemic species) and the risk of species extinctions is increasing. Threats include pollution, climate change, resource use (overfishing), agriculture and invasive species.
- Uganda has one of the highest rates of forest loss worldwide.
- Recently, attention is also paid to accumulation of micro- and small macro-plastic in water, shoreline sediment and fish of the lake used for fishing and drinking water supply.

Pollution with agrochemicals appears to be minor and limited to regional hotspots. Fertilisers are not used to significant quantities, and the input of phosphorous and nitrogen nutrient is mainly attributed to soil erosion, atmospheric deposition of biomass combustion products and, to a small extent, to untreated wastewater.

Generally, low levels of pesticide residues are reported from surface water ecosystems. However, some hotspots of organochlorine were found in soils around former storage areas, suggesting bad stock management practices. DDT and lindane were the dominant pesticides detected in all the studied areas of Lake Victoria, with concentrations in biota all significantly below the FAO/WHO standards for safe fish consumption (a typical observation in the East African Great Lakes).

Most of the surface water research in the Lake Victoria focussed on shallow, near shore waters in densely populated Gulfs with limited water exchanges with the open lake (Mwanza Gulf/Tanzania and Nyane Gulf /Kenya) and the area close to Kampala (Uganda). Here, problems of eutrophication and other anthropogenic pollution are obvious, and they exceed the extent seen in the other East African Great Lakes. However, the few studies based on a spatially more representative dataset at lake scale show an overall good physio-chemical water quality, with problems only in the specific areas named above. In particular, the water quality in these areas worsens specifically during the rainy seasons.

These regionally observed water quality threats are mainly due to untreated urban effluents, domestic and industrial waste and from soil erosion-induced nutrient runoff. The situation is worsened by the disappearance and deterioration of huge wetland areas, acting as a natural sink and purifier for nutrients, the frequent non-functionality of existing wastewater treatment facilities, and the ever more intensive subsistence farming and ongoing deforestation in the lake basin. Atmospheric deposition of nutrients and other pollutants from forest fires and other biomass burning adds on to the problem.

Geogenic chemical groundwater pollution in the basin in northern Tanzania, revealed the presence of fluoride and arsenic as serious pollutants for drinking water. Biological and nutrient pollution of groundwater is reported, but in most cases the sampled wells were contaminated by animal faeces or from close open latrines. In so far these data cannot be used to conclude on the groundwater status as such, but give rise to concern about the general lack of safe access to drinking water.

Although nutrient inputs have not decreased since the 1980s, the condition of Lake Victoria has improved since then, giving rise to two hypotheses. First, the thermal gradients within the water column have decreased as a consequence of the rapid warming of the deeper waters that occurred over the last decade. This fact, assisted by a general increase in wind speeds over the lake, favoured mixing and reduced deoxygenation thus improving the water quality. Second, the eutrophication observed during the 80s (due to the release of nutrients from the land use changes and urbanisation) was compensated by the increase of lower trophic levels, assisted by the intense fishing of big top-predator fishes like the Nile perch. Both factors would lead to a higher consumption of nutrients. As a result, a new ecological equilibrium with a primary productivity being more effectively utilised by consumers at lower trophic levels, would naturally mitigate the effects of eutrophication.

Freshwater biodiversity is declining (almost 20% is threatened, and the percentage rises to 76% in the case of endemic species) and the risk of species extinctions is increasing. Threats include pollution, climate change, biological resource use (overfishing), agriculture and invasive species (Sayer et al., 2018). Overfishing is reported, especially from the northern (Burundi) and southern (Zambia) parts of the lake, where the fishable stock of high-valued sleek lates has significantly declined.

Poor natural resources management is negatively impacting both the basin economy and poverty levels, as degradation affects about 40% of the basin land. In this regard, Uganda has one of the highest rates of forest loss worldwide (2.6% every year). Forest degradation and deforestation, caused by encroachment of agriculture and increasing demands for fuelwood, charcoal, timber, and construction purposes has accelerated runoff and had increased exposure of soils to erosion. In addition, the increase of deforestation has amplified the damage caused by erosion, leading to sedimentary deposition in the littoral zone (habitat for organisms). Turbidity and changes in substrates can alter habitats, disrupting food chain/web and primary productivity and affecting biodiversity.

All the northern drainage area and more than half of the central area have been cleared of their natural vegetation, which is likely to cause more erosion and sedimentation.

Extensive wetlands around the lake were destroyed or degraded through conversion to agricultural land, excavation for sand and clay, and the use as disposal

Figure 22. Key activities and mitigation option in the context of water quality and environmental issue.

Research and surveillance

- Monitoring and mapping of bacteriological water quality.
- Monitoring and mapping of the emergence of waterborne disease in the context of hydropower/irrigation projects.
- Assessment and mapping of environmental impacts from mining activities, including oil exploitation.
- Mapping of ground water resources for geogenic pollutants.

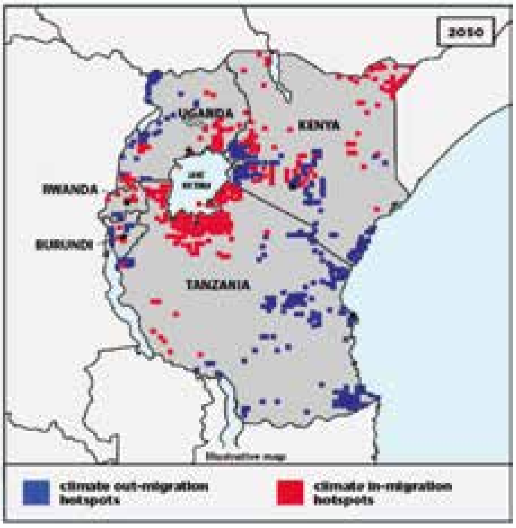
Mitigation

- Improve domestic and industrial wastewater treatment, waste management (esp. in the areas of high urbanisation, see map) and access to (chemically and biologically) safe drinking water.
- Wetland protection and restoration.
- Erosion protection (incl. Improved cook stove programs to reduce firewood consumption and improve indoor air quality).

sites. It was estimated that about 75 percent of Lake Victoria's wetlands area had been affected significantly by human activity, and about 13 percent had been severely damaged. (World Bank, 2009). Additionally huge amounts of solid waste have been transported into the wetlands by wastewater. In Uganda, these issues were addressed at national level, and a wetland restoration project is envisaged (SWECO, 2016).

5.3.2.6 Climate change and climate variability

Figure 23. Internal climate migration hotspots in the LVB. Source: World Bank (2021).



Climate in the basin ranges from a modified equatorial type (substantial rainfall across the year, mainly over the lake and its vicinity), to a semiarid type (with intermittent droughts over some areas). Two rainy seasons are observed in the basin: long rains from March to May (MAM) and short rains from October to December (OND), although their onset within the basin varies both spatially and from year to year (Kizza et al., 2009). Trends in precipitation and river flow hydro-climatic extremes are dominant during OND season in comparison to MAM one, and mostly concentrated in the north and north-eastern parts of the basin (Mbungu et al., 2012). Besides, the basin's north-eastern and middle western areas are more prone to extreme meteorological events, whereas the southern part is more likely to experience extreme agricultural drought events. Drought recovery times mostly depend on drought duration and they are usually between 1-2 months (except for the north-western area, where they can exceed 8 months; Hao et al., 2021). The lake's water balance has been defined as "atmosphere controlled", because 80% of its water input is rainfall over the surface (hence precipitation variability controls the fluctuation of water levels, causing ecological, environmental, hydrological and socio-economic effects; Kizza et al., 2009). Rainfall patterns over LVB are strongly influenced by lake surface temperature (LST) values and their distribution (spatial asymmetry), in addition to topography, large-scale flow patterns and teleconnection effects originating from the Indian Ocean (Sun et al., 2010).

Climate change scenarios suggest more pronounced dry and wet spells, arising from a combination of increasing intra-annual variability and a seasonal shift in precipitation (later onset and a later shift of a few days in discharge peaks during the rainy seasons). Even if the average annual precipitation is not likely to experience large changes until 2050s and rainfall intensity could eventually increase, lower runoff is expected due to higher evapotranspiration (Tramberend et al., 2020). Mean annual temperature is projected to increase 0.2-0.5 ºC per decade during the 21 superscript century, causing an increase of precipitation during wet months (from December to February, increase of 5-20% of annual rainfall) and a decrease during dry months (June to August, 5-10% in the volume of annual rainfall) (Adaptation Fund, 2016). In this context, internal migration hotspots could emerge within the basin (estimated internal migrants ranging from 16.6-38.5 million by 2050, which could be reduced by 30% with proper climate and development actions).

Climate variability and change - challenges

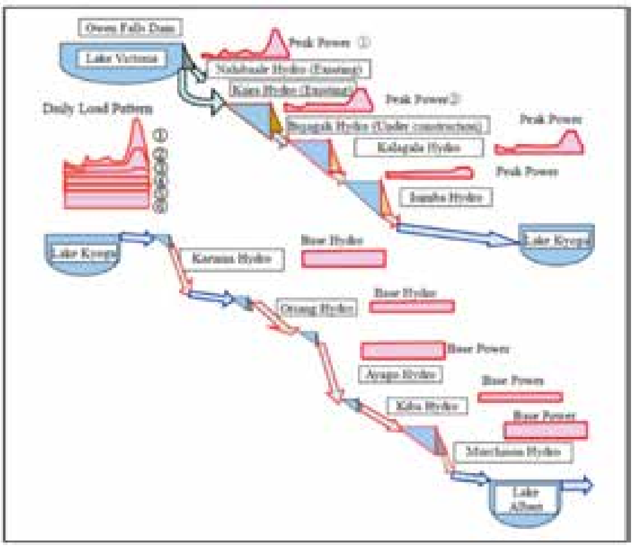
- Two rainy seasons are observed in the basin: long rains from March to May and short rains from October to December, although their onset within the basin varies both spatially and temporally.
- Trends in precipitation and river flow hydro-climatic extremes are dominant during the short rains season, and mostly concentrated in the north and north-eastern parts of the basin.
- The southern part is more likely to experience extreme agricultural drought events.
- Drought recovery times mostly depend on drought duration and they are usually between 1-2 months (except for the north western area, where they can exceed 8 months).
- The lake's water balance is very sensitive to climate because 80% of its water input comes from rainfall over the surface.
- Climate change scenarios suggest the occurrence of more pronounced dry and wet spells, arising from a combination of increasing intra-annual variability and a seasonal shift in precipitation: rainfall intensity could eventually increase and lower runoff is expected due to higher evapotranspiration.
- Climate change impacts on internal migration: hotspots could emerge within the basin (estimated internal migrants ranging from 16.6-38.5 million by 2050, which could be reduced by 30% with proper climate and development actions).

5.3.2.7 Water and energy

The LVB is endowed with great renewable energy potential, able to generate power from solar resources, hydro resources, biomass and wind. However still population access to any kind of electricity is very low (Uganda for example is below 50%) and the issue is even more urgent outside of the cities, where electrification drops to just 38 per cent where 70 per cent of the population lives. This low electrification rate is a major barrier for economic development and poverty reduction. A solution being investigated in Uganda is the use of mini grids since they can supply reliable and grid-like electricity in most villages where grid extension is not financially viable (GIZ, 2020).

The White Nile Basin (to which the LVB belongs) lies entirely in the Eastern African Power Pool (EAPP) which connects Uganda, Rwanda, Burundi, South Sudan, and eastern DRC in the African Great Lakes region. The latter is densely covered by the high, medium and low voltage African power grid, maintaining high voltage connection (>66 kV) also to Kenya and Tanzania. Connection to the sparely connected basin regions north of Uganda are in the planning phase, aiming to provide Sudan and South Sudan electricity access to the Great Lake region (World Bank, 2022). However, the execution of the high voltage power interconnection is challenging due to high investment costs. The EAPP energy mix relies mainly on oil, gas, coal, hydro and geothermal power. For instance, South Sudan has an annual oil production of 3.5 million barrel, ranking third in oil reserves in Sub-Saharan Africa (Mayar, 2021). Foreign know-how and investment, mainly from China, has been requested to support the exploitation of the untapped 90% of gas and oil reserves. Another project, the East African Crud Oil Pipeline (EACOP), also known as the Uganda-Tanzania Crude Oil Pipeline (UTCOP) is currently under construction and aims at transporting crude oil from Uganda's oil fields to the port of Tanga (Tanzania). Environmentalists draw attention to large displacements of communities and wildlife caused along the pipeline course. Besides established renewable hydro and geothermal power, the EAPP region reveals significant wind and solar energy potential. These power generation systems could be placed at existing operating geothermal and hydropower systems, taking advantage of its power grid infrastructure. In addition, floating photovoltaic systems installation could reduce evaporation rates from lakes or hydropower reservoir surfaces (Gonzalez Sanchez et al., 2021).

Figure 24. Existing and potential hydropower projects along the Victoria Nile. Source: Charles (2019).



Hydropower plays an important role in the Upper White Nile basin around Lake Victoria and Lake Albert. Uganda has the greatest potential for hydropower generation and the largest developed hydropower energy sector within the LVB (GRID/Arendal, 2017). Electricity generation in Uganda is dominated by hydropower, which accounts for 78% of the total installed capacity (1,182.2 MW). Concretely, large-scale hydropower is located in the Victoria Nile and has an installed capacity of 813 MW, considering Bujagali (250 MW), Kiira (200 MW), Nalubaale (180 MW), and the Isimba Falls (180 MW), which became operational in 2019. Karuma and Ayago stations are currently under construction (600 MW each), due to be operational by 2020 and 2021, respectively (O'Brien et al., 2021), while Kalagala (non-existing today) will have an installed capacity of 330 MW (Charles, 2019). Besides, there are more than 29 smaller hydropower developments (<50 MW) in operation or being built in Uganda, with a total production of 176 MW (production could reach 332 MW with the new developments). As the country has one of the lowest levels of electricity consumption in the world (only 22% of the population and 14% of the households have access to electricity), in recent years Uganda has been able to export electricity to neighbouring countries (Tanzania, Kenya, Rwanda and DRC). In this regard, the improvement of electricity transmission and distribution will be necessary to increase domestic consumption (O'Brien et al., 2021).

Potential hydropower generation in the Kenyan part of LVB is estimated at 563 MW (159 MW from the Nzoia river, 114 MW from the Yala river, 249 MW from the Sondu-Miriu river and 27 MW from the Kuja-Migori river system, but it is currently limited (GRID-Arendal, 2017) and only 30% of the Kenyan Lake Region population has access to electricity (Council of Governors, 2017), while population with access to electricity is almost 70% at country scale. At national level, hydropower was the primary electricity source in Kenya in 2013 (4,435 million GWh), followed by thermal oil (2,162 million GWh) and geothermal energy (1,781 million GWh). Besides, electricity cost is very high in comparison to other countries. According to the International Hydropower Association (IHA), with an installed hydropower capacity of 596 MW, Tanzania is ranked 18th out of 43 African countries (Uganda and Kenya are ranked 13th and 15th, respectively) (IHA, 2021). Concretely, large hydropower amounts to 35% of total generation capacity in Tanzania and two additional hydropower projects are currently under consideration: Rumakali (222 MW) and Ruhudji (358 MW) in the Njombe region. However, changing rainfall patterns and recent droughts have resulted in reduced output, extensive load shedding and use of expensive emergency fossil fuel-based power plants as base load. Besides, current electricity connection is estimated at 24% at national level and only 11% in rural areas (AfDB, 2015). Rwanda's power sector has grown rapidly in the past decade, increasing the percentage of population with access to electricity from 10% in 2009 to more than 50% in 2019. Under the National Strategy for Transformation, Rwanda aims to achieve universal electrification, a more diverse energy mix for power supply, lower system losses and fewer and shorter outages. However, even if electricity production in Rwanda has grown 11% per year during the period 2010/18, electricity tariffs are still among the highest in the region and a major constraint for development. In this context, hydropower plays a key role in Rwanda's generation capacity, which more than tripled from 2010 (88 MW) to 2019 (221 MW) and which allowed electricity sales to increase from 286 GWh to 654 GWh over the same period. Concretely, hydropower has a share of 47%, followed by oil (26%), lake methane (14%), peat (7%), solar (5%) and imports (1%). Regional hydropower projects under development include the Rusumo project (80 MW, under construction) and the Rusizi III project (147 MW, early project development stage) (World Bank, 2019). Burundi has many small hydroelectric dams, such as the Rwegura (18 MW), Kavuruga and Ndurumu (less than 1 MW each), but some of them suffer from insufficient water supply during the dry season and only 11% of Burundi's population had access to electricity in 2019 (GRID-Arendal, 2017). Burundi is ranked 36th out of 43 African countries regarding installed hydropower capacity (57 MW in 2021) (IHA, 2021).

Figure 25. Examples of mitigation strategies in the context of energy issues.

STRATEGIES

- Improve basin-based water sharing strategies by abandoning state-centric water development approaches and develop sustainable cooperation over the shared water to meet the climate change challenges
- Improve regional dialogue for better cooperation (coordination and collaboration) in power infrastructure development among countries to make a regional power market and cross-border exchanges feasible and beneficial to the Nile citizens
- Complete the high voltage power interconnection to White Nile regions north of Uganda
- Further expand the great potential of renewable energy production: hydropower, geothermal, wind and solar power
- Implement floating photovoltaic systems on Great Lakes water surfaces to produce energy and reduce evaporation from open water
- Minimize environmental risks of EACOP construction (displacements of wildlife and communities) and operation (oil leakages, illegal oil extraction from the pipeline)

5.3.3 Summary map and priorities

After analysing the main issues and concerns presented in the previous sections, the priorities highlighted in the following chapter have been identified. In order to ensure and facilitate the discussion, criticism and final choice (and ranking) of the key issues, the selection has been shared with stakeholders and managers and specifically for LVB EEAS-Kampala (Uganda) and IGAD reviewed the list. EEAS-Kampala expressed particularly interest about this kind of assessment as ensuring the comprehension and scaling of the issues at a transboundary scale: this was particularly the case of water quality issues in terms of setting the orders of magnitude. Some potential improvements to be considered for further development of such analysis are: the inclusion of the institutional framework, and of the geopolitical/security framework (conflict sensitivity analyses).

- Addressing changes to hydrological regime
    - *Release curve of water from the lake:* Lake Victoria and Lake Albert basin largely influences water inflow into the Nile, providing about 14% of the total Nile flow, and contributing till 80% during Blue Nile's dry season. The catchment has an important hydrological role, acting as a constant source of water. Water release by the lake and the impact of current and new hydropower plants still have to be carefully quantified: currently only an agreed release curve is available and not clear transboundary rule and agreement is in place.
    - *Competition across sectors:* Different management scenarios have been tested, resulting in a clear contradiction and competition between hydropower requirements, navigation and natural flows; the agreed management curve has resulted in very high fluctuations of the lake level.
    - *Lake levels:* Changes of lake levels have been mainly associated to precipitation changes and trends and to dam management at the lake outlet, but specific analysis on the influence and importance of the two factors still need an in-depth study.
    - *CC and CV*: Assess impacts of climate change and variability on local precipitation trends and changes: indeed, the lake's water balance is very sensitive to climate because 80% of its water input is rainfall over the surface.
    - *Monitoring, modelling*. Complex hydrology of basin, lack of water management (e.g., water sharing), water scarcity
    - *Extreme events:* Natural disasters (e.g., floods and droughts), climate change.

- Management of the increasing water demand
    - o *Wetland shrink:* A general decreasing trend of wetland extension is reported in the basin: in Uganda, wetland area decreased by 11% between 2008 and 2018, as a result of increasing pressure from urbanization expansion, settlement, and extension of agricultural land.
    - o *Monitoring, quantification*. Recommended measures to tackle it include: monitoring fluxes and stocks of water (both temporally and spatially), development of robust socio-eco-hydrologic models and scenarios to characterise future water demands in the basin.

- Addressing challenges related to food security and agriculture development
    - o *Enhance land management:* At basin scale, agriculture is the main economic sector (85% of the LVB population depends on it for food security, income generation and employment). Poor natural resources management is negatively impacting LVB's economy and poverty levels, as land degradation affects diffused area of the basin (in Uganda, 41% of the country's land is degraded)
    - o *Enhance crop productivity:* Agricultural productivity is low and volatile due to several factors, such as lack of quality inputs, distorted markets, minimal modernisation, high incidence of pests and diseases, poor soil health or low investment in infrastructures. Besides, climate variability and change pose a large threat to the attainment of development goals (for example for Big 4 agenda (100% of nutritional and food security for all Kenyans in 2022). Strategies to identify adapted and resilient agriculture systems are in place, but a special and constant focus need to be fixed on soil fertility management: actions to boost agricultural system have been identified at strategic level.
    - o *Ensure fishing sustainability:* Lake Victoria is the most important source of affordable animal protein in the form of fish in East Africa.

- Addressing land degradation and water quality and health issues
    - o *Invasive species:* Water hyacinth, an invasive aquatic weed, has a considerable socioeconomic impact in the region: it not only causes losses in transportation and fisheries (estimated approximately at US 350 million per annum, its impact on the fishing industry alone would be around USD 130 million), but also negative social impacts. Eradication strategies, as well as alternative valorisation solutions (hyacinth-bioenergy systems) can be adopted to reduce the problem but: a detail identification and quantification of its diffusion in the Lake and water systems is required to identify most effective and commercially viable solutions.
    - o *Assessment of wetland conservation strategies*. The rate of loss and degradation of wetlands is accelerating in all regions and not matching up with wetland restoration targets in place and resources iii) clear monitoring of adopted wetland conservation practices effectiveness is required and should be applied at a transboundary scale (for all riparian countries).
    - o *Impact of cropland expansion, erosion*. Conversion from forest to cropland has caused loss of soil organic carbon and nitrogen (low land productivity)

- *Biological water quality*: Together with the important issues of malnutrition, HIV, and indoor air quality problems - the biological water quality is a key human health issue in all riverine countries.
- *Monitoring and mapping of bacteriological water quality and waterborne diseases:* The main waterborne diseases include cholera, typhoid, dysentery, and certain intestinal parasites. The emergence of vector borne diseases such as malaria, schistosomiasis, lymphatic filariasis, dengue, yellow fever goes hand in hand with urbanisation-induced ecological changes. Research and surveillance improvement: monitoring and mapping of bacteriological water quality and of waterborne diseases, specifically for new dam/irrigation schema projects; assessment of environmental impacts of mining and oil exploitation
- *Impacts of mining and oil exploitation:* Anthropogenic chemical pollution of the environment is currently not a priority for human health and the environment at basin scale: problems occur locally due to occupational risks and the mismanagement of domestic and industrial wastes.
- *Mitigation strategies for water quality*: improvement of wastewater treatment and waste management and access to safe drinking water; wetland restoration and erosion protection

- Addressing socioeconomic issues
  - *Enhance awareness of socioeconomic value of the lake*: The socioeconomic importance of Lake Victoria to East Africa is associated with the fact that it is the largest inland water fishing sanctuary; a major inland water transport link for the EAC Partner States; a source of water for domestic, industrial, and commercial purposes; a major reservoir for hydroelectric power generation; a major climate modulator; and a rich biodiversity sanctuary.
  - *Fishing stock control and regulation*: The decline of fish catches mainly due to overfishing (and illegal practices) poses a large threat to the local economies and livelihoods of the riparian countries: laws and regulation from riparian countries banned all type of unconventional practices, but still no regulation is enforced to ensure sustainable fishery. Solutions are being explored as the use of farming practices for Nile perch (NFRRI in Jinjia) but still many worries persist for fishing community. Unless monitoring and enforcement of fishery regulations (such as slot size, gillnet mesh size, hook size and number of vertical panel nets) are strengthened and enforced via association groups, Nile perch overfishing will continue to increase unabatedly.
  - *Improve WASH services:* Access to water, sanitation and hygiene (WASH) services must be improved.
  - *Assess climate change impacts on internal migration:* hotspots could emerge within the basin (estimated internal migrants ranging from 16.6-38.5 million by 2050, which could be reduced by 30% with proper climate and development actions). The development of weather services is key as Lake Victoria is one of the most dangerous waterways in the world.

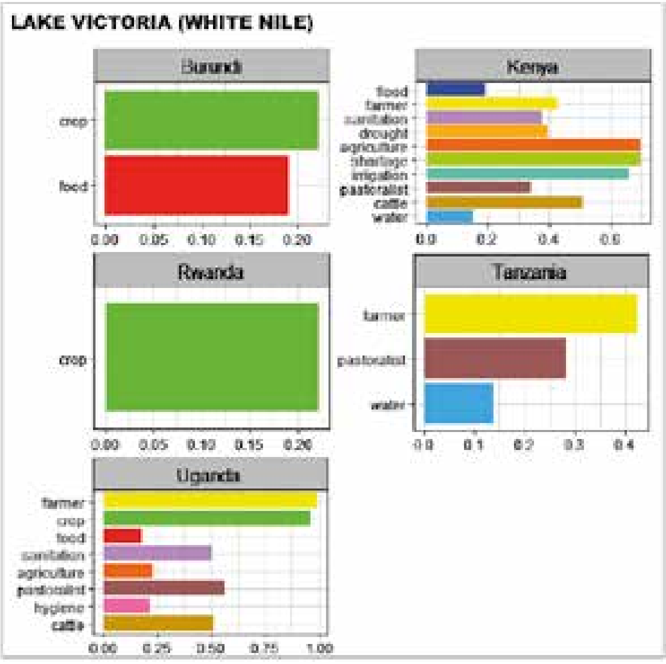
- Management of the increasing energy demand
  - *Enhance water sharing*: Improve basin-based water sharing strategies by abandoning state-centric water development approaches and develop sustainable cooperation over the shared water to meet the climate change challenges
  - *Improve regional power market and cross border exchanges*: Improve regional dialogue for better cooperation (coordination and collaboration) in power infrastructure development among countries to make a regional power market and cross-border exchanges feasible and beneficial to the Nile citizens
  - *High voltage network development*: Complete the high voltage power interconnection to White Nile regions north of Uganda
  - *Renewable energy:* Further expand the great potential of renewable energy production: hydropower, geothermal, wind and solar power. Explore the potential of implementation of floating photovoltaic systems on identified water surfaces to produce energy and reduce evaporation from open water
  - *Minimize environmental risks of EACOP* construction (displacements of wildlife and communities) and operation (oil leakages, illegal oil extraction from the pipeline)

- Coordinated basin water use monitoring, data collection and management as the basis for effective basin operations and management, including at riparian state national levels.

Summary notes: IGAD ranked and reviewed the section on water and hydrological regime. The most important and urgent priority is identified by IGAD in the assessment of the impact of Climate Change (CC) and Climate Variability (CV), and specifically on the issue of “uncertainty of the rainfall over the lake and about its variability”. Linked with CC and CV, the issue of analysis and research on extreme events (such as floods, droughts, etc.) is also ranked as important even if its impact and awareness is already well know (and trend analysis and early warning systems have been developed and used in the basin). In general also other issues identified in the report have been classified and ranked as very important or important. Among these more specific suggestions focus on: i) the need of quantification of water release by the lake and the impact of current and new hydropower plants still have to be carefully quantified, and even if the issue is known among the major agencies, several studies have been conducted, but it is not clear if and how the outcomes of such analysis have been valorised (it seems outcomes and benefits of research have been not enough or effectively disseminated); ii) Lake levels: generally there is good consensus on the impact on navigation and water supply systems of the lake fluctuations, but still the cause of such changes is not clear. In this sense iii) Monitoring and modelling and Water demand Quantification are also identified as Very important priorities: Preliminary work on understanding lake water balance have been developed by IGAD, under the framework of ACEWATER phase 2 project and currently the focus is more on forest modelling (including analysis of impact on water resources and lake levels). Concerning water demand, even if large water users are known, still what is missing is the monitoring of variable (across space and time) water demands, such as for example, the irrigation one. (Reference for more details: ANNEX_I_TAB_03.LAKEVICTORIA.xlsx).

Most recurrent water related keywords per country in the river basin:

Figure 26. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



RIVER BASIN 2

NIGER

5.4 River Basin 2 – Niger

5.4.1 Introduction

The Niger River basin (NRB), located in Western Africa, covers 7.5% of the continent (2.1 million km^2) even if only approximately 1.2 million km^2 contribute effectively to river discharge (Long et al., 2014) (Mosugelo et al., 2002; Pricope et al., 2015). The active basin (excluding Algeria area) is shared by nine countries: Benin (2.5%), Burkina Faso (3.9%), Cameroon (4.4%), Chad (1.0%), Côte d'Ivoire (1.2%), Guinea (4.6%), Mali (30.3%), Niger (23.8%) and Nigeria (28.3%). It is home to more than 130 million people. From its headwaters in the Fouta Djallon Massif in Guinea to the terminal delta in Nigeria, the Niger river (the third longest one in Africa) travels through 4,200 km and shapes an important corridor for migration and trade, a potential source of conflicts and a chance for transboundary cooperation (Andersen et al., 2005). The basin comprises sub-regions with very different hydrographic and climatic conditions: The Upper, Middle and Lower NRBs, the Benue and the Niger Delta.

Figure 27. The river basin.

Together with its associated aquifers, it constitutes one of the most important water resources in Africa, providing drinking water, supporting livelihoods (e.g., large-scale irrigation, fisheries and livestock herding), generating hydropower and allowing navigation. In addition, one of the largest Ramsar sites in the world comprises the Inland Niger Delta, a hotspot of biodiversity and a vital part of eco-regional network (Zwarts et al., 2006). Other freshwater ecosystems of international importance are protected through national parks (such as the W Park, in the Mékrou river basin) or their inclusion within conservation areas for certain taxa (e.g., fishes, birds or other vertebrates). The Niger delta, which can be divided into four ecological sub-zones (being mangrove the dominant one) has been described as “a rich region with poor people”, due to its abundant crude oil and natural gas resources (Week and Wizor, 2020). However, the basin is also extremely vulnerable due to its pronounced hydroclimatic variability, both spatially and temporally, and its complex socioeconomic context (growing population, high poverty levels, food insecurity and values of the Human Development Index (HDI) amongst the lowest in the world; (Vaucelle, 2015). Hence poverty, heavy reliance on natural resources, ongoing conflicts, politically instability and climate change make this area one of the most fragile in Africa.

From a water management perspective, the basin faces three main challenges: i) growing water demands, ii) underdeveloped infrastructure and iii) extreme water hazards due to climate variability (FAO and IHE/Delft, 2020). Other water-related challenges include degradation of land and water resources, inefficiency and poor performance of agriculture and vulnerability to disasters. In this context, water-related interventions are needed (Namara et al., 2011).

The Niger Basin Authority (NBA), established in 1980 by the 9 riparian countries, aims to coordinate national water resource management efforts through an integrated development plan for the basin, in order to improve the life conditions and prosperity of the population. Currently, the basin has a great potential for development: it is estimated that only 9% of the agricultural lands are irrigated, whereas only 20-25% of the potential hydropower capacity is installed. Therefore, within the framework of the Sustainable Development Action Plan (SDAP, approved in 2007), three new large dams were initially planned in cascade: Fomi dam in Guinea, Taoussa in Mali and Kandadji in Niger (NBA, 2015; World Bank, 2020). Other identified investment opportunities in the basin include transportation facilities (including navigation, whose potential is estimated at 3,000 km), environmental management (especially in the Fouta Djallon basin and the Inland Delta), flood and drought mitigation, significant livestock and fisheries potential and ecotourism (Andersen et al., 2005).

5.4.2 Key challenges

5.4.2.1 Hydrology

The Niger river basin is normally divided in subregions characterised by different hydrology and climatic conditions: In the Upper NRB, headwaters of the Niger river accumulate on the plateau’s region with annual precipitation of about 1,500 mm/y. The upper Niger flows into the Inner Delta, a vast wetland (whose surface can reach 80,000 km^2) where water is evaporated from natural and agricultural areas. The middle region of the NRB is the driest area and continues up to the border of Nigeria, receiving water input mostly from the right-bank subbasins (for example the Sirba and Goroul catchments). The lower NRB ranges from the Nigerian border to the confluence of the Niger and the Benue river: in this area average precipitation is about 1,000-1,500 mm/yr. Finally, the Benue basin, in the Eastern part of the NRB, originates from Cameroon plateau and has one of the main water inflow contributions to the Niger.

Mean annual input by precipitation in the NRB is nearly 1,500,000 million m^3/year, of which around 11% becomes runoff. However, the runoff ratio is spatially heterogeneous (moderate in the east and west of the basin and very low in the centre; 35% of the NRB does not contribute to runoff because it is located within the hyper-arid Sahara) and water losses take place mainly in the wetlands of the Middle Reaches of the Niger in Mali and Niger (Mainuddin et al., 2010; Grijsen et al., 2013). The annual river flow does not occur at the same time in different parts of the NRB due to topography and climate. In the Upper Niger, high water discharges take place in September, while April-May is the low water season. The Inland Delta, with an estimated storage capacity of 70 km^3 and a high rate of loss due to evapotranspiration, delays the peak flow by three months and there is a phase of receding water extending into February. In the Middle Niger, a double hydrograph is currently observed, while May and June are the low water months. The Benue has only one high-water season (from May to October, earlier than the Middle Niger). Finally, the high-water period in the Lower Niger (downstream of the confluence with the Benue) begins in May/June and the low water one is at least one month shorter than in the Middle Niger (because of the earlier start of rains in the south) (Andersen et al., 2005).

During the last decades, changes in stream flows in the Sahel region have given rise to two paradoxes. The first Sahelian paradox refers to the increase of the Sahelian rivers' flow rates, despite the dramatic droughts which started in the 1970s and lasted till the mid-1990s. This first paradox is usually explained by changes in land use and land cover (LULC) due to drought and anthropogenic factors. The second Sahelian paradox portraits the increase of flow rates with the so-called "re-greening" of the Sahel after the droughts, and it is attributed to changes in the water-holding capacity of the soil, decrease of woody vegetation and increase of the drainage network. Besides, the increase of rainfall extreme events supports both paradoxes (Massazza et al., 2021). Therefore, there is an ongoing discussion about which is the major driver of increasing floods in the Sahel: LULC or climate trends. In this regard, current land cover in the NRB can be summarised in four main categories: bare/sparse vegetation at high altitude in Algeria, grassland in the Middle basin, shrub land and rainfed crops in the lower basin, and forest in Guinea, Nigeria and Cameroon at the lower latitudes. The largest irrigated areas are located in the Inner Delta and in the areas managed by Office du Niger, while Kainji, Sélingué and Lagdo reservoirs are the main artificial water bodies.

Tarhule et al. (Tarhule et al., 2015) found increasing flows and transition to a wetter period after the extremely dry period during 1970s and 80s. A general change point of hydroclimatic behaviour has been observed in 1969, after which both rainfall and river streamflow show a positive trend, confirming the wetting trend. Since the 1970s, the Niger river regime has changed from a single hydrograph to a two-flood one, due to a sharp increase in runoff of the right bank tributaries. Concretely, in Niamey, the river has a first flood peak between August and September (the red or local flood, which has its origin in local rainfall) and a second one around January (the black or Guinean flood, originated from the water fallen in the Fouta Djallon during June-September). Potential causes could include the increase of bare and crusted soils, due to the extension of crop areas and shortening of fallow periods, and changes in connectivity of the river networks (which could cause an increase in the contributing basin area (Descroix et al., 2012). Besides, increase in both accumulated precipitation (11%), the number (51%) and magnitude (54%) of extreme events in the Middle NRB, along with a greater concentration of rainfall and extremes (78%) in August have been

Hydrology - challenges

- Ongoing discussion about which is the major driver of increasing floods in the Sahel: LULC or climate trends.
- Since the 1970s, the river regime has changed from a single hydrograph to a two-flood one, due to a sharp increase in runoff in the case of the right bank tributaries.
- Increasing flows and transition to a wetter period after the extremely dry period during 1970s and 80s. A general turning point in hydroclimatic behaviour has been identified in 1969, after which both rainfall and river streamflow show a positive trend.
- Floods are increasingly perceived as a major threat: flood damage can be exacerbated by dam operations (e.g., releases from the Sélingué dam during 2001 flood in Mali, uncontrolled releases from Lagdo dam in Cameroon or floods in the Niger Delta).
- Increase in both accumulated precipitation (11%), the number (51%) and magnitude (54%) of extreme events in the Middle NRB, along with a greater concentration of rainfall and extremes (78%) in August have been found to reinforce the positive anomalies of the red flood in Niamey.
- Accurate weather forecasts could be a valuable tool for improving water management in the basin, but the accuracy of the Global Forecast System (GFS) is uneven in the NRB.
- Groundwater quantity is generally not an issue except at local scale, while water quality is generally good.

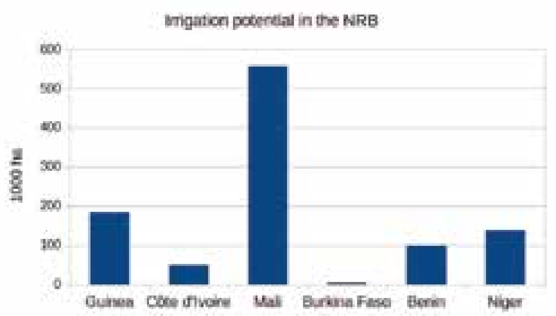
found to reinforce the positive anomalies of the red flood in Niamey (2.23 standard deviation in 2020) and the sustained increase of hydrological indicators (27% in the case of annual maximum flows). River-bed silting and levee effects are other concurrent drivers which could make Niamey more prone to extreme hydrological events (Massazza et al., 2021). However, Aich et al. (2015) concluded that the shares of LULC and climatic changes as drivers for flood increase could not be quantified in the case of the local flow of the Niger river at Niamey or for the Goroul river, although both drivers were estimated to contribute equally in the case of the Sirba basin.

Floods are increasingly perceived as a major threat, affecting people at a scale of millions (Aich et al., 2014) because of increasing vulnerability, population growth and distribution, along with climate change and its impacts on river discharges (Descroix et al., 2012). Concretely, an increase of occurrence of catastrophic flooding in the last two decades is reported (Aich et al., 2016). According to Roudier et al. (2014), there is an urgent need to take into account other factors influencing runoff, especially water consumption and land use changes, in order to conduct a more comprehensive flood risk assessment. Indeed, land use changes have been identified as main drivers for flood risk increase, especially in dry Sahelian zones (Descroix et al., 2013). Besides, flood damage can be exacerbated by dam operations. For example, during the 2001 flood in Mali, the reservoir of the Sélingué dam was already full and the gates of the dam had to be opened with little warning to preserve the infrastructure. As a result, irrigated rice fields, crops and settlements sustained extensive damages, prompting responses from those affected and the national and local governments (Goulden and Few, 2011). Uncontrolled releases from Lagdo dam in Cameroon have also been reported to result in major flood events along the Benue and Lower Niger rivers in Nigeria. In the case of the Niger Delta, floods heavily compromise food security at household level, reducing the efficiencies of farmland in terms of food security, income reduction and poor livelihoods (Week and Wizor, 2020). In this regard, reservoir operation should be carefully assessed to integrate hydrologic, environmental and economic constraints when conflicting objectives exist (such as hydropower generation and flood control during the pre-flooding season) (Olukanni et al., 2018). Besides, accurate weather forecasts could be a valuable tool for improving water management in the basin, but the accuracy of the Global Forecast System (GFS) in the NRB varies depending on climate regime, lead time, accumulation time scale and spatial scale. Concretely, a large overestimation bias has been found in the Guinea region (wet climate), a moderate one in the Savannah region (moderately wet climate) and no bias in the Sahel (dry climate). In the case of daily rainfall forecasts, their performance was very low except for the watersheds of Markala and Kainji dams (Yue et al., 2022).

5.4.2.2 Agriculture and food security

Three main agro-ecological zones can be identified in the NRB: semi-arid, Sahelian zone (mean annual rainfall ranges from 250 to 750 mm/year, concentrated in a single wet season spanning from May/June to September/October and which allows a growing period of 90-120 days); northern Guinea zone (precipitation ranging from 750 mm to 1,400 mm, unimodal rainy season of five to six months and a growing period of 150-180 days) and; southern Guinea zone (annual rainfall up to 1,600 mm, rainy season of seven months and growing period of 150-210 days). Main agricultural activities and crops include cereals and nomadic herding in the Sahelian zone; maize, sorghum, millet, rice, yams, groundnut, soybean and beans in the northern Guinea one and; grains (maize and rice) and root crops (yams and cassava) in southern Guinea (Akumaga and Tarhule, 2018). Subsistence farming is the predominant agricultural system in the basin. The dry-season livelihoods depend on *fadama* farming (lowland or inland valleys), recession flood farming, agroforestry, irrigated rice farming and fishing, while cereal cropping and transhumance are the main livelihoods during the wet season (Namara et al., 2011). Livestock comprises camels, donkeys, goats, horses, poultry and sheep, being milk and by-products an important source of protein for the basin's population. However, livestock feeding and access to water pose a serious problem, particularly during the dry season, and productivity is low (Namara et al., 2011). Fisheries in the basin are both a substantial economic activity (employing an estimated 20% of the total agricultural workforce and with women playing a major role in fish processing and marketing) and the main source of animal protein for many people in the basin (total annual catches estimated at 300,000 tonnes, with Mali and Nigeria being the largest contributors). Artisanal fishing is very intensive in fresh and brackish waters and adapts to the hydrological cycle (decreasing when fishes are dispersed in the

Figure 28. Irrigation potential in the NRB by country. Source: elaborated from Van Der Wijngaart et al. (2019).



floodplains or during the rainy season) and, more recently, to the effects of environmental degradation (diversification of fishing methods, emergence of new technologies). From 1950 to 1970, fishing pressure experienced a large increase due to a growing number of fishers and the introduction of synthetic nets, but fish production decreased afterwards (from 1973 to 1991, mainly due to drought) and then increased again along with the flows in the Inland Delta. Aquaculture has been introduced to supply the high demand for fish products, but it is not very developed (Laë et al., 2004). According to the Nexus Regional Dialogue in the Niger Basin (Phase II), 70% of NRB's inhabitants live in areas where food security is threatened by unreliable and changing rainfall patterns, smallholder agricultural production, biomass and endangered ecosystem services.

Rainfed agriculture is prevalent in the NRB, while irrigation area has been estimated covering 1 to 5% of the total crop area (Van Der Wijngaart et al., 2019), although other authors reported higher values (15% of the cultivated area, Ghile et al, 2014). The basin has a huge potential for irrigation development (up to 1.5-2.9 million ha), but multiple barriers need to be overcome (e.g., absence of well-developed institutions for irrigation, prevalence of subsistence farming and high investment costs, Van Der Wijngaart et al., 2019). In this context some existing infrastructures have not achieved the irrigation potential identified in the preliminary studies. For example, in the case of the Sélingué dam only 13% of the potential was achieved in 2017. Besides, existing irrigation schemes can suffer from various problems: farmers reported that services provided by the irrigation agency were poor and grossly inadequate, revenues were unable to meet the costs, productivity and crop yields were lower than expected and access to inputs was also difficult (Oriola, 2009). Van Der Wijngaart et al. (2019) concluded that, despite the largest irrigation potential of the basin, investing in both irrigation and rainfed intensification could achieve the best potential gains in the basin. In the past, inadequate agricultural expansion, along with climatic factors, have led to famine. Dam developments and new irrigation schemes have been identified as potential solutions to foster food security and expand farmers' production opportunities, although several concerns feed the debate about potential negative impacts on local economies (e.g., due to impacts on the Inner Delta, reduction of the flood peak, higher flows downstream of the dams and water shortages downstream or, reduction of the flooded area for recession farming). Environmental degradation due to the development of the gas and oil industries also threatens food security in the Niger Delta, where oil pollution is aggravated by attacks and sabotages to the pipelines (youth militants, locals) or irresponsible actions from local contractors (such as burning the oil spills). In this context, the impact of oil pollution on farmlands, crops, trees and water is so devastating that people cannot longer obtain food by farming or fishing. As a result, traditional food has become either scarce, unavailable, unaffordable for local communities.

Food and agriculture - challenges

- 70% of NRB's inhabitants live in areas where food security is threatened by unreliable and changing rainfall patterns, smallholder agricultural production, biomass and endangered ecosystem services.
- The dry-season livelihoods depend on *fadama* farming (lowland or inland valleys), recession flood farming, agroforestry, irrigated rice farming and fishing, while cereal cropping and transhumance are the main livelihoods during the wet season; Livestock feeding and access to water pose a serious problem, particularly during the dry season, and productivity is low.
- Rainfed agriculture supplies most of the food products (about 78%) but it is highly vulnerable to climatic factors: need to increase the resilience of rainfed systems to climate variability and change, along with a careful consideration of the interlinkages and competition issues with the pastoral and livestock breeding systems.
- Huge potential for irrigation development (up to 1.5-2.9 million ha), but multiple barriers need to be overcome (e.g., absence of well-developed institutions for irrigation, prevalence of subsistence farming and high investment costs). Irrigation water demand is already dominant (85% of the total).
- Ongoing projects in the basin will entail the expansion of irrigated agriculture: over 210,000 ha in the case of Fomi dam, mainly downstream dry-season irrigation located in the Office du Niger scheme (World Bank, 2015) and 45,000 ha in the case of Kandadji dam (AfDB, 2018). Besides, Taoussa dam will enable the development of 139,000 ha of hydroponic systems.
- Future agriculture developments should consider aspects such as water productivity, sustainable management of groundwater storage, seasonal and climate variability and the impacts on the people and ecosystems downstream.
- Irrigation efficiency is rather low, as the water supply is continuous regardless of the irrigation demand.
- Existing infrastructures in the basin have not achieved the irrigation potential identified in the preliminary studies.

5.4.2.3 Socioeconomic

In 2015, population in the NRB was estimated at 138 million people (mainly living in Nigeria (69%), Niger and Mali (9%, respectively). Population is increasing at a fast pace (2-4% annually) and population density within the basin is much higher than the national averages (4 to 5 times) (World Bank, 2020). Although average population density is about 50 inhabitants/km^2, its distribution is heterogeneous (population density is more than 200 inhabitants/km^2 in certain places along the river course, while the northern part of the basin is mostly unpopulated) and it is estimated that about two thirds of the population is rural (Namara et al., 2011). Seven of the ten riparian countries are among the twenty poorest countries in the world, with large disparities both in terms of income and gender (World Bank, 2015). Along with climate and water-related drivers, development in the basin is hindered by a combination of multiple socioeconomic factors, including inadequate public services, institutional and governance failure, high population growth and urbanisation, poor macroeconomic performance and unemployment (Namara et al., 2011). In this context, the basin is an important socioeconomic asset for the riparian countries, contributing between 20-50% to the national GDPs and sustaining major metropolitan centres, such as Bamako, Niamey and Abuja (World Bank, 2020). However, and according to the Nexus Regional Dialogue in the Niger Basin (Phase II), most of the population lack access to basic services, such as electricity (two thirds of the population), improved water sources (30% of the population) or improved sanitation facilities (75%).

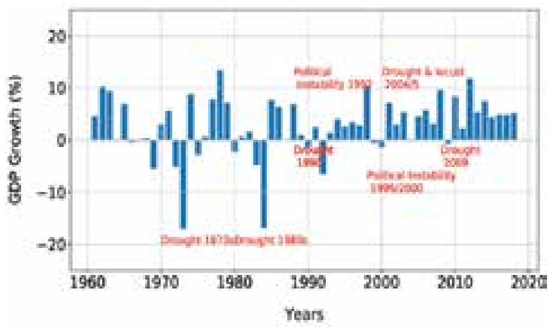
Agriculture represents a large part of the GDP in the NRB (25-35%), while livestock and fisheries contribute to 10-15% and 1-4% respectively (Namara et al., 2011). Concretely, in the Least Developed Countries (LDCs) of the basin (Benin, Burkina Faso, Chad, Guinea, Mali and Niger), agriculture and animal rearing generate 40-60% of their export income and employ between 80-90% of the active population (CIMA, 2012). In Niger, where more than 77% of its landmass receives an annual precipitation of less than 150 mm, 80% of the population relies on rainfed agriculture and the primary sector accounts for 45% of GDP, water scarcity and drought pose serious challenges for both the agricultural and the livestock sectors and heavily influence GDP growth. Negative precipitation variability (e.g., a short-term dry spell) has been found to be more dangerous than an overall change in precipitation trends for triggering political violence in the NRB, which could be explained by its impact on agricultural markets (Landis et al., 2017).

Socio economic - challenges

- Population is increasing at a fast pace (2-4% annually) and population density within the basin is much higher than the national averages (4 to 5 times).
- The basin contributes between 20-50% to the national GDPs and sustains major metropolitan centres, such as Bamako, Niamey and Abuja. However, most of the population lack access to basic services, such as electricity (two thirds of the population), improved water sources (30% of the population) or improved sanitation facilities (75%).
- In Niger, where 80% of the population relies on rainfed agriculture and the primary sector accounts for 45% of GDP, water scarcity and drought pose serious challenges for both the agricultural and the livestock sectors and heavily influence GDP growth.
- Negative precipitation variability (e.g., a short-term dry spell) has been found to be more dangerous than an overall change in precipitation trends for triggering political violence in the NRB, which could be explained by its impact on agricultural markets.
- UN Human development Index: riparian countries belong to the lowest quintile; High mortality rate in children due to respiratory and water related diseases. Still 30% of the population do not have access to an improved water source and 75% do not have improved sanitation facilities.
- Unlock markets for farmers is a key issue. Market access could be enhanced through the development of river navigation, roads and, in general, the transport network system.
- The Niger Delta region (Nigeria) is considered as the main area regarding oil exploitation in West Africa. However, oil exploitation is considered detrimental for the local communities, as resulting environmental degradation negatively impacts agricultural livelihoods and income while increasing poverty.

The landlocked nature of several of the riparian countries act as a barrier for the importation and exportation of capital goods, coupled with a poorly developed transportation network. Both domestic and external transport mainly depend on roads (which are often badly maintained and/or damaged), due to the lack of railways, the inadequacy of airport facilities and the current low navigability of the Niger river. Market access could be enhanced through the development of navigation, but it would be necessary to consider the impacts of water abstraction on navigation downstream and adapt the existing infrastructures to allow sailing.

Figure 29. Influence of drought in Niger's GDP growth. Source: Adamou et al. (2021).



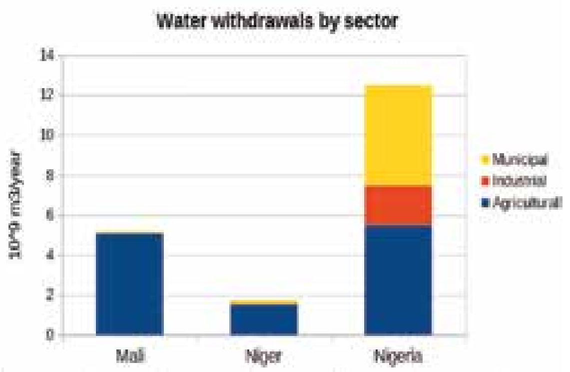
Oil exploitation in the Niger Delta region of Nigeria started in 1956, and it is still considered as the main area regarding hydrocarbon production in West Africa or even in the whole continent. Nigeria is the largest oil producer in Africa and it was the sixth largest oil exporter in the world in 2014, being the oil exploration and exploitation industry the most important earner of foreign exchange in the country. Since the 1970s, Nigeria's economy relies heavily on the oil industry, which contributes to 40% of the country's GDP and provides more than 95% of export earnings. However, oil exploitation is detrimental for the communities living in the Niger Delta, as resulting environmental degradation decreases agricultural livelihoods and income while increasing poverty (Elum et al., 2016).

5.4.2.4 Water use and demands

The riparian countries are not homogeneous in terms of contribution to water resources in the basin and dependence on them. Main contributors include Guinea, Cameroon and Benin, whereas Mali and Niger are the main consumers. Nigeria is both a significant contributor and consumer, and the rest of the countries (Ivory Coast, Burkina Faso and Chad) play a minimum role due to their relatively small share of the basin (Andersen et al., 2005).

Current crop water demands in the NRB are generally met through precipitation (most of the irrigated area corresponding to small scale flood recession cultivation). It is estimated that around 6 km^3/year are withdrawn for agriculture (out of a total outflow of 180 km^3/year in the Niger Delta). Largest irrigation withdrawals in the basin generally take place from January to March (there is also a peak in irrigation water requirements between March and April), while lowest water use for irrigation purposes occurs from July to September. According to Namara et al. (2011), while the withdrawals of Markala dam for the Office du Niger amount to 5% of the wet season flows, the percentage raises to 80% of the flows during the dry season. Some factors that highlight the criticality of the issue are: i) in the view of a 2 ºC global warming scenario, average crop water demand in the basin could experience changes up to 15%; ii) even if water availability could increase in some areas, a general decrease of the irrigation potential in the Sahelian basins would range between 10-30% (Sylla et al., 2018). Concretely, most significant future irrigation water requirements in the NRB could be located in Mali, Niger and rarely in Burkina Faso (from 16.3 mm/day to 45.9 mm/day, depending on the GCM and the selected scenario). The zones of the basin with lowest irrigation requirements would be Guinea, southern Mali, Ivory Coast, centre and southern Nigeria and Cameroon (1.29 mm/day to 33.4 mm/day) (Abdoulaye et al., 2021).

Figure 30. National water withdrawals by sector in three selected countries of the NRB (2018). Source: elaborated from AQUASTAT.



Water demand - challenges

- Largest irrigation withdrawals in the basin generally take place from January to March, while lowest water use for irrigation purposes occur from July to September.
- Current irrigation demand (the highest demand, accounting for about 80% of the total) is about 7% of the average annual discharge of the Niger, but it could rise to one third by 2045. Besides, the impacts of small-scale water abstraction on river levels could be important but have been generally neglected.
- While the withdrawals of Markala dam for the Office du Niger amount to 5% of the wet season flows, the percentage already raises to 80% of the flows during the dry season.
- Most significant future irrigation water requirements in the NRB could be located in Mali, Niger and rarely in Burkina Faso
- Additional dam development in the NRB has been identified as a solution to mitigate the negative impacts of climate change on hydropower generation and ecosystem health. Ongoing developments in the basin include i) the Kandadji Ecosystems and Niger Valley Development Programme; ii) the construction of the Fomi dam (which will suppose suppose a huge upstream storage (up to 20% of the total annual flow at Bamako and four times the volume at Kandadji); iii) multipurpose Taoussa dam to enable irrigated agriculture (139,000 ha by 2040), fishing, hydropower (intended installed capacity of 25 MW) and facilitate navigation (from Timbuktu to Taoussa).
- Despite the existence of large groundwater resources in the middle and lower parts of the NRB (such as the Iullemeden and Taoudéni transboundary aquifer systems) and its potential role in adaptation policies, their exploitation rate is relatively small. Borehole wells are an important source of drinking water at household level (mainly in the rural, poor areas).
- Poor knowledge about aquifer systems in the region is a key limiting factor: the need to develop scientific analysis and promote human capacity development (HCD) initiatives is a key issue. Various ongoing activities aim at addressing scientific research and joint management efforts on aquifers.

Additional dam development in the NRB could mitigate the negative impacts of climate change on hydropower generation and ecosystem health to some extent (Yang et al., 2018). Ongoing developments in the basin include the Kandadji Ecosystems and Niger Valley Development Programme, which entails the construction of the Kandadji dam in the Niger's portion of the river (at Kandadji, in the Tilláberi region) in two different phases: a first one from 2019 to 2025/26 (height of 224 m) and a second one from 2026 to 2031 (height 228 m). The Kandadji scheme will also entail the resettlement of nearly 50,000 people, the flooding of more than 12,000 ha of agricultural land and multiple ecosystems alterations (loss of fish habitats, a decrease of the wetlands downstream, the implementation of an artificial flow regime or an increase of the amplitude variations and dissolved oxygen; AfDB, 2018). The construction of the Fomi dam will suppose a huge upstream storage (up to 20% of the total annual flow at Bamako and four times the volume at Kandadji), allowing irrigation expansion, hydropower generation and guaranteeing water supply in big cities downstream (such as Bamako). However, the project entails several social and environmental impacts, such as the resettlement of 45,000 people (mostly in Guinea) or changes to the flood regime in the Inner Delta in Mali. Multipurpose Taoussa dam will create a reservoir of 3.15 billion m^3 to enable irrigated agriculture (139,000 ha by 2040), fishing, hydropower (intended installed capacity of 25 MW) and facilitate navigation (from Timbuktu to Taoussa).

Groundwater plays a key role in the Niger river basin and, more generally, in Western Africa. With its relevant storage and complex interplay with surface water bodies, feeding streams in periods of drought or recharge deficit, groundwater is also key to face up climate variability and longer-term climate change challenges through adaptation policies. Besides, borehole wells are the main supply source of drinking water for households across the basin, principally in the rural, poor areas (Namara et al., 2011). Despite the existence of these large groundwater resources in the middle and lower parts of the NRB, the exploitation rate of groundwater resources in the basin is relatively small. One of the main barriers for the exploration, utilisation and management of these resources is the poor knowledge about aquifer systems in the region (both in quantitative and qualitative terms). Regarding water quality, protected deep groundwater is often a relevant good quality resource. Still major quality concerns arise, at regional and local scales, due to geological conditions, as for natural fluoride and arsenic anomalous levels (e.g., related to crystalline basement in Burkina Faso), saltwater intrusion in the Niger delta region, and pollution, particularly of upper phreatic systems, related to human activities, poor sanitation in urban settlements and industrialisation. Promotion of collaborative management policies in transboundary shared aquifers is another key issue.

5.4.2.5 Water quality, health and environmental issues

Water quality related health issues (e.g., vector borne and diarrheal diseases) are generally ranking high in the basin countries. Together with respiratory diseases they represent “traditional environmental hazards”, which, fortified by malnutrition and sometimes conflict, are the top health issues in all NRB countries. The water quality issues herein, which affect human health, are first-hand biological issues. They have little or no impact on the aquatic ecosystems, apart from some eutrophication issues downstream of urbanised areas.

The impacts from chemical water pollution on the environment (e.g., threats to biodiversity due to fertilizers, pesticides, industrial chemicals) seem limited to local pollution downstream of urban and irrigated areas and mining sites. Due to the overall low production compared to developed countries, the net release of chemicals into the environment is still at a low level. They have little or no impact on the aquatic ecosystem as such, which is more significantly affected by land use and flow regime changes associated with modernisation in the agriculture and energy sector.

The current threats to ecosystems and their biodiversity in the basin are generally driven by the overall population growth, which goes hand in hand with dramatic land use changes and thus the physical alteration and destruction of habitats, both terrestrial and aquatic.

Biological water quality issues. According to WHO (2019), the incidence of malaria (2018) in the countries that are part of the NRB was among the highest worldwide (> 250 cases per 1000 population). Among the waterborne vector transmitted diseases, malaria is the deadliest one. The association of malaria with irrigation or dam projects in arid lands has been known in ancient and recent history. Schistosomiasis ranks second next to malaria from parasitic infection in terms of socioeconomic and health impact in tropics (Inobaya, et al. 2014).

It should be noted, that it affects also animals, and hybridisation between animal and man associated species has recently been observed (Léger et al. 2020). The presence of Zika virus is also growing in the NRB. The distribution of Aedes albopictus (also known as tiger mosquito) in Africa has thus far been known to be restricted to coastal Sub-Saharan countries, but it has been observed over several years in increasing frequency in Mopti in Central Mali and later in the capital city Bamako, both adjacent to the Niger River. Pathogens present in surface and drinking water are by far the most impacting human health issue directly associated with urbanisation: high incidence of childhood diarrhoea (22% of deaths in children under 5 years, generally in Mali) from insufficient separation of the oral/faecal cycle has been reported. Indeed, the lack of WASH services, together with malnutrition and (indoor) air quality rank as the top 3 risk factors for premature death and disability in quasi all basin countries.

Chemical water quality issues. In general, contamination by agrochemicals can be considered at low risk level at river basin scale. A 2017 survey on nitrates/nitrites in Bamako (Mali) revealed the absence of nitrites, while nitrates where at an average concentration of about 1.3 mg/l (very low value, as for example, EU drinking standard requires just a value below 50). Similar results have been found for pesticide compounds. Banned organochlorine pesticides exceed limit values around cocoa plantations in Nigeria. Similarly, the concentrations of pesticides resulting from studies of residues in soil and water in Mali suggest that contamination by pesticides in the cotton growing areas is not as severe as might be anticipated. Indeed, human health risks are mainly associated with incorrect and unprotected usage.

Industrial chemicals. Industrial chemicals pose a risk to the (aquatic) ecosystems and human health in the NRB, since the processes are unregulated, without emission control and other protective measures for man and environment. The related hazards can be drastic, but they are commonly limited to the vicinity of the production or mining sites. In this context, rivers can play an important role in pollution downstream of the original sources. For example, mercury pollution of rivers downstream of artisanal gold mining sites (considered an issue at global scale due to the high volatility of Hg) is reported both for Mali and Guinea. Environmental damage and chemical pollution arise from gold mining in Mali and Guinea. Artisanal and industrial scale gold mining are important economic sectors in Mali, Guinea and in some other of the basin countries. Pollution from petroleum and gas mining in the Delta (Nigeria) is another important issue, also due to the lack of regulation and the overall instability in the region. Environmental damage and human risk arising from inland oil and gas exploitation in the basin are documented to a sufficient extent (in the region and elsewhere in the world) in order to go ahead with mitigation concepts. Emissions from non-sustainable E-waste recycling in Nigeria are a concern.

While agriculture is generally an important driver for deforestation and a threat to biodiversity, the contamination with agrochemicals is so far limited to zones of intense, often irrigated cultivation. Cocoa cultivation is a leading cause of deforestation and degradation of West Africa's tropical forest habitats.

5.4.2.6 Climate change and climate variability

Climate variability has long been a challenge for the development of the basin and climate change will compound extreme events and raise further obstacles to the region's development. Three major issues have been identified: i) rise in temperature and evapotranspiration losses, ii) increased variability of rainfall, extreme events such as floods and droughts and iii) impact of sea level rise on the delta. In this context, it is important to cite the Climate Resilience Investment Plan for Strengthening of Resilience to Climate Change in the Niger River Basin (CRIP) prepared and to be implemented by NBA and riparian countries (ABN, 2015).

One climatic factor substantially impacting the vulnerability of the basin is linked with the characteristics of the West Africa Monsoon and of the Sahel-Saharan zone and, more specifically, with its intra and interannual variability (affecting rainfall distribution and the annual length of the dry season; Sun et al., 2010).

Figure 31 shows the precipitation deficit variability in the NRB, with the highest variability located in the northern part of the basin (sub-desertic and desertic areas) and the lowest in the headwaters and the Benue sub-basin (less than 30%, although precipitation deficits of about 50% may occur if a return period of 20 years is considered; Cordano and Cattaneo, 2022).

An abrupt change point in rainfall and streamflow time series was detected in 1969 (but not in the temperature ones, which exhibited strong positive trends in all the NRB sub-basins). After the change point, rainfall and streamflow time series showed positive although non significant trends, while significant negative trends were observed when the change point was neglected. Besides, both rainfall and streamflow in the NRB were found to fluctuate on cycles of 2-4 years (with a few episodes ranging from 6 to 8 years), while temperature usually fluctuates on 1 to 4 years cycles (Tarhule et al., 2015). River flow is very sensitive to precipitation and the propagation of a meteorological drought to a hydrological one usually takes between 1 and 3 months (Oguntunde et al., 2018). In the case of the

Climate variability and change - challenges

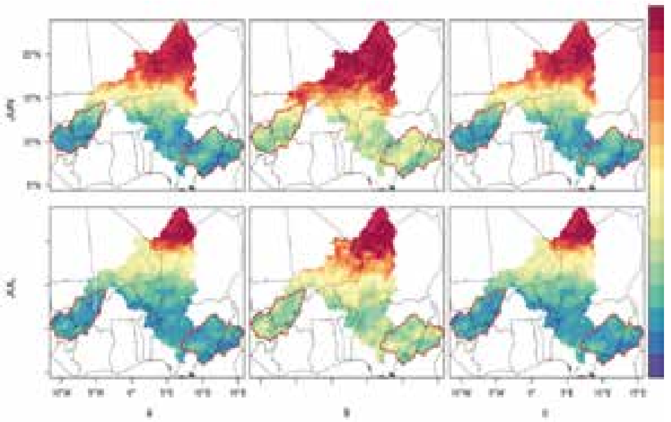
- Three major issues: rise in temperature and evapotranspiration losses; increased variability of rainfall and frequency of extreme events (such as floods and droughts); impact of sea level rise on the delta.
- Higher increases of relative deficit can be reported in low rainfall areas and also during the rainy season (e.g., from June to September).
- Extended hotspots of heat waves.
- Trends: an abrupt change point in rainfall and streamflow time series was detected in 1969. After the change point, rainfall and streamflow time series showed positive although non-significant trends, while significant negative trends were observed when the change point was neglected.
- Temporal fluctuations: on cycles of 2-4 years for rainfall and discharge.
- River flow is very sensitive to precipitation and the propagation of a meteorological drought to a hydrological one usually takes between 1 and 3 months
- CC: Projected changes in rainfall over the West Africa region are not expected to be spatially homogeneous. While future wet conditions are expected in central-eastern Sahel (with a robust increase of rainfall amounts in September-October), dry anomalies could take place over Western Sahel. High uncertainty of predictions: i) agricultural production decreases could take place during the dry season, being more severe in the case of typical dry land rainfed crops; ii) impacts on hydropower, navigation and flooding of the Inner Delta. Adaptation potential measures to cope with these impacts include the reduction of the rainy season irrigated agriculture and/or the implementation of additional storage capacity, while enhancing minimum flows in the Inner Delta and Middle Niger would require to increase the dry season irrigation efficiency during the dry season.
- Recommended measures to tackle climate change impacts include: monitoring fluxes and stocks of water (both temporally and spatially) and the development of robust socio-eco-hydrologic models and scenarios.

Sankarani river (a tributary of the Niger river, where the Sélingué dam is located), rainfall was reduced by 8.7% during the period 1995-2009 (in comparison to 1980-1994), while the flow rate decreased by 32.6% (Diawara et al., 2021). According to Sohoulande Diebou (2015), negative precipitation trends are dominant from September to October throughout the basin, while the March to May season is characterised by a positive precipitation trend. However, Cordano and Cattaneo (2022) did not find significant yearly or monthly trends in the NRB, except for the Benue sub-basin (where a decrease of annual precipitation with a negative trend about 6 mm/year was detected, mainly during May, July and August).

Projected changes in rainfall over the West Africa region are not expected to be spatially homogeneous. While future wet conditions are expected in central-eastern Sahel (with a robust increase of rainfall amounts in September-October), dry anomalies could take place over western Sahel. Besides, average rainfall could increase by 5% in the Southern Guinea zone, by 10-20% in the Northern Guinea zone and by 10-15% in the Sahelian zone (Akumaga and Tarhule, 2018), but impacts on regional precipitation are highly uncertain (other authors obtained modest changes in precipitation across the basin, ranging from –6% to 7%; NBA and World Bank, 2014). Climate change could also increase drought intensity and frequency over the NRB, being the Middle sub-basin the most impacted one and the Upper sub-basin the least (Oguntunde et al., 2018). Besides, a shift in the future onset/cessation of the rainy season in the basin is expected (mean dates of rainfall onset and cessation delayed between 10-32 days and 10-21 days, respectively), along with a shortening of its duration (Akumaga and Tarhule, 2018).

Changes in precipitation patterns could trigger changes in runoff between -18% and 10% (NBA and World Bank, 2014). However, potential changes in peak flow statistics due to climate change in the NRB were found to be generally ambiguous and consistent only in very few areas (Andersson et al., 2017). Regarding agriculture, mild agricultural production decreases could take place during the dry season, being more severe in the case of typical dry land rainfed crops (whose yields could decrease by 15% considering a temperature increase of 2ºC alone). Climate change impacts on hydropower, navigation and flooding of the Inner Delta are expected to be mild to moderate (decrease of 10-20%) and could slightly reduce the economic performance of the Sustainable Development Action Plan (SDAP). Concretely, the economic internal rate of return could decrease by 1.5% if average runoff is reduced by 20% (worst-case scenario). Potential measures to cope with these impacts include the reduction of the rainy season irrigated agriculture and/or the implementation of additional storage capacity, while enhancing minimum flows in the Inner Delta and Middle Niger would require to increase the dry season irrigation efficiency, decrease the irrigated area or to change crop patterns to less water demanding crops. In this regard, the implementation of the SDAP and the construction of Fomi and Kandadji dams could constitute an effective adaptation measure (NBA and World Bank, 2014).

Figure 31. Precipitation deficit in June and July: a) 5 years return period; b) 20 years return period; c) variability. Source: Cordano and Cattaneo (2022).

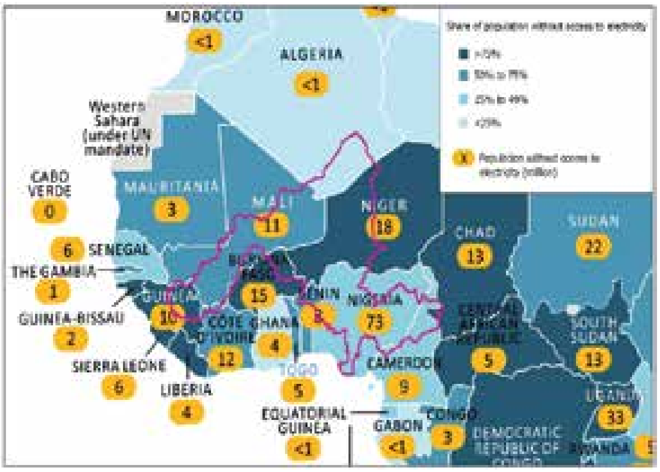


The large intra and inter-annual variability of water resources due to climate variability and change is considered as one of the main challenges that the NRB faces. Further insights on this issue could be obtained through the monitoring of fluxes and stocks of water (both temporally and spatially) and the development of robust socio-eco-hydrologic models and scenarios. Besides, it is necessary to point out that the NRB is mostly ungauged (existing ground measurements of precipitation are discontinuous and usually dated before the 2000s, evapotranspiration measures are even more rare). In this regard, and although remote sensing derived data is useful to characterise climate variability and change, validating and quantifying the uncertainty of this kind of products still pose a great challenge (FAO and IHE/Delft, 2020).

5.4.2.7 Water and energy

By 2020, the demand of energy in the NRB was expected to reach 117,000 GWh (in 2003 it was 30,000 GWh). The basin has one of the lowest power accesses in the world (only 23% of the population, almost 90 million people living without electricity) and fuel wood accounts for 90% of the energy consumed. Niger and Burkina Faso are the countries with the highest share (>75%) of population without energy access (IEA, 2017), due to no or low connection to the African low, medium or high voltage electricity grid; The World Bank, 2022). The share of population relying on solid biomass for cooking is high in all basin countries (>50%), with the highest shares corresponding to Burkina Faso, Niger and Benin (>75%). In the planned extension of the West African power grid, these regions are still not considered. The NRB belongs mainly to the West Africa Power Pool (WAPP), with only small basin areas in Algeria, Chad and Cameroon assigned to adjacent power pools (Medinilla et al., 2019).

Figure 32. Population without access to electricity. From IEA (2017), edited.



The basins hydropower potential of the basin is estimated at 6,000 MW, of which only one third is developed. Largest developments in the framework of the SDAP include Kandadji in Niger, Taoussa in Mali and Fomi in Guinea to meet increased water and energy demands, as well as to address the high inter- and intra-annual variability of water availability. According to Fomi multipurpose project, it is expected to generate 90-100 MW and it will be connected to the WAPP. In the case of the Kandadji project, a new hydropower plant is intended (with an installed capacity of 130 MW), while Taoussa dam will have an associated 25 MW hydropower plant (as stated by the Abu Dhabi Fund for Development in 2010)., According to unofficial sources, the international tender for the construction of Taoussa dam was held in 2020. Annual gross water loss through evaporation (year 2016) is high at big reservoirs such as Kainji (1,883 million m^3) and Lagdo (1,063 mcm) (Gonzalez Sanchez et al., 2020). If water loss is contrasted with hydropower plant produced energy, Lagdo presents the least favourable value of 2.2 million m^3/GWh in the basin, followed by Sélingué (1.1 million m^3/GWh) and Kainji (0.6 million m^3/GWh). At the same time, Kainji, Jebba and Shiroro hydropower reservoirs in Nigeria reveal good potential for floating solar photovoltaics (FPV) (Gonzalez Sanchez et al., 2021). FPV implementation on these reservoir surfaces would not only contribute to an additional energy production (making use of existing hydropower infrastructure) but also entail significant evaporation savings from open waters.

The development of multipurpose projects in the NRB is expected to reduce the annual generation of Kainji (760 MW) and Jebba (578 MW) hydropower plants in Nigeria. Therefore, within the framework of the Niger Basin Water Resources and Sustainable Ecosystems Management Project (sponsored by the International Development Association of the World Bank), a site screening process was conducted in the Benue and Niger rivers in Nigeria to identify additional locations for hydropower plants. After consultation with the stakeholders, three sites on left tributaries of the Benue River were recommended: Manya in the Donga river (136 MW), Bawarku in the Katsina-Ala river (109 MW) and Garin Dalli in the Taraba river (92 MW)

Water and energy - challenges

- The basin has one of the lowest power accesses in the world (only 23% of the population, almost 90 million people, living without electricity) and fuel wood accounts for 90% of the energy consumed. Electricity access rate is up to 35%.
- Basin Hydropower potential in the basin is estimated at 6,000 MW, of which only one third is developed: 18 existing dams, of which 8 are for hydropower purposes and 6 have an installed capacity > 5MW.
- High/medium water losses per hydropower production unit: highest in Ladgo (2.2), Selingue (1.1) and Kainji (0.6) (ratio expressed as mcm loss vs GWh produced).
- High potential of floating solar photovoltaics (FPV) implementation at Kainji, Jebba and Shiroro.
- Largest developments in the framework of the SDAP include 4 dams: Kandadji in Niger, Taoussa and Djenne in Mali and Fomi in Guinea.
- High potential of small hydropower plants to support rural electrification.
- Support multi-purpose infrastructure to share the benefits and reduce the negative impacts, e.g., implementation of FPV on reservoirs Kainji, Jebba and Shiroro.
- Estimates on potential magnitude of future water abstractions upstream of planned hydropower sites, considering different climate change scenarios.
- Reduce biomass use (e.g., firewood and charcoal), related to deforestation, erosion and siltation.
- Integrated and transboundary management and cooperation (e.g., harmonisation of national policies).

(Barker et al., 2016). Regarding future hydropower generation, large uncertainties arise both from the unknown potential magnitude of future water abstractions upstream and those related to regional rainfall under climate change scenarios. At the same time, the environmental and social impacts downstream of large hydropower projects have to be assessed, e.g., the impact on the wetlands in the Inner Niger Delta which is one of the largest multi-use systems (herders, fishermen, farmers) in Africa. Large reservoirs have to deal with higher sediment loads due to increased erosion in the basin triggered by land-cover and land-use changes, mainly deforestation and agricultural expansion. Small hydropower sites as renewable, affordable, clean, local and sustainable energy source could remarkably contribute to the strongly increasing energy demand and solve rural and remote electrification bottlenecks. For example, Nigeria has yet only explored 37 MW of 734 MW potential capacity from 278 potential sites scattered all over the country (Ugwu et al., 2022).

5.4.3 Summary map and priorities

From the number of various studies and analyses undertaken in the NRB over the last two decades, the priorities listed below have consistently emerged as ongoing ones requiring concerted attention. Climate change projections have now sharpened the focus on these priorities and heightened concerns about the impacts, which are most severe and evident for most of the rural population in the NRB at the subsistence and small livelihood socio-economic levels.

In order to ensure and facilitate the discussion, criticism and final choice (and ranking) of the key issues, the selection has been also shared with stakeholders and managers and specifically with EEAS-Niamey/Bamako/Abuja and several Universities and experts (such as Agrhymet, NEPAD, KUNST, NBA, AMCOW, NWRI, GIZ, UCAD, etc.). For the Niger River basin specific ranking scores and notes are available from KUNST University, EEAS-Niamey and NEPAD-UCAD.

The most important key issue identified by all the contributions are: i) *water scarcity and drought*: this is indeed also characterized by high awareness among the river basin; ii) *improve access to basic services as impacted by population growth and distribution:* concerning this issue some notes focus on the need of data and access to knowledge and to new technologies in water conservation, but there is no consensus among the experts for the level of awareness of the issue. Iii) *Improve transboundary collaboration:* again this is identified as extremely important by all feedbacks but with different opinion among the awareness, ranging from low to high.

The complete list of priorities is here detailed:

- Addressing water management and floods
    - o *Major drivers for floods trends:* There is an ongoing discussion about which is the major driver of increasing floods: landuse change or climate trends.
    - o *Enhance flood monitoring and knowledge*: floods are increasingly perceived as a major threat and ensuring their assessment and knowledge is a priority: indeed, flood damage can be exacerbated by dam operations (see for example the flood in Mali in 2001, caused by release of the reservoir of the Sélingué dam; uncontrolled releases from Lagdo dam in Cameroon or; floods in the Niger Delta).
    - o *Red flood anomalies*: Assessment of reinforced positive anomalies of the red flood in Niamey.
    - o *Accuracy of global wheatear forecast*: Accurate weather forecasts could be a valuable tool for improving water management in the basin, but the accuracy of the Global Forecast System (GFS) in the NRB varies depending on climate regime, lead time, accumulation time scale and spatial scale.
- Management of the increasing water demand
    - o *Assessment of water demand variability* (across space and time): 70% of NRB's inhabitants live in areas where food security is threatened by unreliable and changing rainfall patterns, smallholder agricultural production, biomass and endangered ecosystem services. The dry-season livelihoods depend on *fadama* farming (lowland or inland valleys), recession flood farming, agroforestry and irrigated rice farming and fishing, while cereal cropping and transhumance are the main livelihoods during the wet season. Livestock feeding and access to water pose a serious problem, particularly during the dry season, and productivity is low.
    - o *Improve rainfed system and their resilience*: Need to increase the resilience of rainfed systems to climate change and climate variability and to take into more consideration the links and competition with pastoral and livestock breeding systems.
    - o *Assessment and management of the increasing water demand (mainly irrigation) within the catchment*: Manage the development of the huge potential for irrigation (up to 1.5-2.9 million ha), currently limited by multiple barriers (e.g., absence of well-developed institutions for irrigation, prevalence of subsistence farming and high investment costs). Irrigation water demand is already dominant (85% of the total).

- *Analysis of causes for limited water productivity:* Existing infrastructures in the basin have not achieved the irrigation potential identified in the preliminary studies. Besides, existing irrigation schemes could suffer from various problems from the farmers' perspective: an effective strategy could be investing in both irrigation and rainfed intensification (effectiveness).
- *Increase irrigation efficiency:* The irrigation efficiency has been found to be rather low, because the water supply is continuous regardless of the irrigation demand: future agriculture developments should consider aspects such as water productivity, sustainable management of groundwater storage, seasonal and climate variability and the impacts on the people and ecosystems downstream.
- *Transboundary cost benefit analysis:* dam developments and new irrigation schemes could be able to foster food security and expand farmers' production opportunities, although they might also have negative impacts on local economies.

- Address impacts on water resources, biodiversity and livelihoods:
  - *Population growth and access to basic services.* Population is increasing at a fast pace (2-4% annually) and population density within the basin is much higher than the national averages (4 to 5 times). Most of the population still lack access to basic services, such as electricity (two thirds of the population), improved water sources (30% of the population) or improved sanitation facilities (75%). UN Human development Index: lowest quintile; high mortality rate in children due to respiratory and water related diseases.
  - *Management of water scarcity and drought:* In Niger, where 80% of the population relies on rainfed agriculture and the primary sector accounts for 45% of GDP, water scarcity and drought pose serious challenges for both the agricultural and the livestock sectors and heavily influence GDP growth.
  - *Climate variability assessment*: Negative precipitation variability (e.g., a short-term dry spell) has been found to be more dangerous than an overall change in precipitation trends for triggering political violence in the NRB, which could be explained by its impact on agricultural markets.
  - *Unlock markets for farmers is a key issue.* Market access requires to be enhanced through the development of river navigation, roads and, in general, the transport network system.
  - *Assessment of oil exploitation impact (Delta):* Oil exploitation, specifically in the Niger Delta, is considered detrimental for the local communities, as resulting environmental degradation decreases agricultural livelihoods and income while increasing poverty.
  - *Plastic waste*. Plastic waste mismanagement issue (> 0.8 kg/hab/day in Nigeria) and oil spills in the Delta area.
  - Impact assessment of cocoa farming: Pesticides in the cocoa farming sites are reported to locally exceed respective soil and food guidelines. Cocoa cultivation is a leading cause of deforestation and degradation of West Africa's tropical forest habitats.
  - *Erosions on the river banks*: the increasing risks of erosions on the river banks (the area of Niamey capital city of Niger republic pollution due to solid waste management in the Bamako area in Mali and oil in the estuary of Nigeria.

- Climate change impacts
  - *Improve knowledge, research and HCD on CC*: Three major issues: rise in temperature and evapotranspiration losses; increased variability of rainfall, extreme events such as floods and droughts; impact of sea level rise on the delta.
  - *Trends*: an abrupt change point in rainfall and streamflow time series was detected in 1969. After the change point, rainfall and streamflow time series showed positive although non-significant trends, while significant negative trends were observed when the change point was neglected. River flow is very sensitive to precipitation and the propagation of a meteorological drought to a hydrological one usually takes between 1 and 3 months.
  - *Improve accuracy of projections.* Projected changes in rainfall over the West Africa region are not expected to be spatially homogeneous. While future wet conditions are expected in central-eastern Sahel (with a robust increase of rainfall amounts in September-October), dry anomalies could take place over Western Sahel.
  - *Enhance robust socio-economic hydro modelling*. High uncertainty of future scenarios: i) agricultural production decreases could take place during the dry season, being more severe in the case of typical dry land rainfed crops; ii) impacts on hydropower, navigation and flooding of the Inner Delta. Adaptation: potential measures to cope with these impacts include the reduction of the rainy season irrigated agriculture and/or the implementation of additional storage capacity, while enhancing minimum flows in the Inner Delta and Middle Niger would require the increase of the dry season irrigation efficiency.
  - *Monitoring fluxes and stocks of water*: Recommended measures to tackle CC: assessment of impacts of the climate changes on productions activities along the Niger river; monitoring fluxes and stocks of water (both temporally and spatially), development of robust socio-eco-hydrologic models and scenarios, among others.

- Increasing water demand and energy issue
    - *Enhance knowledge of increasing demands*: Largest irrigation withdrawals in the basin generally take place from January to March (there is also a peak in irrigation water requirements between March and April), while lowest water use for irrigation purposes occurs from July to September. Current irrigation demand (the highest demand, which accounts for about 80% of the total) is up to 7% of the average annual discharge of the Niger, but it could rise to one third by 2045.
    - *Groundwater assessment and valorisation and improvement of knowledge and research about aquifer systems:* Despite the existence of large groundwater resources in the middle and lower parts of the NRB (such as the Iullemeden and Taoudéni transboundary aquifer systems) and their potential role in adaptation policies, the current exploitation rate is relatively small. Borehole wells are an important source of drinking water at household level (mainly in the rural, poor areas). Poor knowledge about aquifer systems in the region is a key limiting factor: the need to develop scientific analysis and promote human capacity development (HCD) initiatives is a key issue.
    - Enhance assessment of cost-benefit analysis of new dams: Additional dam development in the NRB has been identified as a solution to mitigate the negative impacts of climate change on hydropower generation and ecosystem health, but it must be carefully assessed to limit negative impacts on local economies (e.g., on livelihoods depending on flood recession agriculture).
    - *Ensure Open Data policy*: Need of estimates on the potential magnitude of future water abstractions upstream of planned hydropower sites, considering different climate change scenarios.
    - *Increase access to energy and reduce biomass use*: The basin has one of the lowest power accesses in the world (only 23% of the population and almost 90 million people living without electricity) and fuel wood accounts for 90% of the energy consumed. Reduce use of biomass like firewood and charcoal, related to deforestation, erosion and siltation.
    - *Improve basin hydropower potential efficient exploitation:* Basin hydropower potential is estimated at 6,000 MW, of which only one third is developed: 18 existing dams, of which 8 are for hydropower purposes and 6 with an installed capacity > 5 MW. Increase water management efficiency: high/medium water losses per hydropower production unit are currently observed: highest in Ladgo (2.2), Selingue (1.1) and Kainji (0.6) (ratio expressed as mcm loss vs GWh produced).
    - New development: largest developments in the framework of the SDAP include 4 dams: Kandadji in Niger, Taoussa and Djenne in Mali and Fomi in Guinea. High potential of small hydropower plants to support rural electrification. Support multi-purpose infrastructure to share the benefits and reduce the negative impacts. Explore alternatives: potential of small hydropower plants for rural electrification.

- Addressing water quality issues and water related diseases
    - *Improve monitoring/assessment of malaria and water borne diseases*: Malaria and other vector borne diseases are the main water quality related human health and mortality challenge at basin scale. These aspects should be included in cost benefit analyses for large scale irrigation and hydropower projects.
    - *Lack of wash services*: Pathogens present in surface and drinking water are by far the most impacting human health issue directly associated with urbanisation as such. The lack of WASH services, together with malnutrition and (indoor) air quality are ranking as the top 3 risk factors for premature death and disability in quasi all basin countries.
    - *Agrochemical management*: The contamination with agrochemicals is low to moderate. Modern agriculture is not yet developed to an extent, although the emissions of agrochemicals can already play a role at ecosystem level.
    - *Impact of mining*: Environmental damage and chemical pollution arise from gold mining in Mali and Guinea: the focus should be on inventorying the artisanal mining sites and implementing existing mercury reduction/replacement technologies and waste management programs.
    - *Enhance waste recycling*: Research is needed to inventory current practice of waste recycling and to assess impacts on environmental and human health. At the same time, awareness rising and technology transfer is needed in the field of waste management and recycling.

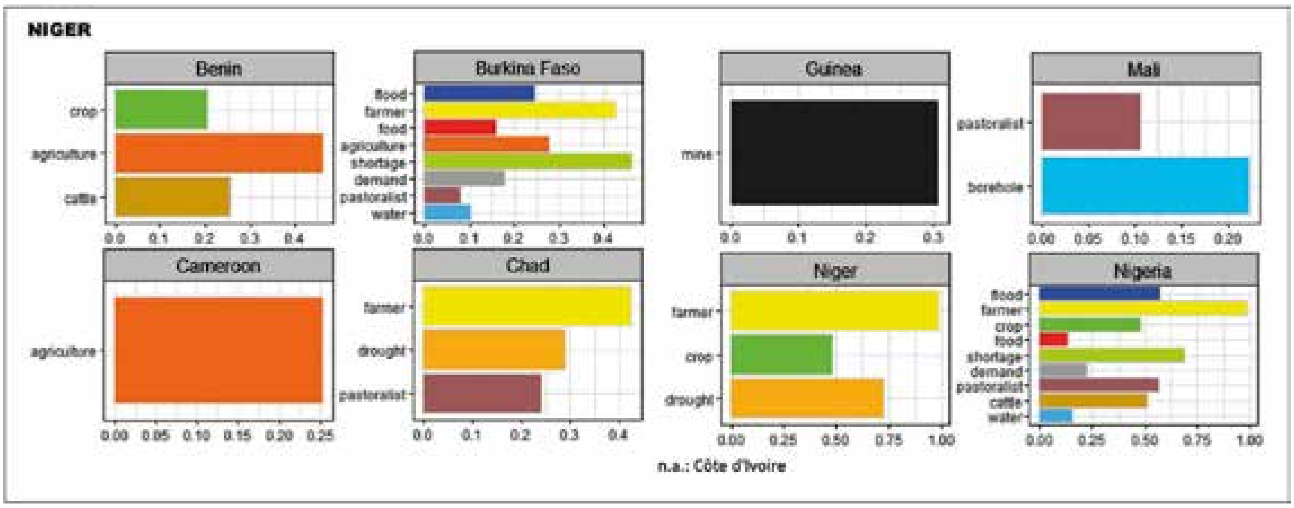
- Coordinated water use monitoring, data collection and management as the basis for effective basin operations and management, including at the national levels of the riparian states.
    - *Improve transboundary collaboration*.

Summary notes (reference ANNEX_I_TAB_02.NIGER_EN.xlsx):

- Hydrology group: highest importance for enhancing floods knowledge and its monitoring and assessment and identification of main drivers (some notes highlighted: very limited capacity for impact-based forecasting and warming (KUNST) and missing knowledge and data on the safety status of dams and their contribution/impact to flooding issue (KUNST).
- Water demands: the issue ranked with higher values are assessment of water demand variability and groundwater valorisation, improvement and increase of resilience of rainfed agricultural systems and increase of irrigation efficiency and in general of knowledge and open data on increasing irrigation water requirements and improvement of water management efficiency inclusion (even if IRWM in practice). (Some specific issue and data knowledge: limited tools availability and capability of taking into account water allocation across sectors (KUNST and NEPAD) and in general missing or very limited knowledge and data on aquifer system and interaction with surface waters (KUNST and NEPAD). Research need for the identification of improved rainfed systems taking into account other uses (KUNST).
- Impact on water resources: another issue highlighted is linked with the assessment of climate variability: Awareness is still limited (NEPAD) even if according to KUNST there is some knowledge on shits and trends of climatological variables. Anyway a more detailed assessment, analysis of trend and link with water conflict is needed (KUNST).
- Water quality: Lack of water services is the priority ranked as more important by different stakeholders, followed in the ranking by agrochemicals, impacts of mining and waste recycling issues. The issue with the lowest value (above all by EEAS) is the one linked with malaria and water borne diseases.

- **Most recurrent water related keywords per country in the river basin:**

Figure 33. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



RIVER BASIN 3

ZAMBEZI

5.5 River Basin 3 – Zambezi

5.5.1 Introduction

The Zambezi River Basin (ZRB) is the fourth largest river basin in Africa, covering an area of around 4.5% of the continent, equivalent to a draining area of 1.4 million km^2 (ZAMCOM et al., 2015). It is shared by eight riparian countries Zambia (41% of the area), Angola (18%), Zimbabwe (16%), Mozambique (11%), Malawi (8%), Botswana (3%), Tanzania (2%) and Namibia (1%) (Silengo et al., 2018). The Zambezi River rises in the Kalene hills (NW-Zambia) and drains into the Indian Ocean (Mozambique). Large wetlands such as the Kafue Flats, Lukanga swamps, Barotse flood plains, Nyambomba swamps, Cuando, Busanga, Luagwa and Luena cover more than 2.6 million ha. The Mozambique section represents the terminal part of the ZRB, including the Cahora Bassa lake/dam and, downstream, the Zambezi delta region. The large Zambezi delta, recognised as a wetland of international importance and a global biodiversity hotspot, includes large mammal populations (e.g., African buffalo, endangered wild dog, African elephant), the largest waterbird concentration in Mozambique, rich grassland and woodland areas (e.g., the critically threatened Zambezian Coastal Flooded Savanna ecoregion) and extensive coastal mangroves as part of the East African Mangroves Ecoregion (Beilfuss, 2012). The delta region provides manifold ecosystem services such as forest, woodland and wetland products, carbon sequestration, grazing land for livestock, nutrient-rich lands for flood-recession agriculture, freshwater (shrimp) fisheries, clean and abundant freshwater, storm surge and coastal erosion protection, flood storage and mitigation, ecotourism and subsistence hunting (Beilfuss, 2015).

Figure 34. The Zambezi river basin: river network, elevation and the 13 main sub-basins. Source: Natural Earth, accessed online.

5.5.2 Key challenges

5.5.2.1 Hydrology

The hydrology of the ZRB is not uniform, with highest precipitation in the northern area (1,400 mm/yr) and lower (500 mm/yr) in the south (World Bank, 2010). The rainfall is also highly seasonal, the main wet season being from November to March. Mean annual discharge at the outlet is about 130 km^3/yr. Apart from the main river, the basin consists of several major tributary systems including the Luangwa, Kafue, Chobe and Shire rivers and several major wetland systems (Luangwa and Barotse floodplains, Lukanga swamps and Kafue flats), as well as Lake Malawi/Niassa, one of the largest natural lakes in Africa (Hughes et al., 2020) and other major lakes (Lake Kariba and Lake Cahora Bassa). The 13 main sub-basins are Upper Zambezi, Lungue-Bungo, Kabompo, Luanginga, Barotse, Cuando-Chobe, Kariba, Kafue, Luangwa, Tete, Mupata, Shire River and Lake Nyasa/Malawi and Zambezi Delta (ZAMCOM et al., 2015). An even finer sub-division of 76 ZRB sub-basins has been identified in the framework of a hydrological SPATSIM model setup (Hughes et al., 2020; Hughes & Farinosi, 2020). According to ZAMWIS 2007, net runoff in the ZRB is highest in the Shire River/Lake Malawi, Upper Zambezi and Luangwa subbasins, while actual evapotranspiration nearly equals rainfall (no net contribution to water availability) in the Mupata, Tete and Zambezi Delta regions.

Table 2. Zambezi River mean monthly flows in m3s -1 (Moore et al., 2007).

Station Period (Years)	Chavuma 1959/60-2001/02	Lukulu 1950/51-2001/02	Katima Mulilo 1967/68-2001/02	Victoria Falls 1951/52-2001/02
Oct	68	271	306	293
Nov	94	310	320	297
Dec	228	468	430	438
Jan	655	803	678	686
Feb	1411	1294	1211	1184
Mar	2031	1645	2374	2175
Apr	1770	1523	3129	3007
May	684	944	2427	2613
Jun	310	575	1326	1621
Jul	188	434	691	845
Aug	124	361	467	519
Sep	83	306	364	376
Mean annual	637	745	1144	1171

In this regard, De Clercq and De Witt (2020) and De Clercq (2020) provided a comprehensive overview of the literature, datasets (raw data, satellite derive products, most of them being hosted at ZAMWIS–ZAMCOM Water Information System) and models, relevant to the analysis of the basin hydrology and related topics. River mean monthly water flow at few key gauging stations in the basin provides an insight of the order of magnitude and intra-annual variability of the fourth largest transboundary river basin in Arica, after, Nile, Niger and Congo (Moore et al., 2007).

Groundwater is a major source that maintains the base flow in the Zambezi River during the dry period and it is also an important resource for large parts of rural Africa providing water for household use through natural springs and both rudimentary and advanced water intake structures (shallow wells and boreholes). A detailed review of the Zambia aquifer systems (Banda 2020a; 2020b) highlights the relevance of groundwater exploitation in the country, with large pivoting irrigation systems in absence of nearby surface water resources. A groundwater flow model was implemented at the scale of the entire river basin (Banda, 2020c), using continental hydrological and hydrogeological datasets, but authors highlight some limitations of the model results at the rough basin scale and the lack of detailed hydrogeological interpretations and of water table and contaminant concentration time series data: hence the need to reinforce the provisions for the setup of a long-term hydrogeological and hydrochemical monitoring network.

According to Hughes and Farinosi (2020), actions to support the knowledge and assessment of water hydrological system in the ZRB are: i) improvement of the knowledge of groundwater recharge dynamics and demand; ii) analysis of the available streamflow data for the identification and removal of anomalies; iii) include various rainfall datasets in modelling applications to provide more robust historical forcing data; iv) develop a better understanding of the dynamics of water exchanges between large wetland and river systems; v) improve the assessment of future water demand from several sectors as impacted by climate change and development.

Hydrology – issues and challenges

- Increase investment in basin water management and development.
- Large water transfer upstream under discussion, to address water stress in South Africa.
- Equitable allocation of water is crucial, to be guaranteed by a proper governance system.
- Environmental degradation (deforestation, inappropriate land use practices) in the upper ZRB causes erosion, sedimentation and changes in environmental flows downstream.
- Improve flood monitoring and forecast specifically in the Mozambican part of the ZRB.
- Upstream river regulation for hydropower production leads to adverse changes in the timing, volume, duration and frequency of floodplain inundation. In this context, identification of mitigation strategies is needed.
- Some current and projected hydropower projects reduce touristic attractiveness, e.g., i) reduced water flow of Victoria Falls during dry season due to diverted water for hydropower production and ii) newly planned Batoka dam could affect 25 rapids used for river rafting.
- Conduct assessment of the socio-environmental impact of dredging and canalization of the Zambezi River and Delta.
- Improvement of the knowledge of groundwater recharge dynamics and demand.

5.5.2.2 Agriculture and food security

Almost 75 % of land in the ZRB is covered by forests and bush, while cropland (mostly rainfed agriculture) covers 13 %, and grassland 8% (World Bank, 2010). Besides, wetlands in the basin are used for intensive agriculture, fisheries and wildlife management, due to their fertile soil and abundant water availability. Most of cropland areas are located in Zimbabwe, Zambia and Malawi. As rainfed is the dominant cropping system, agricultural production is largely influenced by rainfall variability. Four agroecological zones (AEZs) can be found in the ZRB, namely the tropic cool semiarid, tropic cool sub-humid, tropic warm semiarid, and tropic warm sub-humid zones. Each of the AEZs encompasses diversified characteristics regarding to climate, landcover, cropping practices and field sizes (which could vary from less than 2.5 ha to more than 60 ha). Two main seasons can be identified in the basin: a hot, wet season from October to March and a cool, dry season from April to September. The growing period of most crops (maize, sorghum, millet, and rice) takes place during the rainy season. Only a small percentage of the basin area is equipped with irrigation systems, able to support all year-round agricultural practices (such as planting wheat and other crops during the cool season). However, small, highly flexible water storages constructed by farmers can be found in the basin, to support irrigation and aquaculture (e.g., in the Runde catchment in Zimbabwe; Lautze et al., 2017). Since the 1980s, efforts have been made to increase the agricultural production of the basin (mainly through cropland expansion), driven by a major political and socio-economic transition (Bofana et al., 2020).

Figure 35. Cropland areas in the ZRB. Source: Bofana et al. (2020).

Water demands are much less than the available water in the entire basin, therefore resulting in a huge potential for the intensification of irrigation in agriculture, that is currently concentrated in Zimbabwe, Zambia and Malawi. A specific modelling analysis using CROPWAT and focusing on maize, wheat and sugarcane (Ngongondo, 2020c) confirmed such a potential, including the delta downstream (in Mozambique). Ambitious plans aim to triple the area under irrigation by 2025, which will increase the water demand for irrigation to about 4.1% of the basins' renewable water resources. Overall, agriculture is the main source of socio-economic livelihood of communities in the basin, as. about 70% of the basin's population depends on this sector for its subsistence. Most communities practice family agriculture where on-farm activities largely dependent mainly on family farm labour with very minimal mechanisation (if any) (Senzanjie and Dirwai; 2020). Food crop production accounts for around 80% of the cultivated area and maize and cassava are the major staples. Despite large strides being made in improving agricultural productivity and environmental conditions in the basin, a great number of poor families still face poverty, hunger, food insecurity and malnutrition, as rainfed agriculture is largely inefficient. In addition, food and cash crop diversification has been promoted over the past 30 years in the basin through sequential cropping and intercropping systems. Livestock and fishing also constitute an integral part of the agriculture systems in the basin. The relatively high risk of crop production losses due to the unreliable rainfall patterns coupled with high evapotranspiration rates has resulted in the adoption of livestock production (especially cattle and goats) and aquaculture as alternative livelihood strategies (Senzanjie and Dirwai; 2020).

Basic agricultural water management coupled with sustainable agricultural intensification is a key aspect of agricultural production supporting many rural households. Smallholder irrigation practices are dominant in the ZRB, including: bucket irrigation systems, gravity fed off-river and reservoir irrigation, *dambo* irrigation farming, treadle pumps used in conjunction with bucket or drip kit irrigation, motorised pumping irrigation, drip irrigation including drip kits, sprinkler irrigation and centre pivot irrigation. The last two tend to dominate commercial irrigation, with small-scale sprinkler irrigation being found also in smallholder formal irrigation. Most of the agricultural water management practices offer opportunities for uptake and sustainable agricultural intensification based on criteria such as quick and tangible benefits, low risk of failure, estimated cost of the intervention, and technology characteristics such as complexity, divisibility, acceptability and compatibility to the socio-economic environment (Senzanjie and Dirwai; 2020).

Agriculture and food security – issues and challenges

- Generally, food security and access to food is good to moderate in Zambia, Tanzania, Angola and Malawi. Some issues are present in regions of southern Mozambique and Zimbabwe. Indeed, a high number of poor families still face poverty, hunger, food insecurity and malnutrition, as they are mainly dependent on largely inefficient rainfed agriculture systems.
- Agricultural production is largely influenced by rainfall variability.
- The wetland system need to be monitored and sustainable management practices are required: these areas are intensively used (intensive agriculture, fisheries and wildlife management) because of their fertile soil and abundant water availability.
- Ambitious plans to triple the area under irrigation by 2025 are reported. Impact assessments on water resources and other sectors are required.
- Livestock production (especially cattle and goats) and aquaculture are often reported as key alternative livelihood strategies (although further data on productivity and distribution at basin level are necessary).
- Main challenges for the fishing sector are: i) relative low productivity; ii) missing data to conduct sectoral assessments (catches, monitoring); iii) fishery decline due to alteration of the river flow regime (dams, climate change, invasive species, irrigation demand); iv) pollution (mainly due to mining) and; v) overfishing and inadequate regulation of illegal fishing.

Senzanjie and Dirwai (2020) implemented an exploratory WEFE nexus analysis based on the indicators: water availability per capita, water productivity, food self-sufficiency, cereal productivity, energy accessibility, energy productivity and ecosystems good and services. Most of the WEFE indicators showed marginal sustainability. However, the authors stress that the success of agricultural water management interventions will depend to a large extent on the training of the relevant stakeholders so as to capacitate them in terms of knowledge, attitude and skills. Before any training can be undertaken, typically a needs assessment must be conducted to determine the stakeholders who require training, the type of training required and the best way to offer that training. For agricultural water management interventions, returns to training investment are best if this training is focused on those working directly with farmers and the farmers themselves. Short courses for the training of agricultural extension staff and farmers were identified, including: smallholder irrigation water management and crop production, dambo irrigation farming with ecosystems goods and services in mind, drip kit irrigation, operation and management for local food security, and soil and water conservation practices and conservation agriculture under rainfed agriculture, further to a WEFE nexus short course for policy makers, development implementers and researchers that was also proposed.

Regarding fisheries, there are three major ichthyologic regions in the Zambezi River Basin. Waterfalls— Victoria Falls on the Zambezi River, Avumba Menda Falls on the Kafue River, and Kalomo Falls— separate the Upper Zambezi and Kafue Rivers from the lower parts of the system. Fishing and aquaculture have a quite high potential in all the ZRB: in the upper part due to the richness of water and tributaries, in the middle basin because of the presence of the Kafue floodplain, lakes, reservoirs and swamps and, in the lower basin, these activities could be developed in the numerous lakes (Chaora Bassa, Malawi/Niassa/Nyasa, Malombe, small water bodies, Delta, coastal). Main challenges for the fishing sector are: i) relative low productivity in certain regions because of low nutrient levels; ii) missing data for the assessment of the sector (catches, monitoring); iii) fishery decline due to the impact of alteration of river flow and variability (dams, climate change, invasive species, irrigation demand); iv) pollution (mainly due to mining); v) overfishing and regulation of illegal fishing.

Generally, food security and access to food is good to moderate in Zambia, Tanzania, Angola and Malawi. Some issues are present in some regions of southern Mozambique and in Zimbabwe. For example, resources in the delta area are prone to overexploitation and pressure on forest and natural areas is also increasing (as commercial farming and charcoal production are undergoing a fast expansion). In addition, traditional cultivation systems (such as slash and burn) have been abandoned in many regions, in favour of more productive intensive systems. Furthermore, livestock is crucial for crop agriculture, as 95 percent of agriculture in communal areas depends on draught power for tillage. Livestock populations, including livestock for export, have recently been adversely affected by drought and outbreaks of communicable diseases. However, these changes have been accompanied by poor soil fertility management practices, which are now impacting productivity and management costs. In this context, up to a third of the population has depended on food aid in recent years (World Bank 2007b).

5.5.2.3 Socioeconomic

The population of the ZRB is approximately 30 million people, of which about 7.6 million live in 21 urban centres, while the rest (about 75%) are settled in rural areas. Population is unevenly distributed in the ZRB, with lowest population densities (<5 inhabitants per km^2) in the western, Angolan part of the basin and highest densities (>250 inhabitants per km^2) in Malawi and major cities throughout the basin.

Figure 36. Population density in the Zambezi River Basin. Source: SARDC et al. (2012), https://www.grida.no/resources/5213.

The main economic activities are fisheries, mining, agriculture, tourism, and manufacturing. The eight riparian countries are characterised by very different level of economic conditions: ranging from a gross domestic product of 122 $ per capita in Zimbabwe to more than 7,000 in Botswana. In the upper ZRB, rural population is dominant and depends primarily on subsistence farming. In the middle ZRB, the rural-urban ratio is more diversified, ranging from about 92% in Zambia to only 20% in the Copperbelt Province. Concretely, the Zambian part of the ZRB has been characterized by a strong rural-urban link, with important employment and market opportunities in urban centres. The lower ZRB has recently experienced rapid population growth, specifically in Malawi and Zimbabwe. Also, the Delta region faces rapid population growth and immigration, along with the lack of primary health care, housing, access to sanitation and safe drinking water, adequate education opportunities and employment alternatives (Beilfuss, 2015). In this context, many households are increasingly dependent on remittances (World Bank, 2010).

The annual economic growth of the basin is greater than 6% but poverty persists. Poverty is particularly high in rural areas, and among female headed households. An analysis for Malawi evidenced that food requirements accounted for more than half of the total expenditure at household level. In addition, as staple crops are produced only during four months, food insecurity is still a major issue in Malawi. In Mozambique, a general decline of the national poverty rate has been reported. Much of the increased production stems from expansion rather than intensification.

Small-scale subsistence agriculture dominates employment in all the basin, and livestock breeding and fisheries are more prominent in the floodplains areas. Across the basin, women dominate the agricultural workforce. Most of households strongly depend on natural resources such as forest, woodland and wetland products and environments. For example, firewood is the most important natural resource collected in Malawi. Because of population pressure, deforestation constitutes one of the main environmental threats in this country. Fishing is important mainly in the Western Province, where over half of the population is involved in this activity and provides an important contribution to food security as protein input. However, the introduction of unsustainable fishing methods has put pressure on the fish stock.

Mining is a key sector in the ZRB and is often a key driver for urbanisation, as in the case of Zambia. The reach of the Zambezi river located downstream of Cahora Bassa is the longest (570 km) navigable section, and it is used to transport local molasses, construction materials, coal and other minerals from inland Mozambique to the coastal port of Chinde. River dredging and channelisation have negative socio-economic and ecological consequences on river-floodplain systems, e.g., affecting floodplain fisheries and cropping, increasing riverbank erosion and triggering community opposition (Beilfuss, 2012). Straighter, deeper and wider channels drain water faster to the Indian ocean, reduce riverine and estuarine habitats, damage mangroves, desiccate lagoons and wetlands, reduce sediment deposition on floodplain and coastal shelf.

> **Socioeconomic – issues and challenges**
>
> - The main economic activities are fisheries, mining, agriculture, tourism, and manufacturing.
> - Necessary management of negative impacts on subsistence agriculture, as resulting from recurrent droughts, increasing fertiliser prices, and degradation of agricultural land.
> - Adapt to and mitigate the increased risk posed by extreme climate events: e.g., improve farmers' awareness regarding proper soil fertility management.
> - Increase investment in infrastructure.
> - Improve coordination and collaboration between riparian countries.
> - Overcome economic inefficiencies and foster productivity.
> - Reduce inequality: e.g., unequal land distribution in Malawi; unequal distribution of wealth and income in Namibia.

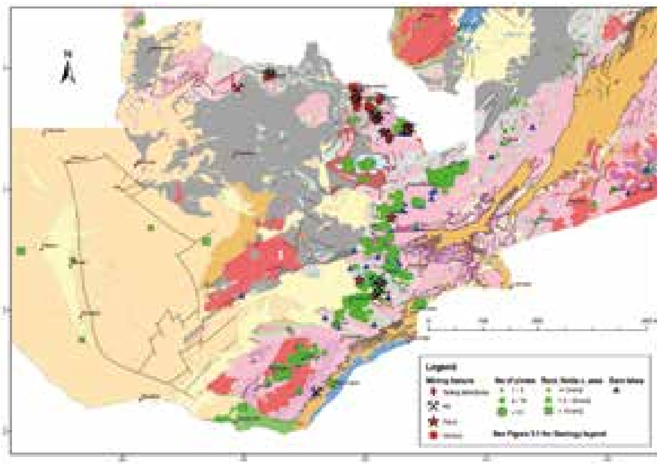
Tourism and activities related to national parks are growing and increasing their contribution to livelihoods and the economic sustainability of households. Although the ZRB is a top ranked tourist destination in Southern Africa, tourism facilities and infrastructure development do not yet match the big variety of tourist attractions offered in the basin (Baipai et al., 2020). Besides, the involvement of local communities in wildlife management in this sense is a key aspect to be improved in the ZRB.

5.5.2.4 Water use and demand

Total water demands in the basin are equivalent to about 21.2% of the total runoff, evaporative losses from lakes and hydropower reservoirs accounting for the largest water share equivalent to about 16.5% of the total runoff (Ngongondo, 2020a, 2020b). Agriculture and environmental releases have a minimum impact, respectively accounting for estimated 3.13% and 1.16%, while water for domestic supply for both rural and urban areas, industry, mining and livestock accounts for less than 1% each. The agricultural sector has the highest water demand in Mozambique with 73% of withdrawn water used for irrigation, livestock and forestry, 25% for municipal sector and 2% for industry (FAO 2016, Nordström, 2019).

The occurrence of Central Pivot Irrigation Systems (CPISs) and its water demands in the ZRB has been analysed using the Landsat-based approach proposed by (Saraiva et al., 2020). CPISs are present in 38 of the 76 ZRB sub-basins identified in the framework of the hydrological SPATSIM model setup (Hughes et al., 2020; Hughes & Farinosi, 2020), covering an area of almost 1,376 km² (equivalent to 0.2% of total area of the 38 sub-basins and 0.1% of total ZRB area). Main occurrence is observed in Central Zambia and Northern Zimbabwe and low occurrence in Mozambique and Malawi. 84% of CPISs in the ZRB rely on surface water and only 16% on groundwater, which is in line with estimates made by regional experts. In Zambia, Mpongwe, Chisamba, Kabwe South and Lusaka West and portions of Lusaka East areas, these systems rely predominantly on groundwater. All other areas rely on surface water, either from the Kafue, Zambezi (including Kariba), Munshibemba and Mkushi, or from storage dams. In Zimbabwe, CPISs are mainly located in the Mashonaland region, with dominance of surface water withdrawal. Few groundwater withdrawing CPISs are in the NW and SW of Harare, between Kadoma and Chegutu and in the NW of Bulawayo. Assuming an average crop water requirement of 750 mm (as proposed by (Hughes and Farinosi, 2020a), the total water demand of all CPISs in the ZRB accounts for 1,032 mcm, of which 871 mcm are withdrawn from surface water and 161 mcm from groundwater bodies.

Figure 37. Irrigation and mining features in Zambia Source: (Banda, 2020b).



A detailed review of the Zambia aquifer systems (Banda 2020a; 2020b) highlights the relevance of groundwater exploitation in the country, with large pivoting irrigation systems in absence of nearby surface water resources and a clear correlation between wells productivity and aquifer lithology. The widespread mining activities located in the Copper Belt, in the North, turn to be a huge threat to both surface water and groundwater quality. Overall, the ZRB in Zimbabwe is generally rich in groundwater resources. Still, a high demand by the predominantly rural communities is reported and the marked increase in urban population (e.g., municipalities) results in failing to supply adequate water at local scale. Potential overexploitation of the groundwater resources occurs in some parts of the country (Makaya and Chinyama, 2020c).

Generally, there is not enough data on groundwater quality to inform its suitability for human consumption and the promotion of food production in the basin. Cases of contamination of groundwater by wastewater are reported in the major urban centre of Harare, even resulting in serious health threats (e.g., a recent outbreak of cholera). Access to groundwater resources is through boreholes, using mechanical pumps in most cases except on commercial farms, national parks and private urban homes (where energy sources such as solar energy, fossil fuels (diesel, petrol) and electricity are used). Overall, the demand for water, energy, food and ecosystems services and goods is expected to increase in the whole ZRB due to demographic changes, economic growth and climate change. From a WEFE nexus perspective, availability of groundwater in the ZRB in Zimbabwe is strongly related to the modes of accessing the water from the aquifers (regarding energy requirements).

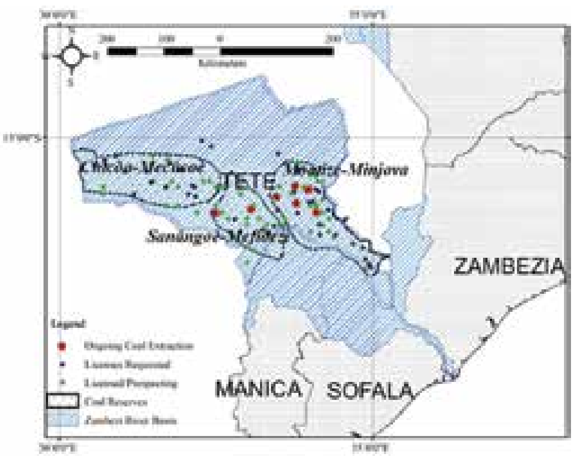
Water demand – issues and challenges

- Need for time series data on water table levels and contaminant concentrations.
- Need for providing support to long monitoring network.
- Include groundwater in the WEFE nexus assessment and policy making processes.
- Evaluate sustainability of groundwater abstractions, mainly used for domestic use.
- Large water transfer upstream under discussion to address the South Africa water stress.
- Equitable allocation of water is crucial, to be guaranteed by a proper governance system.

5.5.2.5 Water quality, health and environment

The Zambezi is one of the most pristine rivers in Africa, representing a very high-quality waterscape (Winton et al. 2021). However, hotspots of degradation associated with human activities are increasing in the basin,

Figure 38. Coal mining in the Mozambique part of the Zambezi River Basin. Source: Nhantumbo et al., 2015.



ranging in magnitude, form and source. The major sources of pollution include contamination from domestic waste, agriculture, the mining sector, industries and dam operation. Water treatment is still limited and not technically advanced in most of the cities. Untreated domestic sewage primarily causes problems such as eutrophication. There is no evidence that nutrient pollution has reached problematic levels in the whole ZRB, as the problems tend to be geographically limited to particular areas. The risk is much higher for waterborne diseases, such as cholera and typhoid fever, even if there is little evidence of such problems at river basin level (probably because limited water abstraction and use are associated to still high dilution levels).

Deep mining activities in the ZRB include the extraction of gold platinum, chrome and copper, and they are associated to acid mine drainage. Water quality is an increasing concern, particularly in the Kafue basin (e.g., due to the presence of heavy metals such as copper or manganese). Large-scale coal, gold, platinum and copper mining are other major sources of water pollution, with direct impact on the Zambezi hydrological system (particularly in the landscape of the lower basin; Dekker et al., 2011; Nhantumbo et al., 2015; SARDC et al., 2012). Small scale gold mining further contributes to water pollution with mercury and cyanide contamination. The Kangaluwi copper mine, located north of Cahora Bassa, is an example of an open pit of pollution risk for nearby large surface water bodies.

Domestic and industrial wastewater in Mozambique is mostly discharged untreated to the Indian Ocean or to the nearest water course. Hence a high priority is set towards the implementation of WASH programs in Mozambique (Nordström, 2019). An increase in the number and regional extent of water borne diseases such as malaria, cholera and schistosomiasis is linked to rising temperatures and flood occurrence due to climate change (SARDC et al., 2012; Kalinda et al., 2018). For instance, cholera outbreaks in Mozambique's floodplains are associated with severe floods caused by cyclones of increased intensity. The navigable part of the Zambezi river south of Cahora Bassa has a heightened risk of contamination and spillages caused by dredging and barging activities (e.g., coal transportation) (Beilfuss, 2012; Netherlands Commission for Environmental Assessment, 2011). Besides, the Zambezi Delta has been considered a rich source for crude oil, natural gas and other minerals with ongoing prospecting and drilling, which could represent a potential threat to its related ecosystems. Finally, pollution from commercial sugar expansion also contributes to an eutrophication of floodplain waterways (Beilfuss, 2015).

Water quality – issues and challenges

- Set up consistent and comprehensive monitoring on surface water and groundwater quality.
- Increase investment in sustainable infrastructure and practices (e.g. waste water treatment, environmental dam operation, riparian protection zones).
- Reduce surface and groundwater pollution from mining mainly between Harare and Bulawayo (iron and steel) and in the Kafue sub-catchment (belonging to the Copper-Belt).
- Reduce excessive use of fertilisers causing eutrophication (e.g., in the Harare are of Zimbabwe) and excessive growth of aquatic weeds (e.g. Shire sub-catchment).
- Saltwater intrusion reported in the Zambezi Delta during the dry season, affecting fisheries and agriculture.
- The Mozambican part of ZRB suffers mainly from upstream pollution, domestic gold and coal mining, inadequate sanitation systems, and impacts from the agricultural sector.
- Reduce negative impacts of dredging and barging contamination downstream Cahora Bassa.

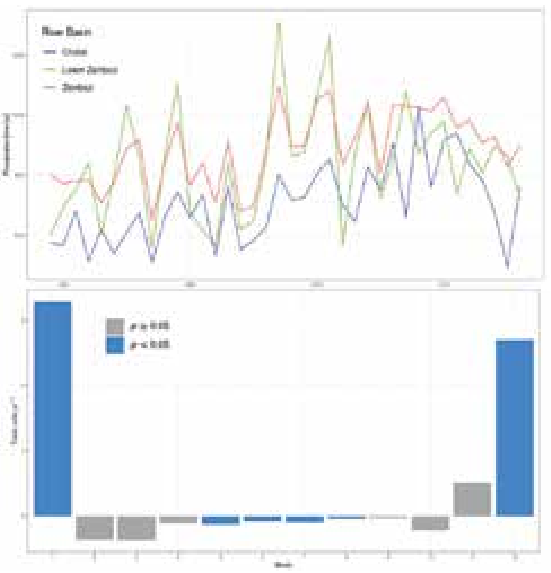
5.5.2.6 Climate change and climate variability

A climate variability analysis has been implemented by Kenabatho and Parida (2020a, 2020b) over the ZRB (and through neighbouring basins as the Limpopo), using trend analysis methods based on Mann-

Kendall (MK) statistic (Z), hereafter referred as MKZ, and the Sen's slope (S) in order to investigate the direction and magnitude of trend, respectively. On extreme events, the standardised precipitation evapotranspiration index (SPEI) based on L-moments have been used to evaluate the dryness/wetness conditions within the ZRB covering the period 1970 to 2015. The climate research unit (CRU) gridded database has been used in place of historical observations, due to the challenges related to data collection from the existing data holding agencies. Therefore, the results must be treated with caution since no validation of these datasets has been undertaken so far, provided that growing usage of these datasets is made in the scientific community (Harris et al., 2014; McMahon et al., 2015).

Overall findings were:

Figure 39. Annual Average Precipitation and monthly trends. Source: Cordano et al., 2022).



- Rainfall decrease (estimated in 8.7% over the basin), with a prevailing downward trend (ranging between +6% and -25%) was detected over the period 1970 to 2015, confirmed by MKZ statistic (-0.58) and Sen's slope (-1.59), although control points showed a limited percentage of statistical significance. If confirmed, such a rainfall reduction may lead to a reduction of dam inflows as well as groundwater recharge, should these trends persist.
- Temperature was found to generally increase over time and across the basin (between 2% to 6% in the case of maximum temperature and between 5% and 12% regarding minimum temperature), indicating a shift towards warmer conditions, being confirmed by a high statistical significance at all control points.
- No significant SPEI trends were detected, the river basin experiencing near normal conditions.

In general, there are signs that the river basin has experienced reduced rainfall in most of its area, along with increased evapotranspiration due to increasing temperatures. This may affect water resources, particularly within the context of climate change, land use change and population growth. The general picture revealed by these findings is consistent with studies previously done in the basin, and other similar environments. As a result, the findings are thought to be reasonable and may be used to inform policy and for decision making.

Main recommendations concern the access to: i) historical observations, to allow validation of the CRU datasets and to evaluate their reliability in representing the observed data; ii) streamflow and flood data, useful in undertaking regional flood frequency analysis and to establish relationships between streamflow and the assumed reduced rainfall.

Climate change and variability – issues and challenges

- Adapt to increased climate variability with downward trend of rainfalls causing reduced flow of 26-40% and runoff yields, increased irrigation deficits, increase of average temperature of 1.5°C, indicating drier conditions.
- Assess future climate change uncertainties.
- Set up system for consistent management and access of historical climate observation data to allow validation of the CRU datasets.
- Investigate interrelations between streamflow, precipitation and flood occurrence.
- Adaptation strategies to reduce impact of natural hazards in Mozambique (cyclones, floods, droughts).

Low lying areas in Mozambique are prone to growing flood risk exacerbated by cyclones, especially during the wet season. Recent cyclones, like Idai and Kenneth in 2019 and Eloise in 2021 (Swiss Re Institute, 2020), have caused severe economic loss, fatalities and homeless people. It is expected that climate change increases temperatures and alters precipitation patterns, leading to more severe droughts and floods and reducing the frequency of cyclones while increasing their intensity (USAID, 2020). According to GFDRR (2019), on average around 2 million people of Mozambique are exposed to cyclone-strength wind and associated storm surge per year, followed by drought (600,000 people), flood (200,000), earthquake (10,000) and landslide (100).

5.5.2.7 Water and energy

A study on hydropower potentials, efficiency and future impacts of climate change, considering different scenarios from wet to dry conditions, was conducted by Mutondo (2020). In general, the occurrence of either wetter or drier hydrological conditions has a big impact on the profitability of hydropower. Drier conditions are likely to reduce the profit, as more than 50% of the time the turbine flow will be below the average turbine flow. With wetter conditions, the profit is expected to increase by 21% for Cahora Bassa, 26% for Kafue Gorge L, 20% for Kafue Gorge U and 33% for Kariba. The analysis highlights the impact of climate change on the Southern Africa Power Pool (SAPP) and shows the importance of linking hydrological and socio-economic modelling. Future research should focus on water reuse, agricultural development and return flows. Some uncertainty can be posed to the agriculture, basin development, population growth and future electricity policies.

Figure 40. Overview map of hydropower dams and key river gauges Source: edited from (SARDC et al. 2012) and (Arias et al., 2022).

A later study conducted by Arias et al. (2022) highlights that Southern Africa could experience major hydrological changes in coming decades, bringing drastic changes to hydropower. Focusing on four large hydropower dams in the Kafue and Zambezi rivers (Itezhi-Tezhi, Kafue Gorge Upper, Kariba, and Cahora Bassa), accounting for over 90% of the installed capacity in the basin, the study analysed how these dams have altered river flows in the past, and how hydropower generation could be affected by future climate change and water use scenarios. Results showed a decrease in median annual water levels for all reservoirs, with largest changes expected at Itezhi-Tezhi (-1.3 to -3.3 m), followed by Cahora Bassa (-0.8 to -2.8 m), Kariba (-0.2 to -0.9), and Kafue Gorge (0.1–0.2 m). Flows downstream of dams show a consistent negative trend, with mean annual flow changes of -30% to -49% at the furthest downstream gauge. The combined reduction in water levels and flows could result in decreases in average annual hydropower generation and increases in interannual variability; annual generation could decrease by -61% to -28% at Kariba, by -51% to -21% at Itezhi-Tezhi, by -7% to -39% at Kafue Gorge, and -27% to -9% at Cahora Bassa. Reservoir operation optimisation could marginally offset the projected changes in hydropower generation, with largest gains for Kariba (+6%) and Cahora Bassa (+10%). Overall, opportunities to offset losses via operations would probably decrease with the expected drier climate and escalating reduction in river discharge and water availability. Given these negative projections, it is becoming critical to adapt and coordinate reservoir operations to best cope with the expected challenging future in this important river basin.

Water and Energy – issues and challenges

- Natural water cycle affected downstream of dams by changes in seasonality and dam water management (peak and low flows).
- Dams on the Zambezi River reduce wet season flows and sediment transport to the Zambezi Delta.
- Occasional flooding caused by backwater effects in the upper part of Cahora Bassa.
- Conduct rehabilitation projects for dams older than 50 years, to avoid risk of dam failure. The ongoing Kariba Dam Rehabilitation Project (KDRP) can serve as a good example.
- Cahora Bassa and Kariba reservoirs reveal great potential for floating photovoltaics (FPV) due to large water surfaces and good solar irradiation. Apart from additional on-site electricity generation, the solar panel coverage would remarkably reduce water losses through evaporation.

Given past operations and future climate change, however, Arias et al. (2022) found that the Zambezi is likely to become more water scarce, with much less reservoir flexibility during most of the time, potentially causing major conflicts with human communities and ecosystems that rely on river water for their subsistence.

Largest hydropower reservoirs Kariba, Cahora Bassa suffer from high water losses through evaporation of 8,037 mcm and 4,329 mcm (year 2016), respectively (Gonzalez Sanchez et al., 2020). However, considering the high energy rates produced, a ratio of water loss versus energy production ranging between 1 and 1.4 is still acceptable if compared to other African hydropower reservoirs (with ratios up to 4).

Besides hydropower production, Cahora Bassa and Kariba are also used for flood-control and irrigation, while Itezhi-Tezhi is solely used for hydropower generation (FAO, 2016). The two planned sites (Mphanda Nkuwa and Boroma) downstream Cahora Bassa are also intended for hydropower production only. According to Gonzalez Sanchez et al. (2021), Cahora Bassa and Kariba would particularly benefit from the installation of floating photovoltaics (FPV) on their reservoirs due to large surfaces and good solar irradiation. While additionally contributing to electricity generation on-site, FPV would remarkably reduce the water loss through evaporation from hydropower reservoir areas partly covered by solar panels.

The Kariba dam has been providing energy to the Southern Africa Region for more than 50 years. To ensure future safe operation of the dam and to avoid catastrophic dam failure, the Kariba Dam Rehabilitation Project (KDRP) has been implemented (Zambezi River Authority, 2020). It includes a series of rehabilitation works, carried out simultaneously to dam operation with minimal interruptions to power generation (World Bank, 2015). Future climate scenarios towards more extreme conditions cause more challenges to the dam infrastructure and water flow management. In this context, a highly vulnerable ZRB requires an adapted way of thinking, planning and designing future water investments (African Development Bank Group, 2015; Beilfuss, 2012b)

Mozambique electricity production is mainly based on hydropower (17,207 GWh) and gas (2,554 GWh). Oil (252 GWh) plays only a minor role in the energy mix (Nordström, 2019). Major hydropower plants in Mozambique are Cahora Bassa (installed capacity of 2,075 MW), Mavuzi (52 MW), Chicamba (38.4 MW), Corumana (16.6 MW), Cuamba (1.9 MW) and Liechinga (0.73 MW) (Nordström, 2019). Most energy produced by Cahora Bassa is exported to South Africa and the SAPP.

5.5.3 Summary map and priorities

The priorities listed below have consistently emerged as ongoing ones requiring concerted attention in the ZRB. In order to ensure and facilitate the discussion, criticism and final choice (and ranking) of the key issues, the selection has been also shared with stakeholders and managers and specifically with EEAS-Gabarone/Maputo/Lilongone and several Universities and experts (such as UNIMA, ZAMCOM, UNZA, KUNST, GSU, GIZ, etc.).

The priorities highest ranked (maximum value of 5, corresponding to extremely important) so far are: i) *Enhance irrigation sustainability and improve water productivity*, taking into account the resilience of farming system to CC and CV. Followed by ii) *Improving transboundary collaboration* iii) Improve *climate variability analysis and impact assessment* and iv) *Environmental degradation* (such as deforestation, inappropriate land use practices in the upper ZRB, erosion, sedimentation and changes in environmental flows downstream).

Anyway all priorities need to be duly considered for river basin development and they can be summarised as follows:

- Adaptation to climate variability and change.
  - *Transboundary water management development*: Increase investment in basin water management and development.
  - *Knowledge among water transfer issues*: Increase knowledge among potential large water transfer upstream under discussion to address water stress.
  - *Enhance equitable water allocation*. Equitable allocation of water is crucial, to be guaranteed by a proper governance system.
  - *Environmental degradation*. Environmental degradation (deforestation, inappropriate land use practices) in the upper ZRB causes erosion, sedimentation and changes in environmental flows downstream.
  - *Flood monitoring and forecast*: Improve flood monitoring and forecast in the Mozambique (lower part of the ZRB).
  - *Improve impact assessment of hydropower*: Upstream river regulation for hydropower production leads to adverse changes in the timing, volume, duration and frequency of floodplain inundation. Some current and projected hydropower projects could reduce touristic attractiveness, e.g., i) reduced water flow of Victoria Falls during dry season due to diverted water for hydropower production and; ii) newly planned Batoka dam could affect 25 rapids used for river rafting.
  - *Impact of dredging and canalisation.* Conduct assessment of the socio-environmental impact of dredging and canalisation of the Zambezi River and Delta.
  - *Improve CV analysis and impact assessment*: Adapt to increased climate variability with downward trend of rainfalls causing reduced flow of 26-40% and runoff yields, increased irrigation deficits, increase of average temperature of 1.5°C, indicating drier conditions.
  - *Improve climate data research and knowledge*. Assess future climate change uncertainties. Set up a system for consistent management and access of historical climate observation data to allow validation of the CRU datasets.
  - *Research in hydrological interrelations*. Investigate interrelations between streamflow, precipitation and flood occurrence.
  - *Natural Hazards.* Adaptation strategies to reduce impact of natural hazards specifically in Mozambique (cyclones, floods, droughts).

- *Impact on fishing sector.* Improve data collection for the assessment of the fishing sector.
- *Improve infrastructure standards.* Improve feasibility studies and planning of new infrastructures considering the natural hazards.

- Management of the increasing water demand
  - *Improve groundwater knowledge:* need for reliable time series of water table data (and contaminant concentrations) for estimation of groundwater potential.
  - *Long-term monitoring of water withdrawals.* Need for providing support to implement a long-term monitoring network.
  - *Enhance inclusion of GW in policy making.* Include groundwater in the WEFE nexus assessment and policy making processes.
  - *Sustainability assessment of water demands.* Evaluate sustainability of current and future groundwater abstractions, mainly used for domestic use under current management.
  - *Transboundary WEFE Nexus opportunities*. Prioritising national water, food and energy security as opposed to transboundary / regional WEFE constrains optimal use of resources. There is a need for assessment and scoping of transboundary WEFE nexus opportunities.
  - *Coordinated management of Kafue, Kariba, Cahora Bassa DAMS.* Harmonized operation of the Zambezi dams is needed to conserve water and mitigate flood and drought risk.

- Addressing water quality and water related health issues
  - *Monitoring and mapping of water quality.* Set up consistent and comprehensive monitoring on surface water and groundwater quality. Mapping bacteriological issues and incidence of water borne diseases.
  - *Waste water treatment and riparian protection zones.* Increase the investments in sustainable infrastructure and practice (e.g., waste water treatment, environmental and multi-purpose dam operation, introduction of *riparian protection zones*).
  - *Monitoring and assessment of the environmental impact of mining:* need to reduce surface and groundwater pollution from mining, mainly between Harare and Bulawayo (iron and steel) and in the Kafue sub-catchment (*Copper-Belt*).
  - *Reduce hotspots of excessive use of fertilisers:* (e.g., Zimbabwe) potentially causing eutrophication (e.g., Harare area) and excessive growth of aquatic weeds (e.g., Shire sub-catchment).
  - *Identification of strategies to limit saltwater intrusion:* in the Zambezi delta, specifically during the dry season, which affects fisheries and agriculture.
  - *Focus on the Delta area:* the Mozambique part of ZRB suffers mainly from upstream pollution, domestic gold and coal mining, inadequate sanitation systems and agriculture.
  - *Reduce negative impacts of dredging* and barging contamination downstream Cahora Bassa.

- Address socioeconomic issues and social tension
  - *Enhance assessment of social impacts on subsistence agriculture*. Social management of negative impacts on subsistence agriculture, as resulting from recurrent droughts, increasing fertiliser prices and degradation of agricultural land.
  - *Improve farmers' awareness regarding proper soil fertility management*. Adapt to extreme climate events and mitigate increased risks.
  - *Improve efficiency and investment for productivity*. Increase investment in infrastructure. Improve coordination and collaboration between riparian countries. Overcome economic inefficiencies and foster productivity.
  - *Enhance irrigation sustainability and water productivity*. Enhance the resilience of subsistence farmers to CC. Explore the role of existing small water storages to support irrigation. Increase moisture retention technics and improve water productivity.
  - *Improve knowledge and monitoring of livestock system*. Improve knowledge and monitoring of livestock movements and demands for access to water and pasture.
  - *Reduce inequality*. e.g., unequal land distribution in Malawi; unequal distribution of wealth and income in Namibia.

- Management of the development of energy sector
  - *Improve impact assessment of dam management*. Natural water cycle is affected downstream of dams by changes in seasonality and dam water management (peak and low flows). Dams on the Zambezi River reduce wet season flows and sediment transport to the Zambezi Delta.
  - *Flooding risk assessment*. Occasional flooding caused by backwater effects of the upper part of Cahora Bassa.
  - *Improve dam efficiency*. Conduct rehabilitation projects for dams older than 50 years, to avoid risk of dam failure. The ongoing Kariba Dam Rehabilitation Project (KDRP) can serve as a good example.
  - *Research of alternative management strategies*. Cahora Bassa and Kariba reservoirs reveal great potential for floating photovoltaics (FPV), due to large water surfaces and good solar irradiation. Besides additional on-site electricity generation, FPV would remarkably reduce reservoir's water loss through evaporation by solar panel coverage.

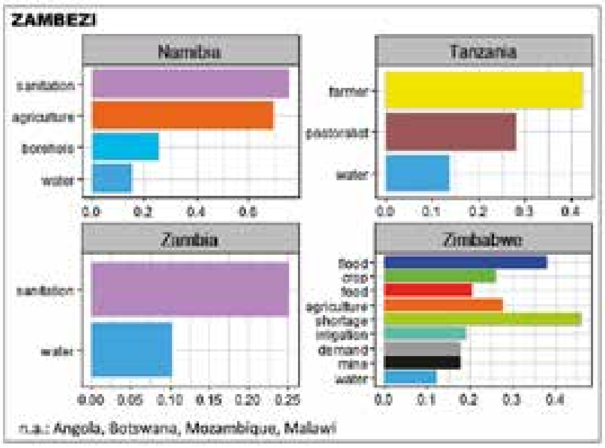
- Coordinated water use monitoring, data collection and management as the basis for effective basin operations and management, at riparian state national levels.
  - *Improve transboundary collaboration*. Improve coordination and collaboration between riparian countries. Coordinated water use monitoring, data collection and management as the basis for effective basin operations and management, including at the national levels of the riparian states.
  - *Strengthen transboundary governance and institutional arrangements*. Strengthening of implementation of transboundary and national laws and legislation.

Other important notes and suggestions emerged from the discussion with stakeholders can be summarised as:

- Adaptation to CC and CV topic: Improve transboundary water management development strategy; EAAS-Botswana and GIZ highlight the importance to update the IWRM Plan and to integrate the EWR framework; EEAS-Mozambique recalls the need for progress on shared planning, data collection, and in general transboundary agreement for water allocation).
- Also flood monitoring and forecasting is highlighted as significant damages and livelihood vulnerability (EEAS-Moz.) are observed; Improve joint management of Kariba, Kafue and Chaora bassa (EEAS-Bot.-GIZ). Impact of dredging and canalisation is also ranked as very important (EEAS-Moz. highlights its key importance in view of possible impacts on water flow, delta and natural flooding and in general the need for the inclusion of an ecosystem service analysis approach).
- Assessment of social impact on subsistence agriculture as resulting from droughts, fertiliser prices volatility and land degradation is also ranked as very important (Indeed EEAS-Moz. draws attention on livelihood strong dependency and vulnerability to weather events and also highlights the problem of the lack of disaggregated data, scenarios and research)
- Other issues ranked with lower priority, but again identified as important are: water allocation and knowledge among water transfer issues; impact on fishing sectors; improvement of infrastructure sustainability standards; transboundary WEFE Nexus opportunities and Coordinated management of dams (newly added by EEAS-Bot. and GIZ); Impact of Mining; Flooding risk and Strengthen transboundary governance and institutional arrangements with a specific focus on the implementation of national laws at transboundary level (EEAS-Bot. and GIZ).

- Most recurrent water related keywords per country in the river basin:

Figure 41. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



RIVER BASIN 4

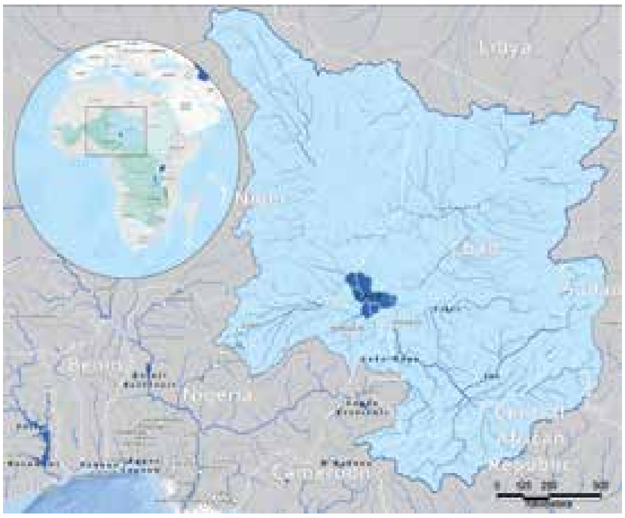
LAKE CHAD

5.6 River Basin 4 – Lake Chad

5.6.1 Introduction

Lake Chad, one of the largest lakes globally, is located on the southern edge of the Sahara Desert and covers a drainage area of about 2.4 million km² (~8% of African continent), but its hydrologically active portion covers about 967,000 km² (**Figure 42**). The basin is a hydrologically closed system and the lake, after being ranked as the biggest inland water body (with a surface of about 25,000 km² in the 1960s) shrunk to less than 2,000 km² in the 1970-1980 period (Mahmood et al., 2019), remaining in this state, also known as "Petit Tchad", to this day. It is shared by the following countries: Chad (44%), Niger (29%), Central African Republic (CAF) (9%), Nigeria (7%), Algeria (4%), Sudan (4%), Cameroon (2%) and Libya (0.1%). The transboundary dimension of the basin is particularly complex, as each country has different rules and interest: Chad is the most dependent on the water and ecosystem resources of the lake itself, Nigeria has a key rule and interest in the southern part of the basin (with dams, reservoirs and agricultural activities), Cameroon and Niger are peripherical, even if important water producers (specifically the Logone basin) and, finally, CAF has very limited access to the river even if it is the largest contributor for water inflow in the lake (with the Chari river system).

Figure 42. The Lake Chad river basin.



With regard to climate, the basin is located at the transition Sahelo-Sudanian zone and it is characterised by a hyper-arid climate in the north, semi-arid in the central part and subtropical in the south. Pluviometry in the basin ranges between 100 and 1,400 mm/yr from north to south, and the high temperatures, specifically in the northern part of the basin, cause high evapotranspiration water losses (normally exceeding 2,000 mm/yr).

Since the 1970s, the lake has been divided by a grassy ridge known as the *Great Barrier* into northern and southern lakes (being the southern lake the only permanent one), due to the sharp shrinkage of the lake. The lake is a transboundary water resource supporting millions of people (estimated at about 47 million in 2013) in four countries (Chad, Niger, Nigeria and Cameroon, even if its transboundary basin straddles the borders of 7 countries), depending on the lake for water domestic demand, fishing, recession and irrigation agriculture, and grazing for animals. Agriculture is the major user of its water resources, providing livelihood to approximately 60% of the population in the whole basin.

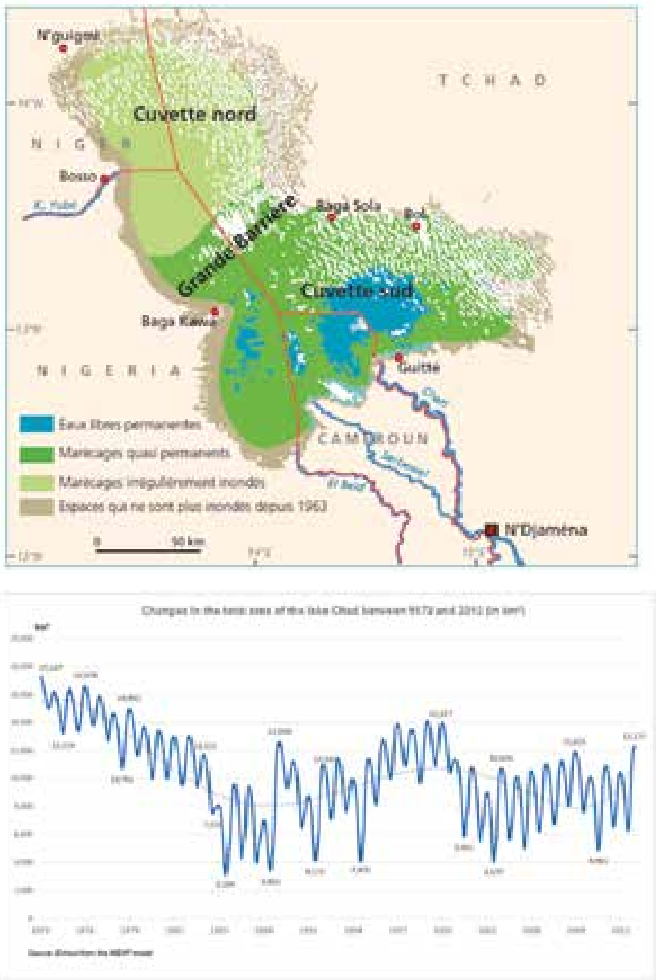
The Chari-Logone and the Komadugu-Yobe are the most important river systems, both supporting water inflow to the lake and the livelihoods of the basin's population (together with other floodplains, small lakes and ponds in the upstream regions). Several protected areas of international importance (30 IUCN Protected areas and 14 recognised as Ramsar sites, including the Lake Chad itself) have been designated and identified in the basin. Besides, it hosts a Biosphere Reserve (Waza), two World Heritage sites (Lakes of Ounianga and Manovo-Gounda), and UNESCO is currently supporting Member States to create a transboundary biosphere reserve and to nominate Lake Chad for its inclusion in the World Heritage List. One key aspect of the Lake Chad Basin (LCB) is its diversity of habitats including desert (52%), mixed shrub-steppe systems (10%), savannah (19%), forest (11%), cropland (6.5%), wetland (0.8%) and mountains (elaboration from Buchhorn et al., 2019 Copernicus Global cover dataset). Lake Chad basin region is highly vulnerable to climate change, experiencing high variability in rainfall, as well as floods and droughts events. As people in the LCB depend mostly on rainfed agricultural systems for their livelihoods, increasing scarcity and competition for water resources will further threaten such a delicate system (rapid population growth, migration, pastoralism system conflicts, increasing demand for energy, etc.). Nevertheless, it is important to point out that, although surface water resources are highly variable during the seasons, groundwater availability is present everywhere in the basin and, in spite of evidence of lake shrinking, LCB is still one of the most important regions in the Sahel providing a viable habitat for animals, plant life and supporting the livelihoods of millions of people. Extensive pasture, arable crop land and rich fish stocks make the basin a key territory, both for economic development and for environment and biodiversity protection.

5.6.2 Key challenges

5.6.2.1 Hydrology

The hydrologically most active part of the river basin can be divided into 2 sub basins: the Chari-Logone River system in the southern and eastern part (mainly CAR, Cameroon and Chad), covering a surface of about 690,000 km^2, and the Komadugu-Yobe river system in the western part (mainly in Niger and Nigeria) covering a surface of about 148,000 km^2. The two rivers have typically a tropical regime, with a single flood occurring at the end of the rainy season (August-November). They are both characterised by their numerous tributaries, channels, water bodies (lakes, ponds, reservoirs) and groundwater resources, mainly stored in Quaternary and Pliocene aquifers. The river system contributing more to the lake inflow is the Chari/Logone: it contributes for about 80-90% of the inflow. The average discharge has been estimated at 15-34 km^3 in dry periods and about 35-43 km^3 in humid ones (Lemoalle and Magrin, 2014). The variation of Chari River flows is the dominant factor controlling the water level of the lake, and its variability is even amplified by the lake extension and depth. It has been observed how a 10% variation of precipitation is associated with a 30% variation in river discharge. The remaining water flow contributing to the lake is supplied by the semi-perennial Komadugu-Yobe river system (and by direct precipitation on the lake).

Figure 43. Lake Chad area and water level variability.



In the Chari-Logone system, the hydrological year begins in May with high flows and ends in April of the following year, while in the Komadugu-Yobe basin the active hydrological year starts in July and ends in the June of the next year. Inputs from the Chari-Logone river generally showed a decline since the 1950s, but an increasing trend has been reported for the last 20 years (Pham-Duc et al., 2020).

There is also seasonal flooding, which feeds the extensive Waza-Logone floodplains and Hadejia-Nguru wetlands, used for pasture, fishing, irrigated and recession agriculture (UNEP, 2004). These large floodplains are key areas, as they support crucial ecosystem services and also play an important role in affecting the water flows that drain to Lake Chad. In a normal wet year, the flooded areas in Massenya and Yaere can reach and area of about 100,000 km^2 (Dimbele-Kombe et al., 2016).

The lake has a long history of wet and dry periods spanning across several time scales, from geological to annual and seasonal scales. During the mid-Holocene (6,000 years ago), the basin held a mega lake (which could have been induced by a northward shift of the Intertropical Convergence Zone (ITCZ) and the associated hydrological response; Sepulchre et al., 2008). A classification in 3 phases has been proposed: the Petit Tchad, the normal Tchad (or median) and the Grand Tchad. Additionally, a fourth phase has been suggested (the Dry Small Lake Chad) to distinguish the state in which the northern pool remains dry throughout the year (Lemoalle et al., 2012). Currently, the lake is in the Petit Tchad or Small Lake phase (from 1973), as already happened several times in the past. The southern lake is mainly supplied by the Chari River (the most important tributary).

It is key to point out the importance of the wetland systems (*marecages*), sometimes not considered as part of the lake system, while representing one of the most important sources of livelihoods for the riparian population. In this condition, the lake is mainly formed by i) a water surface of about 1,700 km^2 ii) the southern wetland area normally flooded all the year iii) the northern wetland irregularly flooded and; iv) an area not anymore flooded from 1970 onwards. Normally, this condition is associated with a supply of less than 34 km^3/yr from the Chari subbasin.

Siltation problems are commonly reported by the population, even if no relevant data are available to support this claim and generally it is not considered as a priority.

Lake Chad's water levels are strongly dependent on rainfall, thus the higher is the variability and reduction of rainfall, the higher is the pressure on the lake ecosystem (as it is the only place within the basin which could act as a buffer against drought and variability). As these water levels started to decline in the 1960s, several projects to implement an inter-basin water transfer (IBWT) from the Congo River have been considered as a potential solution to save the lake. These projects are highly controversial and have triggered discourse coalitions to either promote or block the IBWT concept (Sayan et al., 2020). Researchers have argued that the lake is currently not shrinking. This is not to say that the lake is not affected by climate change, as on the contrary, even if this "Petit lac" condition is natural, climate variability is exacerbating the pressure on lake and basin water resources, intensifying conflicts, opening space for new conflicts, and in general, requiring a more smart and comprehensive assessment of each development strategy in the basin (Vivekananda et al., 2019).

Hydrology - challenges

- The Main challenges are centred around the major lakes: Lake Chad (1350 km^2), Fitri (500 km^2), Iro (110 km^2) and the reservoir Maga (115 km^2) particularly prone to overexploitation and climate change.
- Lake extent dynamics and trends are still controversial. Even if recent studies suggest a slightly increasing trend (inter-annual analysis, based on the Global Surface Water dataset, confirms an increase of the lake extent from 1984 to 2002 and a rather stable but oscillating behaviour from 2003 to 2020). These dynamics should be clarified and agreed among the LCB countries.
- A trend analysis points out a decrease in both streamflow and rainfall, even if a positive trend with a break point in mid 1980s has been observed (specifically for precipitation).
- Droughts and floods equally occur both in the Sudano and Sahelian zones of the Logone basin.
- The groundwater quality of the Quaternary phreatic aquifer is suitable for the needs of the local population and livestock domestic consumption: an assessment to explore exploitation at basin level is still needed.
- Regional groundwater resources are specifically sensitive to surface runoff regimes.
- High exploitation of the aquifer has been already observed specifically due to high usage in Niger and Nigeria.
- Improving policies and regulations for the wells protection, groundwater quality and groundwater renewal dynamics constitutes a key prioritiy.

With regard to extreme events, droughts and floods equally occur both in the Sudano and Sahelian zones of the Logone basin, although the Sudano zone is more sensitive to drier conditions whereas the Sahelian zone is more sensitive to wetter ones. At short time scales, the basin has a low response to rainfall but strong correlations between rainfall and streamflow are found after 12 months (Nkiaka et al., 2017a). The Africa Flood and Drought Monitoring (AFDM) has been adapted with higher resolution for the Lake Chad region to provide near-real-time water levels, short-term forecasts of flood risks, medium-term forecasts of drought events and long-term projections of climate change impacts (Amani et al., 2021).

The Lake Chad transboundary aquifer is a complex and thick multi-aquifer system, whose deposition started in the cretaceous period. The upper quaternary unconfined aquifer is by far the most exploited, both for human water supply, livestock and, partly, for irrigated agriculture. The main aquifer of the Chari-Logone rivers in the Djiamena plain and the dunes complex to the North both discharge to the lake. On the other hand, the aquifer located westwards of the lake, in the highly exploited areas of Niger and Nigeria, seems to suffer a significative depressurization since 1960 (Adamu et al., 2020) and piezometric depression shows up few kilometres west of the lake shores, despite an overall regional groundwater flow direction towards the East. Several piezometric depressions have been identified in Chad (Chari Baguirmi), Cameroon (north of Kousseri and the Limani-Yagoua sand-ridge), Nigeria, and Niger (Kadzell), with water levels being reported as declining in the last decades and some wells having dried out (Lemoalle and Magrin, 2014).

5.6.2.2 Agriculture and food security

Lake Chad and its basin provide many ecosystem goods and services, supporting food security for about 40-50 million of people, specifically by ensuring fishing stocks, agriculture farming and livestock. LCB also plays an important role as a food-exporting hub in the region, providing sustenance for about 13 million people in the hinterland of the basin (WFP, 2016).

Figure 44. Figure form Atlas du Tchad. Irrigation in the Lake Chad region and surrounding area.

Dominant economic activities within the river basin are crop production (food and cash crops), livestock farming (mainly nomadic) and fishing: 80-90% of the population depends on agriculture, fisheries and livestock for livelihoods. Agriculture employs 26% (Nigeria) to 84% (Niger) of population and between 36-56% are woman (FAO, 2017). Subsistence low input cropping system is the most diffused (88%), followed by high input rainfed cropping system (11%), while only 1.4% is currently irrigated (irrigation is more widespread, even if limited, in Nigeria and Cameroon, where it represents 2-3% of cropland). Generally, the irrigated areas make use of pumping systems to control primarily surface water and groundwater. Subsistence cropping system can support local food demand, even if is it very vulnerable to climate variability, floods and droughts and, normally, its productivity is not enough to ensure a production surplus for selling. Cereals are dominant in food crop production (with sorghum and millet accounting for about 48% of cropland), nuts and cowpeas are also diffused (24%). Other more productive systems are allocated for maize (7%), rice (3.7%), cotton and vegetables, specifically in the lake surroundings and in the delta of Chari (5.6%) (Elaboration from SPAM Allocation Model Data, IFPRI, 2019). Productivity of rainfed cereals is generally low, ranging between 0.5 tons/yr in Niger to 2-2.5 tons/yr in Cameroon and Chad for sorghum and millet (higher productive systems may reach 3-3.5 tons); and between 2 and 4.8 for maize (maximal production in Nigeria). Rice is generally characterised by a medium productivity in all regions except in Chad, where it has an average productive below 1 tons/yr (elaboration from SPAM). Most farming is rainfed and based on traditional practices (hand operations) with very limited or without the use of fertilisers and chemicals. It is important to highlight the diffusion of flood-recession agriculture, a technique used along the water courses and in floodplains (Salamat, Waza-Logone) based on the valorisation of naturally flooded soils: even if it is quite diffused and productive, this technique is also particularly sensitive to climate variability and water cycle alteration.

Food and agriculture - challenges

- Enhance subsistence cropping systems: the most diffused agricultural systems (potentially supporting local food demand), but very vulnerable to climate variability and change, floods and droughts and not productive enough to ensure a production surplus for selling.
- Restoring agricultural livelihoods: vulnerable farmers are increasingly exposed to natural hazards.
- Fishing sector: it is necessary to monitor and improve the current knowledge regarding decreasing water availability, floodplain shrinkage, erosion issues, or the presence of illegal and/or unsustainable techniques.
- Monitoring, assessment and knowledge of fishing stock: Fish is among the cheapest and most common protein sources in the region but catches in the LCB have undergone a significant decrease; a regulatory system to control catches is required.
- Ensure enough forage for animal feeding: pasture production is weak and impacted by climate variability and a number of diseases. Ensure strategies favouring the permanence of *Kuri* cow.
- In addition, there is a very limited knowledge of transhumant movements and potential interactions with other sectors: pastoralists are changing paths and moving into new regions in search of new pasture and water resources.
- Develop the assessment of real-time impacts of conflict on food security in the LCB.

Fishing activities are dominant, particularly for the population living nearby the lake, but they are practiced in the whole basin in seasonal and permanent ponds and small lakes, main rivers and their tributaries and channels (WFP, 2016). The total production of fish has been estimated at 50,000 to 100,000 tons/yr, depending on different sources and years (Lemoalle and Magrin, 2014). This has led to important migration fluxes to the lake from the rest of the basin and even from foreign countries. Currently, even with the Small Lake phase, the fishing activity remains highly productive. Fishing represents a significant source of income for households and contributes to the food self-sufficiency of national economies (about 120,000 tonnes of fish sold in 2004, 200,000 people directly involved in fishing activities and 10 million people supported by a sector whose annual fish production is worth US$ 60 million on average). Fish is among the cheapest and most common protein sources in the region but catches in the LCB have undergone a significant decrease (from 220,000 tonnes in 1974 to 100,000 tonnes per annum in 2011) (FAO/LCBC, 2011).

One of the main challenges that the fishing sector is facing is the decrease of water availability accompanied by lower lake water levels, floodplain shrink of area and persistence, water sources drying up and erosion. In addition, the fishing sector is not well monitored, and some illegal or not sustainable techniques (explosives, non-selective catches, toxic compounds) are normally used.

Ensuring food security is one of the major challenges for the nations of the Lake Chad basin. Another interesting alternative source of protein is spirulina, a micro-alga able to endure the harsh growing conditions of the water bodies of oases (wadis) around the lake and which could become a potential source of jobs and income for women in the LCB (FAO, 2008). Currently, the EU's Global Climate Change Alliance Plus (GCCA+) programme allocates €8 million to a project which includes spirulina processing in the Lake Chad.

Livestock is key sector at basin scale, where animal density is currently distributed as follows: 22 million of cattle, 51 million of goats and sheep and about 51 million of chickens (as elaborated from Gilbert et al., 2018). Both settled herders and migratory pastoralists from different countries use land seasonally for livestock grazing. The meat from livestock makes a major contribution to the dietary needs of the population. Particular attention should be given to the Kuri cow, which is endangered and indigenous to the Lake Chad and it is able to produce a high quantity of milk (about 5 l/day), while its meat quality is considered exceptional. One of the main challenges for livestock production in the basin is to ensure enough forage for animal feeding: pasture production is weak and impacted by climate variability and a number of diseases. In addition, there is a very limited knowledge of transhumant movements and potential interactions with other sectors (Dimbele-Kombe et al., 2016): conflicts between farmers and breeders are increasingly frequent.

Most of these activities are highly impacted by climate change and water management at basin level: indeed, food security is strictly linked with rainfall distribution, occurrence and variability, as rainfed systems are dominant in the LCB and because both the fishing and livestock sectors should rapidly adapt to changing environmental conditions. The increasing demand for irrigation in the Chari-Logone River basin, which is indeed the most important hydrological source for the lake, will potentially support food security by enhancing the resilience of crop production in the region, but it will also potentially impact the water availability in the lake and its surrounding area. Besides, the ongoing security crisis is further impacting food security: farmers and fishers are unable to perform their activities due to safety concerns (attacks, presence of explosive devices on farmland), crops are destroyed or harvested by armed opposition groups (AOGs) and military restrictions affect their decisions (e.g., tall crops are avoided to spot the approach of fighters and fertilisers are restricted because they can be used to produce improvised explosive devices; fishers should consider when and where they can fish (as restrictions and embargoes have been put in place to impede AOGs the use of fisheries for revenues), whether they can transport the catches to the markets or not and if these markets remain open or functional, as market places have been regularly targeted by suicide bombers). As a result, agricultural production has experienced large losses (e.g., in Nigerian Borno state, from 2010 to 2015, sorghum, rice and millet production decreased by 82%, 67% and 55%, respectively) and staple food prices have increased in some areas (e.g., in conflict-affected areas in Niger and Nigeria, prices of these products increased by 50 to 100% in 2017). However, the assessment of real-time impacts of conflict on food security in the LCB is extremely difficult, as regular field data cannot be collected due to safety issues and restrictions imposed by the COVID-19 pandemic (Nagarajan et al., 2018; Global Agricultural Monitoring, 2020).

5.6.2.3 Socioeconomic

Once the centre of one of the largest and longest-lived pre-colonial states of sub-Saharan Africa (Kanem-Borno Empire), today the Lake Chad region lags behind in terms of development due to the presence of complex and multifaceted socioeconomic challenges, aggravated by climate and water related issues. A depressed area in comparison with other neighbouring regions, its perspectives are drowned out by the ongoing ecological catastrophe (arising from global change, fragmented ecosystem management, desertification and water mismanagement), the undermining of traditional dynamic livelihood strategies (such as mobility of people and diversity of economic activities), corruption, political neglect and institutional inability to provide basic social services (leading to instability and social unrest), the emergence of violence and armed conflicts (Boko Haram) and the exacerbation of pre-existing food insecurity and nutrition problems (WFP, 2016). These multiple drivers have led to one of the worse humanitarian crises in the continent, affecting about 17 million people, leaving almost 13 million people in need of humanitarian assistance and 2.7 million displaced people (Masaki and Rodriguez-Castelan, 2021; Riebe and Dressel, 2021). During the period 2019-2020, the situation was further aggravated (the percentage of population facing food security crisis or worse increased by 26%), mainly due to the interaction of conflict, economic factors and COVID-19 secondary impacts (FAO and WFP, 2020) In this crisis context, the most affected population groups are women (often subjected to forced abductions, forced marriages and rapes) children and people over 60. Besides, able men and teenagers are forcibly recruited or killed by insurgents, the army or civilian vigilante groups (Casola and Iocchi, 2018).

Although the balance between population and natural resources has historically been precarious and maintained through seasonal migrations, current trends show that population in the LCB is increasing at a fast pace: by almost 4 million people from 2000 to 2015 (total population of 51 million in 2015) and projected to reach 80 million by 2030 (Okonkwo and Demoz., 2014) due to high fertility rates (e.g., in Niger's Diffa and Zinder regions is more than 8 children per woman). However, population in the proximity of the lake declined after the shrinkage, whereas the cities nearby grew (suggesting a local "refugee" urbanisation induced by the lake recession) (Jedwab et al, 2021). Poverty, economic growth and key human capital indicators show a widening gap between the LCB and other areas within the riparian countries. For example, the poverty rate in the Nigerian part of the LCB (72%) almost doubles the one in the rest of the country (38%), while the poverty rate in the Extreme North region of Cameroon (59%) is thrice the one in the rest of the country (19%). The region also lags behind in terms of access to basic services, such as education (literacy rates –15 years old and older- are 21% and 45.5% in the Chadian part of the lake and the rest of the country, respectively), healthcare (in the Chadian part of the lake there is only one doctor for 140,000 inhabitants, a quarter of the national average), electricity (e.g., the national average rate of access to electricity in Nigeria is 59%, but in the part of the country within the LCB is estimated at 38%) and access to improved water and sanitation facilities (in the Far North region of Cameroon, the access to these services is about 36% lower than in the rest of the country). Unfortunately, the region does not show signs of convergence in welfare with respect to the non-Lake Chad areas of the riparian countries, as the conflict has further aggravated the situation by undermining both public and private infrastructures (Masaki and Rodriguez-Castelan, 2021).

> **Socioeconomic – issues and challenges**
>
> - Population in the LCB is increasing at a fast pace: by almost 4 million people from 2000 to 2015 (total population of 51 million in 2015) and projected to reach 80 million by 2030
> - Reduce poverty, enhance economic growth and close the gap between the LCB and other areas within the riparian countries with regard to key human capital indicators.
> - Improve basic services: the region lags behind in terms of access to services, such as education (literacy rate -15 years old and older- nearby the lake is 21%), healthcare (one doctor for 140,000 inhabitants, a quarter of the national average in Chad), access to electricity (38%) and to improved water and sanitation facilities.
> - Enhance the valorisation of rich resources in the LCB: farming, herding and fishing; mineral resources, such as gold and diamonds, kaolin, natron or soda ash, gravel and oil.
> - The development of a transnational forestland governance regime in the LCB could help to mitigate the security challenge (Boko Haram).

This low level of development in the LCB, however, is not in accordance with its human and natural endowments (Emecheta, 2015). The lake provides vital ecological resources at regional level (e.g., water supply, groundwater recharge, abundant diversity of flora and fauna), which sustain the main livelihoods in the basin (farming, herding and fishing). Besides, the basin is very rich in mineral resources, such as gold and diamonds (mainly in the Tandjile and Mayo-Kebbi regions of Chad), kaolin, natron or soda ash (potash, a source of household income in the region), gravel and oil (there is an active oil exploration in the LCB and construction of a trans-Atlantic oil pipeline in the north) (Ekperusi et Ekperusi., 2021). Despite these assets, the economy of the regions of Niger, Nigeria, Cameroon and Chad included in the LCB (17% of the total area of these countries combined) makes up only 5% of GDP. Economic activities are spatially concentrated in a few urban centres (e.g., Maiduguri, N'Djaména, Damaturu, Jimeta, Mubi, Maroua or Zinder), whereas the access of rural areas in the LCB to large markets is constrained by the absence of connective infrastructures, such as all-seasons roads, access to electricity or to the digital world (Masaki and Rodriguez-Castelan, 2021). In this regard, considering regional integration and cross-border linkages is a key aspect to develop the regional economy, given the historical trade, ethnic, cultural and political relationships (Lebrand, 2021). Moreover, it is necessary to note that the presence of valuable natural resources is a two-edge sword for the future of the LCB, as overdependence in them impairs economic diversification and they are often a magnet for violence and conflict. Concretely, Boko Haram insurgency in the region has been portrayed as primarily resource-induced rather than religious related, since the LCB provides both economic resources and a safe haven (mangroves, forest) for criminal groups to thrive (Omenma, 2020; Emecheta, 2015). In this regard, the development of a transnational forestland governance regime in the LCB could help to mitigate the security challenge (Okoli, 2019).

5.6.2.4 Water use, demands and availability

Water uses in the LCB include domestic, industrial, agricultural (flood cropping and small-scale irrigation, large irrigation projects such as Kano River Irrigation Project and livestock), fisheries and ecological uses.

Water abstraction at country level for the year 2018, as reported by FAOSTAT-AQUASTAT statistics, identifies agriculture as the main water demanding sector (except for Nigeria, where the municipal sector has similar importance). If we look at the countries whose territory is mainly within the basin (such as Chad, Niger, Central African Republic, Nigeria and Cameroon, with shares of the basin ranging from 89% to 20%) the highest water abstraction corresponds to Nigeria (12 km^3/yr) while the other countries show a much more limited value (about 1-2 km^3/yr).

These figures confirm that dominant water use at river basin level is for irrigation and for domestic needs, even if both demands are limited: access to safe drinking water is very poor and based on traditional methods, while dominant traditional agriculture is rainfed. Total abstraction (within the lake) has been estimated at about 2.5 km^3/yr in 2010 (LCBC, 2016a): 0.5 for drinking water, 1.8 for irrigation and 0.2 for livestock. Concerning the issue of population growth and development, some scenarios have been analysed at river basin level (by LCBC): the domestic water demand has been estimated at 0.5 km^3/yr for about 47 million habitants (mainly from groundwater) and an increased demand of about 1.4 km^3 is foreseen by 2025 (2.68 in 2050). For the livestock, if the number of animals grows by 5% of animals, the expected water demand will be about 1.4 km^3 in 2050.

Water demand – issues and challenges

- Improve water access: dominant water use at river basin level is for irrigation and for domestic needs, even if both demands are limited; access to safe drinking water is very limited and based on traditional methods.
- Assessment of increasing water demands: an increased demand of about 1.4 km^3 is foreseen for 2025 (2.68 in 2050).
- The role of human activities and water withdrawals in the Chari/Logone river has been particularly relevant in recent years (from 2003 to 2013), even if river basin assessment is required.
- Groundwater is currently the most exploited resource for drinking water: high exploitation of the aquifer has been already observed specifically because of high usage in Niger and Nigeria.
- Ensure cost-benefit analysis assessment specifically in the context of new and large irrigation projects: issues about efficiency and satisfaction of estimated benefit have been pointed out.

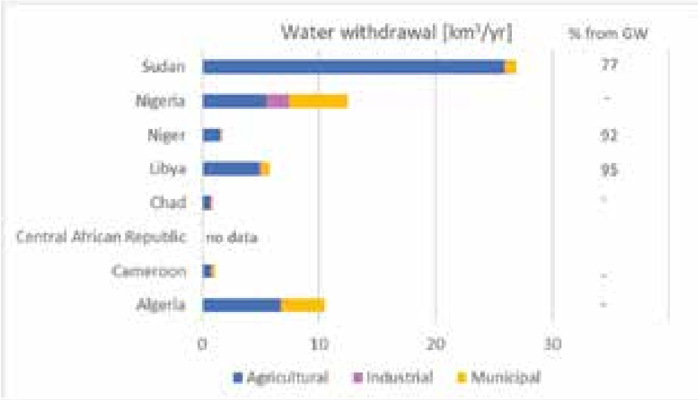
In general, it seems that total water abstraction is not sufficient to explain the shrinking of the lake, hence it may be assumed that the contribution of precipitation (and runoff, ETP, water balance, groundwater dynamics) is much more important. Some recent studies showed how the total water abstraction for human related activities was negligible when compared with lake volume change and with precipitation-evaporation contribution. However, Zhu et al. (2019) estimated that water loss in the Chari/Logone river (which contributes approximately to 90% of Lake Chad's water inflow) is dominated by human activities (73.17%) instead of by climate variability (26.83%). The role of human activities in the Chari/Logone river has been particularly relevant in recent years (from 2003 to 2013). Besides, Gao et al. (2011) pointed out that the failure of the lake to remerge after the rainfall increase in the 1990s is due to irrigation withdrawals.

Water demand for agriculture has often been associated with a high potential increase. For example, several large irrigation projects have been developed in the Komadugu-Yobe basin and around Lake Chad, but most of the projects (close to the lake) are not actually functioning. However, the Maga dam, located in the Chari-Logone basin, and the numerous dams located in the Komadugu-Yobe basin have disrupted the timing and extent of the flooding of the Waza-Logone and Hadejia- Nguru wetlands, respectively.

Groundwater is currently the most exploited resource for drinking water: an estimation of about 80 million m^3 was made for the whole river basin in year 2000. The drinking water needs were estimated in 20 l/hab/day in rural areas and 80 l/hab/day in urban areas.

Irrigation schemes: mega-irrigation projects constructed in the 1970s in the Nigerian part of the LCB were ultimately abandoned due to the receding lake shoreline (e.g., South Chad Irrigation Project (SCIP), currently two stages out of three implemented). Concretely, these projects could be interpreted as "territorial traps", because they force rigid evolutive pathways by setting up physical, relational, cognitive and operative boundaries (Bertoncin and Pase, 2017). Another example of a project which was not completed is the MAMDI Polder Project in Chad. However, in Cameroon, the Société d'Expansion et de Modernisation de la Riziculture de Yagoua (SEMRY) was created in 1954 to promote rice production in the floodplains of the Logone river. Subsequent phases of the project extended the cultivated areas (SEMRY II and III, in 1977-78) and the World Bank recently announced (December 2021) that it has approved a credit of $200 million to further support the agricultural production in this area (Valorisation of Investments in the Valley of the Logone (VIVA Logone project).

Figure 45. Reported water abstraction at country level and percentage of abstraction from groundwater. Source: AQUASTAT - FAO's Global Information System on Water and Agriculture.



5.6.2.5 *Water quality, health and environmental issues*

In the case of Chad, the majority of the population lives nearby the Lake Chad region and in the Logone valley. About 88.9% of the Republic of Chad lies within the basin. In so far, the national health risk data from this country can be assumed indicative for the Lake Chad (basin) population.

In 2019, the 4 most prominent diseases responsible for death in the Republic of Chad were (Figure 6):

• Diarrheal disease, rank 1, plus 2% between 2009 and 2019.

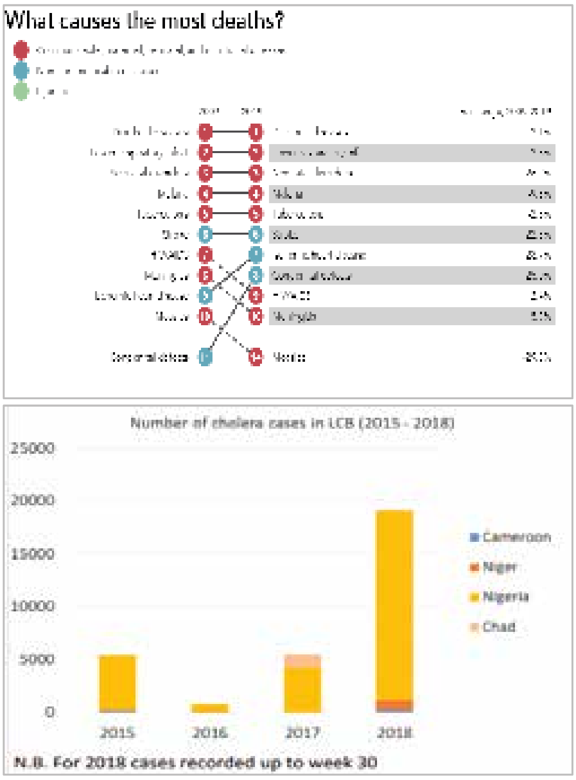
• Respiratory disease, rank 2, plus 3.8% between 2009 and 2019.

• Neonatal disorder, rank 3 plus 29% between 2009 and 2019.

• Malaria, rank 4, minus 9.5 % between 2009 and 2019.

Among those top death causes, diarrheal disease, respiratory disease and malaria can be clearly attributed to environmental/occupational risks. Among the diarrheal diseases, notably cholera is being reported from the basin countries. Waterborne diseases (disease spread by water related vectors) in general are very prevalent in all the LCB (UNICEF, 2017). Besides malaria, yellow Fever, dengue, filariasis and trypanosomiasis are common in the region. A further category of diseases is linked with poor hygiene practices and includes: skin, eye and respiratory infections. All water related diseases are particularly dangerous during the rainy season (UNEP, 2004). The WHO reported the following risk driving factors for death and disability in Chad

Figure 46. Left: Reported Top ten causes of death in Reo of Chad in 2009 and 2019. Source: (Abbafati and AA.VV., 2020). Right: Cholera outbreaks in the lake Chad Basin Countries. Source: (UNICEF, 2018).



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Republic: second and third ranking risk factors are the lack of access to safe water, sanitation and hygiene (WASH) and air pollution[1], which are labelled as environmental/occupational risks. The risk factor number one, malnutrition, although categorised here as a behavioural risk, should be at least partially attributed to the lack of access to water for food production (i.e., environmental risk).

Environmental (aquatic) pollution in the basin and its sources

The Lake Chad Development and Climate Resilience Action Plan from 2015 (LCBC, 2016b) assumed that no large-scale pollution has yet affected Lake Chad, but identified potentially upcoming risks in the basin. Those risks relate to the increasing use of chemical products in agriculture and are associated with the important growth of cities within the basin. Pollution risks are also related to the exploitation of oil fields in the south and in the centre of Chad and the construction of an exporting pipeline in the north of Lake Chad. Artisanal mining activities in the upper part of the basin are also listed as a pollution risk. In a recent literature review, Ekperusi and Ekperusi (2021) report moderate pollution from organic nutrients in the LCB area and a healthy state of surface waters in the Kwatan Dawashe portion of Lake Chad, with the analysis of physicochemical parameters such as DO, BOD, chemical oxygen demand (COD) and total organic carbon (TOC).

Limited data from groundwater showed elevated amounts of salt, fluoride, nitrates, iron, and manganese in the aquifer, especially on the superficial layers. Some levels of organic pollution in water and sediments of the Chari River, which is a major source of water supply into Lake Chad, were attributed to domestic sewage, industrial effluents, and agrochemicals. The discharge of fertilisers and organic wastes from businesses and small industries has resulted in eutrophication. Nutrients in the lake caused growth of aquatic macrophytes which deplete oxygen contents in water and affect aquatic life.

Pollution due to the presence of heavy metals is reported ranging from 0.01 to 80,877 mg/kg in sediments within Dumba and Kwata Yobe in the Nigerian axis of the basin. Metals such as cadmium, chromium, iron, manganese, lead, zinc, and arsenic were above the permissible limit. Cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc were also detected in fish tissues along the Nigerian axis of Lake Chad. Concretely, heavy metals from industrial effluents exceed WHO guideline values for drinking water in the two main tributaries. The situation is particularly serious in the Challawa River in the Komadugu-Yobe basin in Nigeria.

Pesticide's pollution is reported for superficial soils along the Niger axis of Lake Chad and attributed to intensive use of agrochemicals, especially of (nowadays banned, but still regionally employed) organochlorine and organophosphate pesticides. Paraquat concentrations ranging from 953±102 to 3083±175 µg/kg at depths of 0.80 and 2.75 metres below the land surface were reported. Elevated levels of pesticides and heavy metals have also been reported in fish from the Nigerian part of the Lake Chad basin.

It is estimated that, about 500 to 1,000 m^3 of pesticides, are consumed annually in Chad within the cotton industry only. Although Monocrotophos, an organophosphate insecticide, has been discontinued in developed countries, it is still in extensive use. Other insecticides such as Fenitrothion, Deltamethrin, Lindane and Malathion are used extensively by rice farmers across the basin despite their ban as persistent organic pollutants.

In the GIZ Report on the State of the Lake Chad Basin Ecosystem Sources from 2016 (Dimbele-Kombe et al., 2016) the most important emission sectors for chemicals to ground and surface waters are summarised. Generally, across the basin, agriculture close to water bodies is the main source of chemical pollution of surface water. The pesticides that have been identified in the water are those used on cotton crops in Cameroon, on rice and peanut crops in Chad and Nigeria, and for preserving fish. They include Cypermethrin, Glyphosate, Diuron and Atrazine.

A central water pollution problem reported from the basin is the presence of nitrate in groundwater from agricultural (cropping and livestock) and domestic sectors (CBLT and BGR, 2010; Ngatcha and Daira, 2010). This observation concerns "groundwater“ sampled from boreholes. However, these data have to be interpreted with care: nitrate concentrations reported by Ngatcha and Daira (2010) ranged between about 1 and 300 mg/L. Herein a large variation in concentration was observed in wells and boreholes that are only short distances apart. Such small spatial scale variations point to a local contamination of the boreholes, rather than an overall

[1] indoor and open fire cooking, which, besides the known health impacts, leads to deforestation/erosion due to its inefficient fuel use

contamination of the actual groundwater. And indeed, the authors assumed that, in most of the cases where the nitrate exceeded the WHO Standard of 50 mg/L, the contamination was caused by a direct input of animal faeces into the wells. The authors reported that the drinking troughs for the animals are generally located next to the well. Consequently, the surrounding area is excessively contaminated with faeces, which pollute also the wells.

Fluorine concentrations in groundwater were partially found above the 1.5 mg/L guideline set by the WHO along the river Bahr el Ghazal, to the south of Lake Chad, and around Lake Fitri. However, this seems to be due to geochemistry factors rather than to environmental pollution (Dimbele-Kombe et al., 2016).

Bacteriological water quality is an issue specifically in the basin's large cities (N'Djamena, Kano, Maiduguri and Maroua), where large numbers of people live in unplanned areas, wells supplying drinking water are often built too near to latrine pits and leaking septic pits. These represent a potentially serious point source of bacterial and chemical pollution in groundwater (faecal coliforms and nitrates) (DIMBELE-KOMBE et al., 2016). In rural areas, the wells are frequently in sites that are excessively contaminated with animal faeces, thus causing bacterial pollution of drinking water resources (Ngatcha and Daira, 2010).

These field observations underline the conclusions drawn from the epidemiological profile (WHO) of the region: the most important challenge for water resource management is to mitigate the biological threats from environmental pollution.

Pollution increase not only poses a threat to human health, but also to biodiversity. In Lake Chad, local plant species have declined whereas invasive ones have increased (especially aquatic macrophytes such as Typha grass, which currently cover half of the water surface; (Ekperusi and Ekperusi, 2021). Besides, precipitation and water volume decrease have triggered an alkalinity rise and the appearance of eutrophication effects (increased primary productivity of algal blooms, anoxic conditions). In the Nigerian part of LCB, 5 to 8 species of fish have already disappeared, whereas in the Logone valley (south of the SEMRY irrigation project, which triggered the construction of the Maga dam in Cameroon), fish yields collapsed by 90% due to the lack of water inundations (Odada et al., 2003). Maga dam had also a detrimental effect on both livestock and wildlife in the nearby Waza National Park, as the vegetation cover of perennial grasses in the floodplain was replaced by annual grasses (e.g., elephants reversed their habitual patterns, expending more time in the savannah woodland than in the floodplain until the partial restoration induced by the Waza Logone project pilot flooding in 1994; de Iongh et al., 2004). The implementation of the Tiga and Challawa dams in the Hadejia river in northern Nigeria created favourable conditions for the development of weed blockages in the Hadejia-Nguru Wetlands (HNW), to the extent that the Hadejia river stopped contributing to the Yobe river and the reduction of wetlands resources triggered conflicts between upstream and downstream communities (Goes, 2001; Ayeni et al., 2019).

Water quality and health – issues and challenges

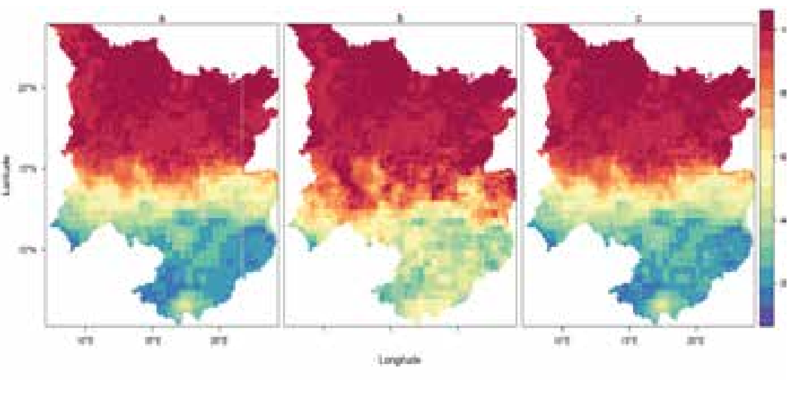
- Human health issues related to water quality (malaria and diarrhoeal diseases) rank high in the basin and can be clearly located in the domain of biological hazards, while chemical pollution of ground and surface water does not seem to impact human health at population level.
- Malnutrition, the main risk factor for death and disability, is at least partially linked to water scarcity.
- Another important risk, although not water-related, is (indoor) air pollution caused by inappropriate cooking environments.
- Improve water access: irrigation and domestic needs are the dominant water uses at river basin level, even if both demands are limited; access to safe drinking water is very limited and based on traditional methods.
- While chemical pollution from industry- and agriculture seems to be limited to local hotspots, the bacteriological pollution of ground and surface waters represents a human health issue at basin scale.
- Pathogens and nutrients released both from domestic and agricultural sources, combined with the absence of adequate WASH services, pose a threat to man and the environment.
- Additional basin-wide biological human health threats arise from the waterborne vectors for malaria, yellow fever, dengue, filariasis and trypanosomiasis.
- The eutrophication issues reported in the basin have to be seen in the context of surface water contamination with nutrients from untreated sewage and animal faeces, rather than attributed to the use of mineral fertilisers.
- Waterborne diseases are prevalent in the LCB and diarrhoeal diseases are the main cause of child mortality. Disease spread by water related vectors is common in the region and includes: malaria, yellow fever, dengue, filariasis and trypanosomiasis.
- In so far, the currently most important challenge for water resource management is to mitigate the biological treats from environmental pollution.
- Land use and land cover changes, deforestation and desertification are other key environmental issues in the basins
- In Lake Chad, local plant species have declined whereas invasive ones have increased.
- Water volume decrease has triggered an alkalinity rise and the appearance of eutrophication effects.

Land use and land cover changes, deforestation and desertification are other key environmental issues in the basin. For example, Lake Fitri, which provides an alternative source of water to relieve population pressure on Lake Chad, has undergone significative land use and land cover changes during the last decades: while farmland and grassland increased from less than 1% in 1986 to more than 40% in 2013, the combination of forest, savannah and steppe decreased from 23% to less than 8% and wetland declined from 14% to 3% in the same period (Djimadoumngar and Adegoke, 2018). In the Lake Chad area of Niger, shrub steppes lost more than 28% of their surface with respect to that of 1990, while rainfed crops increased at their expenses (Abdoulkadri et al., 2021). From 1975 to 2013, Chad's croplands almost tripled (one of the highest annual expansion rates of the region, 5%). This expansion was mainly located in the south (Plaines du Logone, Collines du Mayo-Dala and Maro ecoregions) (CILSS, 2016). In northern Nigeria (including the Lake Chad area), bare-land increased at the rate of 0.96% and 0.28% from 1984 to 2000 and 2000–2016, respectively. In this area, vegetation loss was negatively correlated to temperature and population density but not significantly to precipitation (Nwilo et al., 2020). To face up desertification in the Sahel, the Great Green Wall (GGW) initiative involves the creation of the longest living structure in the planet (restoring more than 100 million ha of currently degraded land and spanning 8,000 km across the continent, from Senegal to Djibouti). Four LCB riparian countries have been selected as intervention zones of the GGW, amounting to almost 45% of the total area of the project: Chad (3 Mha), Niger (47.3 Mha), Nigeria (17.4 Mha) and Sudan (2.3 Mha).

5.6.2.6 Climate change and Climate variability

The two components of climate variability (space and time) play an important role within the LCB. Spatial variability of rainfall in the basin (Figure 7) is characterised by a steep gradient from the southern part (more than 1,000 mm/yr) to the northern one (less than 100 mm/yr) (Niel et al., 2005). Besides, temperature patterns are also heterogeneous throughout the basin. Apart from the northern area (above the latitude of 18ºN and characterised by a hyper-arid climate), other zones within the LCB were prone to heat waves during the period 1979 to 2016 (mainly located around the 10ºN) (Cordano and Cattaneo, 2022). Temporal variability needs to be characterised at multiple time scales, from multidecadal to seasonal ones. While seasonal precipitation in the LCB responds both to dry climatic forcing (harmattan wind) from the north and wet forcing from the south (West African monsoon), interannual and multidecadal temporal variability can be explained by changes of the regional shallow circulation, induced by warming of the Sahara and of the nearby oceans. Concretely, sea surface temperature anomalies were the prevalent force in the Sahelian drought onset during the 1970s and 1980s (Biasutti, 2019). Interannual variability is also linked to higher-level circulation features, as wet conditions seem to be related both to pressure and temperature patterns over the Atlantic and the intensity of the Tropical Easterly Jet (TEJ) over West Africa (Nicholson, 2013). Regarding the role of teleconnections, the cold phase of Atlantic Multidecadal Oscillation (AMO) could have negatively impacted precipitation in the Sahel in the early 1970s (masking the positive effect of La Niña), while its current warm phase and the increase of La Niña episodes seem to play a significant role in precipitation recovery (Okonkwo et al., 2015). Besides, precipitation, river discharge and Lake Chad's levels are negatively correlated to El Niño Southern Oscillation (ENSO), although it could only explain about 31% and 13% of the lake level and rainfall variations, respectively (Okonkwo et al., 2014). In the period 1951-2015, temperature in the LCB increased by 0.22 °C/decade, whereas precipitation decreased by 14 mm/decade (Mahmood et al., 2019). During the last Normal Chad period (the last time the lake was a single water body, from 1954 to 1969), direct rainfall over the lake was estimated in 329 mm/yr, which was reduced to 207 mm/yr during the drier Small Chad period (from 1972 to 1989, Lemoalle et al., 2012). However, increasing rainfall trends since 1990s have been widely

Figure 47. Precipitation Deficit in June: (a) 5 yr return period (b) 20 year return period; (c) variability. Source: Cordano and Cattaneo (2022).



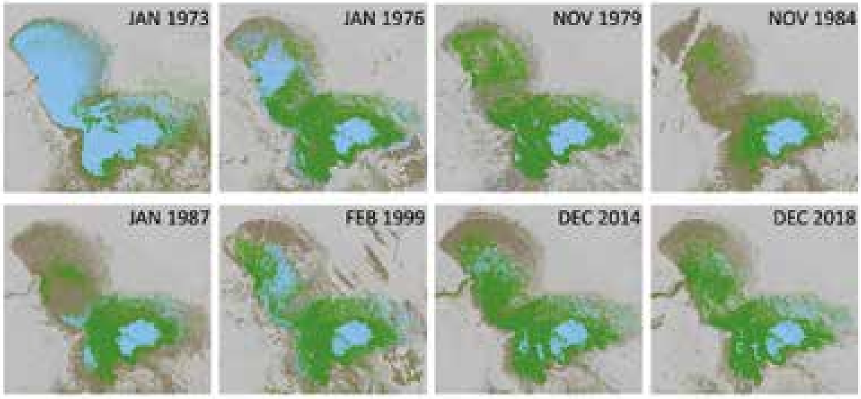
> **Climate variability – issues and challenges**
>
> - Future projections show that temperature could continue its increase by 0.65°C and 1.6°C (with respect to 1960-1990) during the periods 2016-2025 and 2026-2035, respectively. In the case of precipitation, it is expected to decrease in the LCB by 4-21% and 5-16% in the same periods.
> - In the LCB context, the probability of a scarcity-driven conflict is dependent on how vulnerability changes when water supply decreases. In this regard, pastoral livelihoods could be more vulnerable to climate variability than farming and fishing ones.
> - Farmers could be affected by large losses of cropping areas in the central part of the LCB due to the expected shift southwards of the line marking the 120-day growing period (which roughly separates drought resistant crops with a short vegetative period and more valuable, water demanding crops).
> - As climate variability and change (and the subsequent shrinking of the lake) have been suggested as primary drivers of the current security crisis, a combination of climate change adaptation strategies and counterterrorism measures could contribute to regional stability.
> - However, the climate security narrative in the LCB should be cautiously assessed in light of the available scientific evidence, given the geopolitical, economic and climate agendas involved in the current policy discourse.

reported in the region. Besides, precipitation patterns seem to have undergone a backward shift: while monthly rainfall increased in the Logone basin during the pre-monsoon season (April, May and June), the opposite happened during the monsoon one (July, August and September) (Nkiaka et al., 2017b). Future projections show that temperature could continue its increase by 0.65 °C and 1.6 °C (with respect to 1960-1990) during the periods 2016-2025 and 2026-2035, respectively. In the case of precipitation, it is expected to decrease in the LCB by 4-21% and 5-16% in the same periods. However, it should be noted that the Chari-Logone basin (the main contributor to Lake Chad's inflows) has a distinct behaviour: precipitation decrease was stronger during the period 1951-2015 than in the rest of the basin, temperature is expected to decrease in the 2020s (with respect to 1960-1990, maybe due to the presence of dense forest and protected natural resources areas) and it is the only basin within the LCB that shows a 40 to 45-year cycle in temperature (whilst all basins show a 20 to 25-year cycle in precipitation) (Mahmood et al., 2019). The LCB could be regarded as a paradigmatic case of how climate variability and change act as threat multipliers when they interact with other existing risks and vulnerabilities to trigger regional instability and conflict. In the LCB context, the probability of a scarcity-driven conflict is dependent on how vulnerability changes when water supply decreases. In this regard, pastoral livelihoods could be more vulnerable to climate variability than farming and fishing ones (due to their limited social networks and livelihood income strategies, their proneness to climate-structured aggressive behaviour and to conflicts with other resources users arising from their migratory lifestyle) (Okpara et al., 2015; 2017). Nonetheless, farmers could be affected by large losses of cropping areas in the central part of the LCB over the 21st century (from 71,000 km^2 to 135,000 km^2 depending on the scenario), due to the expected shift southwards of the line marking the 120-day growing period (which roughly separates drought resistant crops with a short vegetative period and more valuable, water demanding crops) (GIZ, 2015). As climate variability and change and the subsequent shrinking of the lake has been suggested as primary drivers of the current security crisis, a combination of climate change adaptation strategies and counterterrorism measures could contribute to regional stability (Frimpong, 2020). However, the climate security narrative in the LCB should be cautiously assessed in light of the available scientific evidence, given the geopolitical, economic and climate agendas involved in the current policy discourse (Daoust and Selby, 2022). Adaptive responses to lake drying could be classified as: 1) agronomic (changes in timing of land preparation, use of improved crop varieties and expansion of cultivated areas); 2) economic (trade in crops and in processed fish during low farming/fishing periods, migratory fishing in groups and collective livestock grazing and seasonal migration, recession cultivation); environmental (afforestation, seasonal flood identification and exploitation, decrease of herd size based on resources' availability) and; technological (small dams and ponds, wells, water harvesting, access to weather information) (Okpara et al., 2016).

5.6.2.7 Water and energy

The LCB, as the largest endorheic basin in Africa, has been facing increased human-made pressure on surface water, threatening environmental and socio-economic stability in the region. Main challenges are centred around the major lakes: Chad (1,350 km^2), Fitri (500 km^2), Iro (110 km^2) and the reservoir Maga (115 km^2), particularly prone to overexploitation and climate change. This has led to a shrinkage of Lake Chad's surface since the 1960s, which is controversially discussed in literature (Magrin, 2016). While there is a general agreement on the shrinkage of its extent from the early seventies to 1984 (from about 25,00 km^2 to less than 2,000 km^2, being permanent water surfaces restricted to the southern part of the lake), opinions differ on the lake evolution from the 1980 to 2020. Some studies postulate a continuation of the lake shrinkage trend if no countermeasures are taken. Others state that the lake extent has remained rather stable since 1984, with even a slight increasing trend of water surfaces over time (Pham-Duc et al., 2020). Our own inter-annual analysis using the Landsat based Global Surface Water dataset (Pekel et al., 2016a) confirms an increase of lake extent from 1984 to 2002 and a rather stable but oscillating behaviour from 2003 to 2020 (Figure in the Box). This demonstrate that climate change is one of the main drivers, but also irrigation and population growth have not only caused a reduction of the lake surface during the last decades, but also remarkable inter-annual fluctuations of the lake water level. This causes high variability and uncertainty of water levels with strong direct and indirect consequences across the Sahel, including forced displacement, violent conflicts, and political instability (Nagabhatla et al., 2021; Vivekananda et al., 2019). Moreover, changes in the surface runoff regimes directly impact the aquifer recharge in the basin, since surface water bodies mainly contribute to groundwater recharge (BGR (Federal Institute for Geosciences and Natural Resources) 2020). To reverse the shrinking of Lake Chad and boost economic and agricultural growth in the region, an Inter-Basin Water Transfer project (IBWT – Transaqua) is being under discussion. It foresees a transfer of water from the Congo River Basin to the Lake Chad Basin via a 2,400 km canal connecting the Ubangui River with the Chari River (Sayan et al., 2020).

Figure 48. Water surface change (blue) of Lake Chad since 1973 as from Stickel (2020) (edited). Vegetated and swamped areas are indicated in green and dark grey, respectively.



Water and energy – issues and challenges

- Apply sustainable strategies to stabilise or increase the water extents of the major lakes in the basin.
- Adapt to increased inter-annual variability and uncertainty, regarding Lake Chad water levels.
- Ensure livelihoods (water supply, sanitation, irrigation for agriculture, fishery) and increase the resilience of lake dependent communities.
- Provide climate-based projections on surface water extent (shrinkage or expansion), considering detailed inter- and intra-annual time series analysis over the last four decades.
- Achieve electrification of rural areas not connected to the African power grid, ideally through decentralised renewable energy technologies (such as solar and wind energies) to support economic growth in central and northern parts of the LCB.

The LCB is part of the Central African Power Pool (CAPP) and the West African Power Pool (WAPP), with an energy mix of natural gas, crude oil and strong solar and wind energy potential. No major power plant is reported inside the LCB (Global Energy Observatory et al., 2018). Access to the low and medium voltage (<66kV) African electrification grid (World Bank, 2022) is only provided to the southwest of the basin at Kano metropolitan area (Nigeria) and south of Lake Chad (Nigeria and Cameroon). These two regions also concentrate the majority of dams and associated reservoirs (Lehner et al., 2011; Mulligan et al., 2020). Most important dams are the Tiga (1,968 Mm^3) and the Challawa (930 Mm^3) dam south of Kano and the Maga dam in northern Cameroon (625

Mm³). Water from the reservoirs is mainly used for irrigation and water supply. Only one new dam, Bini Warak, in the northeast of Ngaoundere (north-eastern Cameroon), is currently planned in the LCB, as reported in the Future Hydropower Reservoirs and Dams database (FHReD) (Zarfl et al., 2015) and Geo-Referenced Dams database (FAO, 2016). It aims at closing the energy production gap in the northern regions of Cameroon by supporting the Lagdo dam (Andzongo, 2021).

5.6.3 Summary Map and priorities

For Lake Chad feedback and ranking of priorities have been provided by EEAS-Niamey, and NEPAD-UCAD. The key priorities highest ranked (maximum value of 5, corresponding to extremely important) are: i) *Improve monitoring network and data access (Open DATA) for both surface and groundwater. Ii) Reduce poverty and other social gaps between the basin and the riparian countries (*specifically new research is needed about this issue as highlighted by NEPAD-UCAD). Iii) Explore solutions of renewable energy and rural electrification.

Other important issues ranked as very important (score of about 4) and can be summarised as: Assessment of CC impacts on stream flow and lake water balance; improve access to safe drinking water; improve basic services (education, healthcare, electricity, etc.); enhance agriculture and specifically ensuring forage land for livestock and local species. And with lower ranking but nevertheless still important: Lake water dynamics and trends, monitoring and assessment of groundwater, monitoring water availability, water demand assessment and allocation, enhance subsistence cropping system, forest governance, monitoring and regulation of fishing sector, improve research and surveillance for water quality issues and eutrophication, and improve transboundary collaboration.

The complete key priorities list identified through the assessment is here reported:

- Improve knowledge of hydrological regime and lake water balance
    - *Improve knowledge on lake water dynamics and trends*: Even if some recent studies suggest a slight increasing trend of lake extent, lake water balance dynamics should be clarified and agreed among LCB countries. Climate change impacts on stream flows are highly uncertain.
    - *Improve monitoring and exploitation of groundwater* at transboundary level: indeed, groundwater resource of the region is specifically sensitive to surface runoff regimes and high exploitation of the aquifer has been already observed (specifically because of high usage in Niger and Nigeria). Challenges related to climate variability and change, clearly highlight the relevance of groundwater and the need for increased attention, monitoring and research.
    - *Improve monitoring network and data access*: Need for improvement of surface and groundwater quantity and quality monitoring networks, and for addressing hydrological and groundwater modelling.
    - *Improve knowledge on erosion issues*. Monitoring and further knowledge of decreasing of water availability, floodplain dynamics, lake shrinkage and persistence and erosion issues
    -
- Management of increasing demand on water resources
    - *Improve quantification of water demand*. Population in the LCB is increasing at a fast pace: by almost 4 million people from 2000 to 2015 (total population of 51 million in 2015) and projected to reach 80 million by 2030. Assessment at river basin level of increasing demand from several country specific sectors and agreement on abstraction and usage.
    - *Water withdrawals monitoring*. The role of human activities and water withdrawals in the Chari/Logone river has been particularly relevant in recent years.
    - *Assessment of GW exploitation sustainability*. Groundwater is currently the most exploited resource for drinking water and high increase of water usage is foreseen.
    - *Improve access to safe drinking water*, currently very limited and based on traditional methods. Improving policies and regulations for the protection of wells, groundwater quality and groundwater renewal dynamics is a key priority.
    - *Identification of adaptation to inter-annual variability*. Adaptation to increased inter-annual variability and uncertainty of Lake Chad's water levels.
- Socioeconomic aspects
    - *Enhance subsistence cropping system:* the most diffused and potentially supporting local food demand, but very vulnerable to climate variability, floods and droughts and not enough productive to ensure a production surplus for selling.
    - *Reduce poverty and social gaps*. Economic growth and key human capital indicators gap between the LCB and other areas within the riparian countries is very high.

  - *Improve basic services:* the region lags behind in terms of access to services, such as education (literacy rates -15 years old and older nearby lake: 21%), healthcare (one doctor for 140,000 inhabitants, a quarter of the national average), electricity (38%) and access to improved water and sanitation facilities.
  - *The development of a transnational forestland governance* regime in the LCB could help to mitigate the security challenge.
  - *Monitoring, assessment and knowledge of fishing stock*: fish is among the cheapest and most common protein sources in the region, but catches in the LCB have undergone a significant decrease. Therefore, a regulatory system to control catches, illegal or not sustainable techniques is required.
  - *Ensure enough forage for animal feeding*. Pasture production is weak and impacted by climate variability and a number of diseases. Ensure strategies favouring the permanence of *Kuri cow* and enhance knowledge of transhumant movements and potential interactions with other sectors.
  - *Ensure cost-benefit analysis assessment*, specifically in the context of new and large irrigation projects: issues about efficiency and achievement of estimated benefit have been pointed out.
  - *Support dialogue with scientific evidence*. Narratives on the interactions between climate and security issues in the LCB should be cautiously assessed in light of the available scientific evidence, given the geopolitical, economic and climate agendas involved in the current policy discourse.

- Addressing water quality issues

  - *Improve the assessment and monitoring of pathogens and nutrient* .The human health issues related to water quality (malaria and diarrheal diseases) rank high and can be clearly located in the domain of biological hazards, while chemical pollution of ground and surface waters does not seem to impact human health at basin level. Currently, one of the most important challenges for water resource management is to mitigate the biological threats from environmental pollution. Pathogens and nutrients released both from domestic and agricultural sources, combined with the absence of adequate WASH services, pose a threat to both man and the environment.
  - *Improve research and surveillance for bacteriological and water borne diseases.* Waterborne diseases are much prevalent in the LCB and diarrhoeal diseases are the main cause of child mortality. Disease spread by water related vectors is common in the region and includes: malaria, yellow fever, dengue, filariasis and trypanosomiasis.
  - *Monitoring of hotspots of chemical pollution*. While chemical pollution from industry and agriculture seems to be limited to local hotspots, the bacteriological pollution of ground and surface waters represents a human health issue at basin scale.

- Assesment and reduction of land degradation

  - *Improve assessment of land degradation*. Land use and land cover changes, deforestation and desertification are key environmental issues in the basin.
  - *Management of invasive species*. Local plant species have declined in Lake Chad, whereas invasive ones have increased.
  - *Mitigation of alkalinity and eutrophication.* Water volume decrease has triggered an alkalinity rise and the appearance of eutrophication issues. Eutrophication issues reported in the LCB must be seen in the context of surface water contamination with nutrients from untreated sewage and animal faeces, rather than from the use of mineral fertilisers.

- Water and energy

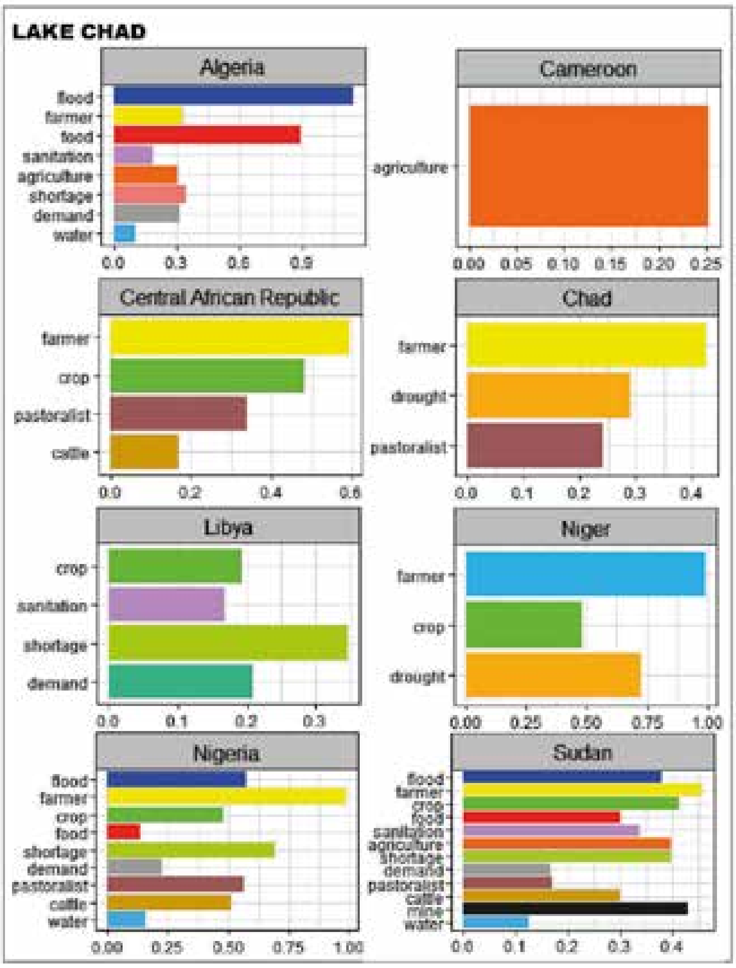
  - *Improve sustainable hydropower management*. Apply sustainable hydropower management strategies to stabilise or increase water extents of major lakes in the basin. Adapt to increased inter-annual variability and uncertainty of Lake Chad water levels.
  - *Research to reduce uncertainty of CC impact*. Provide climate-based projections on surface water extent (shrinkage or expansion), considering detailed inter- and intra-annual time series analysis over the last four decades.
  - *Achieve electrification of rural areas and explore solutions of renewable energy*. Improve energy access specifically for rural areas not connected to the African power grid, ideally through decentralised renewable energy technologies (such as solar and wind energies) to support economic growth in central and northern parts of the LCB.

- **Coordinated water use monitoring, data collection and management** as the basis for effective basin operations and management, at riparian state national levels.
    - o *Improve transboundary collaboration.* Improve coordination and collaboration between riparian countries. Coordinated water use monitoring, data collection and management as the basis for effective basin operations and management, including at the national levels of the riparian states.

- **Summary notes from stakeholder involvement:** It is interesting here to point out that for several priorities a very different ranking has been assigned by EEAS or CoEs. This form one side would require to ensure a greater number of feedback (not yet available at this stage) but also may be linked with the different perspective that different experts may assign to some specific issue: that can be for example perceived as less important because of 1) knowledge that the issue is really not relevant for the region (and not clear to other because of missing data dissemination, openness and sharing) 2) bias from sectorial knowledge or expertise of the expert (for example we can expect, even if it is not always the case, that a centre of research with a focus on CC and CV would not rank as extremely important rural electrification or fishing, etc.). At the opposite other ranking feedback maybe subject to political interest or constraints and not really supported by ground DATA and scientific knowledge. (Reference ANNEX_I_TAB_04.LAKECHAD.xlsx)

- **Most recurrent water related keywords per country in the river basin:**

Figure 49. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



RIVER BASIN 5

ORANGE

5.7 River Basin 5 – Orange

5.7.1 Introduction

The Orange-Senqu River is born in the Lesotho Highlands (3,400 m), more than 2,300 km from its mouth (that is located at South Africa's border with Namibia and is a Ramsar site; THE RAMSAR CONVENTION SECRETARIAT, 2022). With a total area of about 970,000 km^2, the Orange-Senqu transboundary river basin (OSRB) is one of the largest basins in Africa, encompassing nearly all Lesotho, about half of South Africa and respectively 27 and 12 % of Namibia and Botswana (Lange et al., 2007). The four countries are co-basin states of the Orange (or Senqu in Lesotho) river, if the ephemeral, endoreic, Molopo-Nossob River system is included. The latter three countries are riparian to the main stem, as well as to tributary rivers such as the Vaal (South Africa), Caledon (Lesotho and South Africa), and Fish (Namibia) that contribute to the flow of the main stem river.

Situated in a largely semi-arid region, precipitation decreases sharply from its headwaters in the east to its mouth in the west (ranging from 1,000 mm/yr to less than 50 mm/yr). While socio-economic activities vary enormously across the basin, water plays a vital role in supporting more than 14 million people within the basin and at least a further 5 million living outside it, through water transfers to adjacent basins. The four basin countries rely to varying degrees on the system's water resources for agriculture, industry (mining and manufacturing), energy, domestic and subsistence needs, conservation and tourism. The OSRB is of major economic importance to South Africa, supporting both the urban/industrial heartland of Gauteng and large areas of irrigation, producing crops for local consumption and export. The water resources are also of strategic importance, producing both hydropower and providing water at a high level of assurance for the cooling of thermal power plants. The Vaal sub-system, augmented from the upper Orange (Senqu) by the LHWP, supplies water to the economic heartland of South Africa; the total Gross Value Added is more than 40% of that of the country. It also supplies water to the thermal power stations on the Highveld; some 29,600 MW, or 67% of South Africa's installed electricity generating capacity. In addition, irrigation schemes covering large areas along the Vaal, middle and lower Orange rivers, account for 60% of South Africa's total water use in the basin. Some 15 million people, or more that 30% of the nation, are dependent on secure water supplies from the basin. Over the last century, South Africa has invested heavily to secure the water resources of the basin. Many large dams were built, such as the Vaal, Bloemhof and Grootdraai dams on the Vaal River, Gariep and Vanderkloof dams on the Orange river, and the Katse and Mohale dams on Lesotho, as well as long conveyance infrastructure (such as tunnels, pipelines and canals).

Figure 50. The Orange-Senqu river basin.

Namibia invested mainly in irrigation schemes on the Fish River in southern Namibia, for which purpose the Hardap and Naute dams were built. Some irrigation is taking place on the Namibian side of the Orange river itself. Namibia has indicated its intention to increase irrigation development along the Orange, as well as the Fish River.

Lesotho's water requirements, largely for domestic and stock-watering purposes, are met from streams and fountains. Botswana has similar types of demand in its sparsely populated part of the basin, with boreholes being the main source of water.

Present demands on the Orange system (dominated by South Africa) are broadly in balance with supply. Any further demand will have to be met by either increasing the supply (by building more storage) or improving the management of the existing uses. Increasing the supply will be expensive and it is likely to be viable only for municipal industrial purposes, as has been evidenced by the recent decision by South Africa and Lesotho to build the Polihali Dam as a next phase of the LHWP. In South Africa, this will be accompanied by a concerted water demand management action, and projects to recycle water.

The basin is a highly complex and integrated water resource system, characterised by a high degree of water regulation and a large number of major inter-basin transfers. Only in the source areas, mainly in Lesotho, flows not subject to regulation can be found, while the rest of the basin is intensively regulated by more than 30 major dams. The most significant inter-basin transfers include the transfer of water from the Lesotho highlands to the Vaal sub-basin (in South Africa) and from the Gariep dam on the Orange River to the Eastern Cape. Storage and inter-basin transfers have been developed because of the mismatch between the location of abundant water resources and the location of the greatest demands (and thus also increasing the heterogeneity of the distribution of water resources and level of development across the river basin). This intensive development of the river system is also the underlying cause of many of the ensuing transboundary issues.

In this context, the transboundary river basin management is supported by the Orange-Senqu River Commission (ORASECOM), established by the four riparian countries to promote equitable and sustainable development. A number of bi-lateral agreements preceded the multi-lateral agreement that created the Orange-Senqu Commission (ORASECOM) in 2000. The most important of these were:

- Agreement between South Africa and Botswana establishing a Joint Permanent Technical Committee (JPTC) in 1983.
- Treaty on the Lesotho Highlands Water Project (LHWP) between South Africa and Lesotho in 1986.
- Agreement on the establishment of a Permanent Water Commission (PWC) between South Africa and Namibia in 1992.

In addition to the bi-lateral cooperation, the establishment of the ORASECOM provided the four countries the opportunity for cooperation on basin-wide issues. For this purpose, the Commission embarked on a number of projects, many of which are still in progress. These projects are coordinated by the ORASECOM Secretariat and sub-committees of the Commission.

5.7.2 Key challenges

5.7.2.1 Hydrology

The Orange-Senqu River basin is a highly complex and integrated water resource system characterised by a high degree of regulation and a large number of major inter-basin transfers. The basin can be divided in three main subbasins: i) the Upper Orange-Senqu originating in the Lesotho highlands, ii) the Vaal River and its tributaries and; iii) the Lower Orange (after the confluency of the Vaal and Orange-Senqu rivers). Much of the Orange–Senqu basin is semi-arid to arid, with only the highlands of Lesotho and the eastern escarpment classified as temperate and where annual average precipitation exceeds evapotranspiration (UNDP–GEF and ORASECOM, 2014). The large majority of water surface runoff is generated in the upper parts of the Senqu (35% in Lesotho) and its main tributaries (about 58% for the whole Senqu system), along with the Vaal River (34%), while Molopo and Nassob and Namibia river systems (northern part) have a more limited contribution (3% and 4%). The natural runoff of the basin is approximately 11,600 million m^3/yr, of which about 4,000 million m^3/yr originate from the Lesotho Highlands. Contributing catchments downstream the Orange/Vaal confluence supply near 900 million m^3/year, while areas contributing to the Vaal, Caledon, Kraai and Middle Orange rivers provide approximately 6,700 million m^3/year (ORASECOM,, 2007).

The Orange-Senqu system is currently regulated by more than 30 major dams. Most of them are in the Upper Orange-Senqu and Vaal river systems and they mainly store and supply water for irrigation, while only a few generate hydropower (Mueller et al., 2021). The Gariep dam (5,675 Mm^3) and Vanderkloof dam (3,237 Mm^3) on the Orange river downstream of Lesotho are the largest reservoirs. Both are used to regulate the river flow for irrigation purposes as well as to generate hydropower during the peak demand periods, with a combined installed capacity of 600 MW (about 36% of the current total hydropower generation capacity). The Upper Orange-Senqu River is also impacted by a diversion scheme, moving water to the Vaal system in (South Africa) (first phase of the LHWP).

Figure 51. Orange river nearby Namibia and South Africa border (Source: Adobestock©Marek).

The Vaal River flows west near Johannesburg city, one of the most important economic areas of South Africa. It has a typical average discharge of about 300 m^3/s (Jury, 2016), supporting municipal, industrial and agricultural services via important dams (Vaal and Bloemhof, with 2.2 and 1.2 billion m^3, respectively). The flow of the Vaal river during the dry season is currently maintained with the support of water transfers.

Fish river (which drains southern Namibia) is the largest river in Namibia. Its flow varies considerably even if its variability is not yet well known or monitored: up to now, water demand in Namibia is satisfied mainly by means of Vanderkloof dam, to ensure water availability as contributions from the Fish river are too much variable. In addition, it is currently not possible to have a rapid management of the dam, as flows require 2-6 weeks to reach Namibia.

The normal seasonal pattern of the flow regime has changed a lot from its natural condition (ORASECOM, 2008): the total annual flows have been reduced to a fraction of their natural levels, along with corresponding perturbations in their inter-annual and intra-annual variability. Most of floods and flow peaks are captured by reservoirs, altering natural flooding and river flows, with very severe impact on riverine ecosystems and on its mouth. An important impact on flow regime and water availability is also linked with the cited water transfers: the most significant inter-basin transfers include the transfer of water from the Lesotho highlands to the Vaal sub-basin and from the Gariep dam on the Orange River to the Eastern Cape.

The lower part of the river basin relies mainly on groundwater resources, even if several small dams and irrigation systems play an important role along the lower reach of the Orange river. The Orange estuary is a small geographic area of about 30 km^2, extending from the mouth to 9.5 km upstream. It is recognised as an ecologically important area, that has been designated as a Ramsar site by both Namibia and South Africa. However, it remains in the Montreux Record since 1995, following the rapid degradation and collapse of its saltmarsh component (caused by adjacent diamond mining activities and flow regulation (dam construction) in the Orange river). Concerns about the future of the estuary have raised, due to further infrastructure development in the river: Lesotho's Metolong dam (completed in 2015) and Polihali dam (expected to be completed in 2022, delayed to 2028 according with the latest information), Neckartal dam (Namibia's largest dam, completed in 2020) and a potential feasibility study for the long-mooted Vioolsdrift dam in South Africa) (Matthews, 2015).

Hydrology – issues and challenges

- Potential supply options based on supplementation/augmentation and amended sharing agreements.
- The volume of water currently reaching the mouth of the Orange–Senqu River is estimated to be approximately less than half of the annual natural flow.
- The frequency of smaller floods has also been reduced, with most of them being absorbed by upstream abstraction and storage.
- Environmental flow requirements need to be adequately addressed. Need for an agreed definition.
- Changes of the hydrological regime: multiple issues (lower flow, wetland shrinking, inadequate management of the catchment and resultant erosion in Lesotho) contribute to sedimentation and loss of storage capacity in reservoirs located in Lesotho and downstream (in South Africa).
- Reduced groundwater recharge (missing knowledge for quantification); inefficient water use and low perception of water use efficiency importance. Botswana and Namibia strongly depend upon groundwater. MAR (Managed Aquifer Recharge) is one of the emerging approaches aimed at augmenting groundwater storage.
- Declining water quality: due to nutrient surplus; increased salinity; microbial contamination and; sediment loads. Localised hotspots of heavy metals, persistent organic pollutants, radionuclides and polycyclic aromatic hydrocarbons and acid mine drainage. In this context, relevant water quality variables at different geographical locations should be modelled (to assess the suitability of the water source with regard to its intended use).
- Need for improvement or implementing surface and groundwater quantity and quality monitoring networks, further improvement of groundwater information systems (as the SADC-GMI Portal), and addressing hydrological and groundwater modelling.
- Disaggregate into basin-wide vs country-level issues and challenges; considering geographical and temporal scales.

Groundwater

The complex interlinks between surface water and groundwater are fully acknowledged in the basin. Among the riparian countries, South Africa characterises for the largest populated areas, advanced industrialisation and widespread irrigated agriculture, resulting in a huge water demand partly satisfied by the existing water transfer schemas from Lesotho. In this framework, the pressure on groundwater is large, resulting in both availability and quality problems (due to both point and areal sources). Managed Aquifer Recharge (MAR) is one of the emerging approaches, aimed at augmenting the groundwater storage (see MARs in https://ggis.un-igrac.org/view/marportal; Murray and Harris, 2010).

In the middle and lower section of the Orange basin, the significant reduction of rainfall, jointly with much higher evapotranspiration rates, result in an increasing relevance of groundwater. Botswana is very sparsely populated, the limited water demand being almost entirely satisfied by local groundwater resources. Stock farming largely prevails in Namibia, being mostly dependent upon rainfall and groundwater. Groundwater salinisation, acid mine water drainage and the widespread presence of invasive plant species with deep root systems (resulting in sensible water table lowering), are a few of the specific key issues reported in the region (ORASECOM, 2014). The situation is further exacerbated by the typical quality and health problems due, among others, to leakage of pathogens from poorly (or un-) treated waste waters and nitrates. In Botswana and Namibia, accounting systems explicitly distinguish between surface water and groundwater, further disaggregating the former in water coming from perennial or ephemeral/seasonal rivers in consideration of their limited availability (Lange et al., 2007). The SADC-GMI portal (Groundwater Management Institute in South Africa) provides a rich database, relevant to the assessment of groundwater quantity/accessibility and quality, even it has still to undergo some improvements to enhance the impact of such data (as most of the time series dataset are generally lacking; Banda, 2020).

Definitely, the following needs are identified: carrying out detailed groundwater assessments, drilling and aquifer testing for hydrogeological properties characterisation; implementing and maintaining piezometric head and quality monitoring networks; developing aquifer potential maps (transmissivity, yields, quality); identifying well fields protection zones and; improving studies on groundwater recharge estimates. A flagship example of the groundwater challenges in the arid-semiarid part of the basin is provided by the Stampriet transboundary multi-aquifer system, shared by South Africa, Botswana and Namibia. Given the pressure of irrigated agriculture on the aquifer system, a preliminary groundwater flow model was implemented in FREEWAT (open source tool based on USGS codes, developed as a H2020 EU funded project; Rossetto et al., 2018) and a Regional Training on Groundwater modeling delivered in Johannesburg, South Africa (UNESCO-SADC, 2017).

5.7.2.2 Agriculture and food security

Lesotho is located entirely within the Orange basin and it is one of the richest countries in water resources in Southern Africa, but its food security is largely threatened by adverse agro-climatic conditions (such as droughts), increasing population, poor farming practices, soil erosion, decreasing soil fertility, limited arable land (only 13% of the country) and reduced labour supply due to HIVS/AIDS infections (Lesotho has the second highest prevalence of this disease worldwide) (IFAD, 2019; Verschuur et al., 2021). As a consequence, it heavily relies on food-aid (which does not solve the issues related to poverty and food insecurity in the long term, creates dependence on donor countries and it is destructive for the local economy, as prices are depressed in the local markets) and imports (which makes the country very vulnerable to spike prices, mainly when they occur in the South African grain markets; (Rantšo and Seboka, 2019). For example, the 2007 drought created food insecure conditions for about 20% of Lesotho's population (400,000 people), due to crop production failures (maize production was reduced by 40% when

Figure 52. Calculated mean annual runoff at tertiary catchment level (ORASECOM, 2014a).

compared to the previous year, sorghum by 42% and wheat by 4%, respectively) and the price spike of maize in South Africa (maize price increased by 41% and 100% when compared to 2006 and 2005, respectively). Besides, climate change is expected to increase the likelihood of food shortages in the country, due to the predominant rainfed nature of crop production (large influence of climate on yields), limited domestic production and high reliance on a trading partner (South Africa) with similar climate conditions (Verschuur et al., 2021). From the period 2004/06 to the period 2018/20, the prevalence of undernourishment in Lesotho increased from 13.7% to 23.5% of the total population (FAO et al., 2021).

In the Namibian part of the Orange-Fish basin, development opportunities are mainly constrained by aridity (which results in a sparse population). The most common income-generating activity is farming with small stock (Hardap and Karas regions support 78% of karakul sheep in Namibia, 62% of dorper sheep and 15% of all goats) and irrigation farming is practised along the rivers (e.g., Hardap irrigation Scheme and Naute dam in the Fish river, grape crops at Aussenkehr in the Orange river) (Seely, 2009). However, Namibia has declared several national emergencies over the past 10 years due to extreme drought events (2013, 2016 and the last one in 2019, when the country registered the lowest rainfall in 90 years), which have largely threatened food security in the country (Liu et al., 2021). In October-November 2021, 26% of Namibian population was facing high levels of acute food insecurity and the situation was expected to worsen from December 2021 to March 2022. Although drought can be regarded as the main driver of the current Namibian food security crisis (causing crop and livestock losses, the latter due to lack of grazing fields and drinking water), two additional factors have been identified: price shocks (food prices increased by 2-6% in 2021, due to the rise of global fuel prices) and the economic impact of the COVID-19 pandemic (due to disruptions in food and non-food supply chains induced by restrictive measures) (IPC, 2022). Besides, high poverty rates, inequality of the income distribution and HIV/AIDS incidence also contribute to food insecurity and undernourishment in the country.

Food security and agriculture – issues and challenges

- Increase water use efficiency and consider the suitability of growing higher value crops in irrigated areas (normal flood system still predominates).
- Increase share of irrigation towards food-insecure farmers. Consider affordability and cost-benefits ratio of irrigated agriculture (CAPEX, OPEX and affordability are key disincentives).
- Ensure irrigation water supply, thus increasing the use of capital-intensive cropping systems.
- Water quality issues impact on crop production (citrus).
- Enhance household self-sufficiency capacity to produce food crop in all countries (except for South Africa): common causes for agricultural poor performance are mainly related to harsh agro-climatic conditions, lack of arable land, rainfed nature of crop production and inadequate farming practices.
- Some additional issues which affect food production at national level are the high incidence of HIV/AIDS in Lesotho (which reduces the available labour force) or the absence of incentives in the case of Botswana (given the high GDP, poor access to land and generous government handouts). In Namibia, conjunctural causes of the current food crisis are price shocks and economic impacts of the COVID-19 pandemic, although drought remains as the main driver.
- Reduce inequality among countries and regions: it is a big issue for food security at household level, as poor households are more vulnerable to price shocks in the staple food markets (as the ones triggered by drought events during the last years).

The Orange-Senqu River basin is of major economic importance to South Africa, supporting the production of crops for local consumption and export. According to the Global Food Security Index (GFSI), in 2021 South Africa was ranked as one of the most food secure countries in Africa (70th out of 113 countries at global level, within the moderate performance part of the table). In fact, the country was able to export agricultural commodities valued at USD 11.2 million in 2019 (USDA, 2019). However, it also leads the list as the most inequal country in the world (its Gini index was estimated at 0.63 in 2014 by the World Bank). As a result, the country is food secure at national level (as there is enough food available for everyone through domestic food production and food imports) but not at household level (almost 21.3% of South African households had inadequate or severe inadequate access to food in 2017; (Stats SA, 2019). Food availability and accessibility at household level are further threatened by drought events (in 2018, agricultural production losses due to drought were the mainly contributor to GDP contraction in South Africa) and the decreasing number of households involved in agricultural activities (from 19.9% to 13.8% during the period 2011-2016 (Stats SA, 2019).

Botswana still faces food security issues both at national and household levels. At national level, the country imports about 90% of its food supply (mainly from South Africa), due to the poor performance of the agricultural sector and the removal of trade-restricting border measures in the grain industry as from 1991. Causes of agricultural poor performance include the semi-arid to arid climate and poor soils (less than 0.5% of the total land is arable, crop farming is limited to an area around 2,500-3,800 km^2 in the eastern and northern country borders), the rainfed nature of crop production, the low adoption of modern farming methods and the incidence of diseases and pests (Bahta et al., 2017). Besides, population engagement in agricultural activities is further hindered by high GDP, poor access to the land and over-reliance on generous government handouts (Mosha, 2016). At household level, agriculture fails to provide an exit from severe poverty in Botswana (more than 18% of the population are below the poverty threshold). Women play an important role in food security as they own more arable land than men (58% vs. 42%, respectively). However, men are the main players in livestock production and rates of women unemployment and female-headed households living in poverty are higher than those for their male counterparts (FAO, 2018). Besides, rural households are more prone to suffer food insecurity than urban areas.

Agriculture outlook

The high climatic variety of the basin is also reflected in the wide variety of crops: in the northern-eastern part, rainfed and irrigated system coexist, while production in the western area is much more dependent on irrigation. Most diffused crop is maize (grain and silage), other cereals, sunflower, and several vegetables and fruits (apples, grapes, citrus and dates) (ORASECOM, 2008). Most of the irrigation (>95%) is located in South Africa, even if some new areas are now implemented in the Namibian side of the Orange basin; indeed, the irrigation cropping system in Namibia represents about 60% of total agriculture production. Major irrigation schemes have been established in the Orange-Senqu river, mainly using reservoirs (for example Gariep, Vanderkloof, Hardap Scheme…) as water sources, and currently the area under irrigation is estimated at 385,000 ha, with a demand of about 3,800 Mm^3 (ORASECOM, 2011). Food security issues have raised the interest in irrigation even in Lesotho and Botswana, where currently no or very limited irrigation is adopted.

Central Pivoting Irrigation Systems (CPIS) play an important role in the Vaal basin, using mainly river water along the Orange and its tributaries (Vaal, Riet and Vet). CPIS cover an area of almost 270,000 ha and, depending on crop type, their water withdrawals could be remarkable (ORASECOM, 2022; UNESCO-IHP, IGRAC, 2016). Water logged areas along the river banks of irrigated agriculture areas are subject to water quality problems, mainly when the saturated zone reaches the surfaces (ORASECOM, 2014). In the arid regions of the Lower Orange, groundwater is mainly used for water supply and livestock watering.

5.7.2.3 Socioeconomic

The Orange-Senqu basin is home to almost 16 million people, but it is unevenly distributed across the riparian countries: most of the basin's population is concentrated in South Africa (84.9%), followed by Lesotho (13.5%), Namibia (1.3%) and Botswana (0.3%) (ORASECOM, 2014). Considering a medium variant scenario, by 2100 South Africa's population will increase by 35% (from 58.5 million in 2019 to 79 million), while population in Botswana, Lesotho and Namibia will increase by 81%, 27% and 115% respectively (in 2019, these three countries had a population between 2-2.5 million people; United Nations, 2019). National realities differ with regard to development, as Botswana and South Africa are included in the High Human Development country group and Namibia and Lesotho in the Medium and Low Human Development ones, respectively (UNDP, 2020). Besides, people living in rural areas generally have more limited access to basic services than their urban counterparts, such as electricity (which in the case of rural population ranges from 27.9% in Botswana to almost 90% in South Africa) or water, sanitation and hygiene (WASH). The amount of urban population at country level currently ranges from 71% in Botswana to 29% in Lesotho (in South Africa and Namibia the values are 67% and 52%, respectively). Riparian countries also show large differences with regard to their ability to transform the water resources of the basin into GDP and jobs. The contribution of each economic sector is uneven across the basin, due to the structure of

Figure 53. Access to WASH services in Southern Africa at household level (rural vs. urban). Source: (WHO and UNICEF, 2021).

the national economies. Agriculture provides food, employment and supports the rural economy of the basin, but its development heavily depends on the existence of dams for irrigation purposes. Hence irrigated areas in the basin are mainly placed in South Africa, while livestock grazing is widespread across the basin. Mining, manufacturing and power generation generally represent a smaller proportion of water withdrawals (although in Lesotho the industrial sector represents almost half of the country's water use; ORASECOM, 2014), but they are key contributors to the GDP of the riparian countries. For example, the estimated contribution of each drop of water to the GDP in the Vaal basin is 148 USD/m^3 for the mining sector, 36 USD/m^3 for the urban and industrial sector and 4 USD/m^3 for the agricultural one (ORASECOM, 2014). The Vaal basin largely supports South Africa's economic hub (contributing nearly 20% to the national GDP), more than 30% of its population and over 70% of its maize production (Remilekun et al., 2021). In fact, South Africa in the Orange-Senqu basin is one of the most upstream dependant basin-country units in the world (before storage and other human interventions are considered) (Gaupp et al., 2015). In this regard, water transfer to South Africa through tLHWP constitutes both a source of income and electricity for Lesotho.

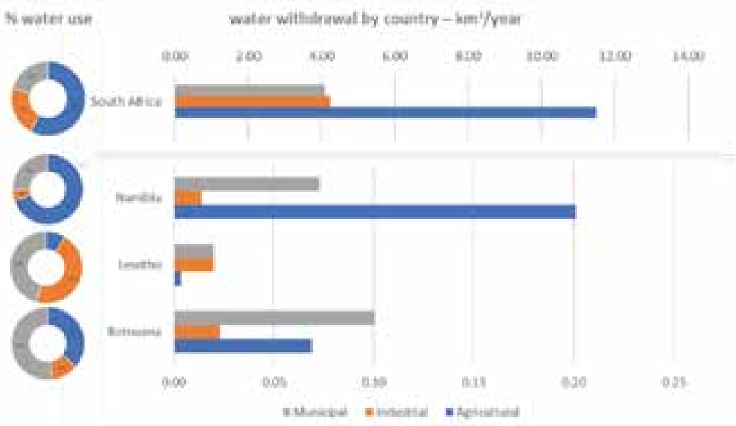
Socioeconomic – issues and challenges

- Population in the basin amounts to 16 million people and, according to projected population trends at national levels, it is expected to increase during the next decades. Urban migration is expected, hence re-thinking urban planning could offer opportunities to manage it (e.g., through integrated development planning, urban sensitive design and smart cities approaches).
- Level of development differs across the riparian countries, but rural population lag behind in all countries with regard to access to basic services.
- The contribution of each key economic activity (agriculture, mining, manufacturing and hydropower generation) to the basin economy is spatially heterogeneous across the basin. Due to the presence of dams, irrigated agriculture and hydropower production are mainly take place in South Africa. Concretely, the Vaal basin is the most important sub-basin in terms of GDP contribution (90 USD milliard) and a central pillar of the South African economy.
- Importance of water accounting to indicate the relative contribution of different economic sectors to socio-economic development issues (job creation, provision of basic services, GGP, GDP, resource use efficiencies. This can guide proper water use allocations at appropriate geographical scales - local, regional, basin-wide/national).

5.7.2.4 Water use and demands

Water in the Orange–Senqu basin is used for irrigation, urban and rural domestic activities, industry, mining, power generation and farming activities. Most of the water requirements in the river basin are supplied by means of the Integrated Vaal river system (Grootraai, Sterkfontein, Vaal and Bloemhof dams) and the Orange river project (Gariep and Vanderkloof dams) and by several transfer schemes. South Africa accounts for about 93% of total water use (2010 estimation (UNDP–GEF and ORASECOM, 2014)), with 77% of South Africa's demand located in the upper basin and 20% in the lower basin. The current water use from Lesotho, Namibia and Botswana is very low (about 7% of the total) and linked with different sectors. Irrigation demand is much dominant in South Africa and Namibia, while it is much lower in Botswana and practically negligible in Lesotho. In Botswana and Lesotho, livestock watering accounts for virtually all agricultural water use. Total water use at basin level is about 7,100 million m^3 (for year 2000) distributed as follows: in the case of South Africa, 5,798 correspond to the Upper Orange and 1,143 to the Lower Orange, 101 in Namibia, 43 in Lesotho, and 1 in Botswana (Lange et al., 2007).

Figure 54. Water abstraction by sector: national data as reported by Faostat for 2018.



Botswana has very limited internal water resources and it is considered as a water scarce country (FAO - Aquastat). Water demand at country level is reported at 355 Mm^3/yr (estimation for 2020) (UNDP–GEF and ORASECOM, 2014), and it is mainly associated with agriculture and livestock production (identified as more effective than cropping as water user). No hydropower demand is reported in the country. Lesotho is the primary water producer in the basin (about 40% of runoff). Most of its agriculture is based on a subsistence cropping system, with very limited use of water. Indeed, the most important water demand in the country is coming from the manufacturing sector. The bulk of the country's GPD is coming from the transfer of water to South Africa: as a further development of such strategy (LHWP Project) has been foreseen for the coming years, impacts of this scheme on water availability at basin level need to be considered. Lesotho's hydropower production is currently based on Muela dam, producing about 76 MW. Water resources from Orange-Senqu basin are key for Namibia's agricultural and mining sector (being agriculture the dominant use, with a share of about 75%). A 35% increase of the water demand has been estimated between 2000 and 2010 (UNDP–GEF and ORASECOM, 2014), even if some uncertainty is reported due to limited data availability at the river basin scale for the different periods. In any case, growing water demands resulting from population growth and development are expected: e.g., Namibia is looking to expand water-intensive economic activities, such as mining and irrigation along the Orange river (Sullivan et al., 2013).

Water demand – issues and challenges

- Water is abstracted for irrigation, industry and mining, domestic use and livestock farming. Demands are steadily growing with little water surplus for increased abstractions: the sharing of water has become a particularly urgent issue for Namibia and South Africa.
- Data and accounts: still a physically based water accounting estimation at river basin level is not available. Thus, substantial improvements in data collection and sharing are needed at basin level, to make water accounting a useful tool for managing the river basin and for the effective implementation of planning (for example, more reliable information about crop specific water uses, water divergence schemes, water allocation between sectors, etc.).
- Research and identification of optimal water conservation practices are key priorities (e.g., demand management, re-use of water, desalination, rainwater harvesting, etc.).
- At present, environmental requirements are not well identified or agreed and aquatic ecosystems have deteriorated.
- Groundwater is of major importance in the drier western areas of the basin for domestic use, stock watering, wildlife and tourism and even some irrigation, but little is known about this hidden resource. Rural towns have groundwater as their sole source.

The strategy for new infrastructure development is not yet defined. Nevertheless, two main opportunities have been identified for inter-basin transfers to augment the Vaal System: i) further phases of the Lesotho Highlands Water Project: a possible Phase II of the project comprising a dam at Polihali transferring water to Katse dam, with a yield of about 500 Mm^3/a and, ii) the expansion of the Thukela – Vaal transfer scheme (ORASECOM, 2008).

Also, a number of possibilities for new infrastructure to increase the Orange River system yield have also been identified and studied and the two favoured options are: construction of a re-regulating dam at Vioolsdrift to reduce operating losses catch spills from the Vaal and, construction of a dam on the Upper Orange at Bosberg, a site just downstream of Lesotho.

Groundwater use in the basin is quite intensive and even if reliable data of volumes abstracted at river basin level are limited, it has been observed a high diffusion in all the basin of boreholes (average density in the order 1-25 per 10 km^2) that are normally denser around urban areas and throughout the agricultural zones of the basins. Some recent estimation of water abstractions (even if not based on formal and structured data) from groundwater are here summarized: 1800-1900 Mm^3/yr in South Africa (Hughes, 2005), 13.81 and 1.12 Mm^3/yr respectively in Namibia and Botswana (Lange et al., 2007).

5.7.2.5 Water quality, health and environmental issues

Water quality networks do exist in South Africa, but they are less well developed in Lesotho, Botswana, and Namibia. Thus, the information reported below refers mainly to the basin wide campaigns executed under the responsibility of the Orange-Senqu River Commission (ORASECOM, 2008).

The water quality in the Orange River Basin is highly variable due to a combination of natural and anthropogenic factors. The catchment includes the main urban and industrial agglomerations of South Africa, the main gold mining areas of the country, parts of the Highveld coal field, some of the country's power stations and significant areas of dryland and irrigation agriculture. Although the arid western part of the catchment is less developed, irrigation agriculture occurs extensively along the lower reaches of the river. The Orange River is one of the few major rivers in Africa with no harbour at its mouth.

High pollution in the Vaal catchment has implications for water resource availability and transboundary impacts. The water quality of the Upper and Lower Orange is said to be good; however, there are insufficient data for certain categories of contaminants to make any conclusive statements (ORASECOM 2008).
Furthermore, urban agglomerations throughout the catchment cause localized micro-biological pollution from untreated and partially treated sewage entering the rivers (ORASECOM 2008).

However, unlike many other African river basins, the biological threats to human health in the Orange basin are few. This is not necessarily related to a better biological quality of ground and surface waters, but to the access to clean water, higher hygiene standards, sewage treatment, and a reasonably well-developed health care system for most of the basin population.

Water quality, health – issues and challenges

- Research and surveillance: setting up a groundwater monitoring network; continuation and refining of basin wide monitoring/localisation of domestic and industrial emissions; monitoring the surface water quality of the Upper and Lower Orange (Lesotho, Namibia, South Africa); implementing a basin-wide monitoring programme for radionuclides in ground and surface waters; basin-wide monitoring of POPs, heavy metals, and radio-nuclides in biota; basin-wide monitoring of chemicals of emerging concern, such as pharmaceuticals and microplastics.
- Mitigation: adequate environmental management and control in the mines (mostly gold and uranium); further development of sewage treatment and urban and industrial waste management; further improvement of WASH services in Lesotho and Namibia.

Waterborne diseases (such as malaria or schistosomiasis) are, unlike in less developed African river basins, not an issue at population level. (https://www.healthdata.org/south-africa).

In contrast, chemical pollution is increasingly observed because of the important role of the industrial sectors of mining, production (mainly in South Africa) and agriculture. Persistent Organic Pollutants (POPs) and heavy metals in sediment and biota have been identified as a key concern (ORASECOM 2015), while the pollution from the uranium mines - especially its transboundary effects - has not been assessed at basin scale. Serious issues near gold mining areas have been reported, although the impacts of illegal gold mining using mercury are not yet assessed at basin scale. Little is known about chemicals of emerging concern, such as pharmaceuticals or microplastics.

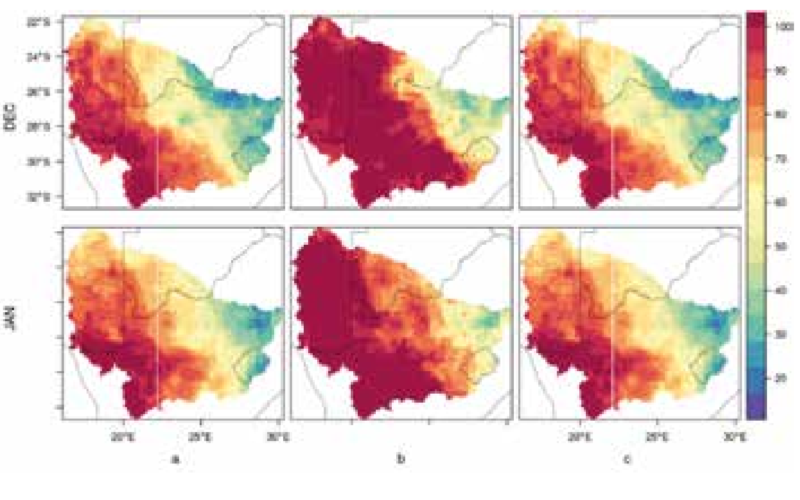
The increase in Total Dissolved Solids (TDS) in the Vaal and Lower Orange catchments, along with the concomitant increase of chloride and sulphate, has major implications for domestic, industrial and agricultural water use. Eutrophication due to nutrient from agriculture and domestic wastewaters is a severe problem in the Vaal catchment and in isolated parts of the basin (ORASECOM 2008).

Little is known about the quality of the major aquifers in the basin.

5.7.2.6 *Climate change and climate variability*

Highly variable hydroclimatic conditions characterise the Orange-Senqu River basin, where climate and aridity vary from the "water tower" regions of Lesotho and the headwaters of the Vaal/Wilge system in the east (where annual rainfall could exceed 1,500 mm/year in high rainfall mountainous areas) to the arid regions of Namibia in the west (being annual rainfall less than 50 mm/yr around the river mouth). Average rainfall in the basin is about 330-400 mm/yr and it is strongly seasonal, usually linked to convective thunderstorms between October and April. During December-January, precipitation deficit is less variable (30-50%) in the headwaters than in the river mouth (Figure in the Box, (Cordano and Cattaneo, 2022a). Precipitation maxima shows a westward progression through the season (taking place in

Figure 55. Precipitation deficit in December and January: a) 5-year return period; b) 20 year return period; c) variability. Source: (Cordano and Cattaneo, 2022b).



November to February in the eastern part of the basin and around February to March in the confluence of the Vaal and Orange rivers), while rainfall in the Namibian part of the basin is mostly associated to summer storms (although winter precipitation can occur occasionally) (Knoesen et al., 2009; CRIDF, 2019). Regarding temperature, it increases westwards (from the temperate climate in the Alpine belt in Lesotho, where June and July temperatures can fall below -10ºC at night, to the mid 40ºC recorded in the hottest areas of the basin) (ORASECOM, 2008). In this context, extreme events are common (such as the 2010/11 floods or the droughts during the 1990s and between 2014 and 2016; Blumstein, 2017). For example, the January 2010 flood in the Vaal River (when its flow reached 2,801 m^3/s) has been related to NW-cloud bands, a key mode of summer rainfall variability. In this regard, further research on the connection between NW-cloud bands, the equatorial Atlantic Ocean circulation and the Pacific Southern Oscillation could help to improve seasonal hydrology forecasts in the Vaal basin, as the latter drives evaporative losses whereas the east Atlantic influence provides an advance warning of flow variability (Jury, 2016). Regarding the incidence of heat waves, prone areas are mostly located in the northwest (Namibia) and the eastern, upper part of the basin (South Africa and Lesotho highlands) (Cordano and Cattaneo, 2022).

Climate change and variability – issues and challenges

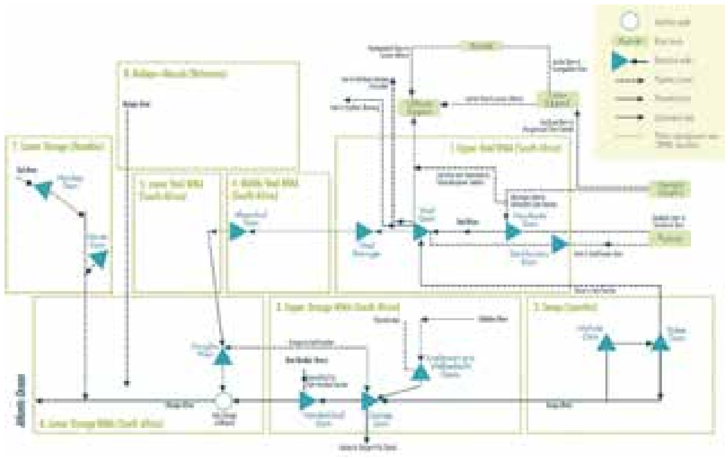
- Spatial variability: precipitation and temperature are highly variable across the basin, where a steep gradient exists from the "water tower" regions in the east (annual rainfall > 1,500 mm/year) to the river mouth in the west (annual rainfall < 50 mm/year). Precipitation deficit variability also increases from east to west.
- Temporal variability: precipitation is strongly seasonal, most of it occurring between October and April. Precipitation maxima takes place sooner in the eastern part of the basin (November to February) than westwards (February to March). In the Namibian part of the basin, rainfall is mainly linked to summer storms.
- Extreme events: droughts and floods are common. Most prone areas to heat waves are mainly located in the northwest and the eastern, upper part of the basin. Climate change is expected to modify the occurrence of wet/dry spells across the basin.
- Predictive (regional) models for climate change impacts – particularly droughts and flood occurrences. Relevance of available global models or N-Hemisphere configured models – model development, or recalibration for localisation/regionalisation.
- Climate change impacts on stream flows are highly uncertain and are expected to be unevenly distributed (runoff increase in the upper part and reductions in the rest of the basin).

Despite the premise for conflict set by the basin's natural climate variability, in terms of water cooperation the Orange-Senqu basin is one of the most highly institutionalised and stable basins in Africa (Blumstein, 2017). However, as the riparian countries are highly dependent on the water resources of the basin, impacts on their future availability due to climate change are a paramount concern. Average temperature could increase between 1 and 2.5 ºC in the second half of the 21st century, while precipitation might moderately decrease in most of the lower basin and increase in the upper basin. Related river runoff changes are highly uncertain, although stream flows could increase in the upper part of the basin whilst they are likely to experience reductions in the rest of the basin (ORASECOM, 2011).

Concretely, the Vaal River catchment could experience monthly average stream flow reductions between 8 and 10% during the summer months beyond 2040 (Remilekun et al., 2021). Besides, climate change is expected to spread the annual rainfall distributions in the two major water source regions of the river system (Lesotho for the Senqu river and the Vaal and Wilge basins, which directly feed the Vaal dam), with increases in extended wetter and drier periods. Reduced overall rainfall is expected further west, along with an increase of dry spells and a corresponding decrease of wet ones. However, in the area where the Vaal and Orange rivers converge (downstream from the Vanderkloof dam on the latter), even if temperatures will increase throughout the century across the basin, the inter-annual variability of precipitation less evapotranspiration will not change greatly. Finally, climate signals in the area surrounding the river mouth suggest fewer future wet spells (CRIDF, 2019).

5.7.2.7 Water and energy

Figure 56. Water management infrastructure of the Orange-Senqu River Basin (Source: ORASECOM, 2014).



The largest reservoirs in the basin with capacities exceeding 1 Mm^3 are Gariep, Vanderkloof, Sterkfontein, Vaal, Katse, Bloemhof (ORASECOM, 2014). The four hydropower plants Muela, Gariep, Vanderkloof and Neusberg account for a total energy production of 1,248 GWh (year 2016) (Gonzalez Sanchez et al., 2020b). The Gariep site shows the largest reservoir extent (232 km^2) among all hydropower sites in the basin, followed by Vanderkloof dam (112 km^2), causing relatively high-water losses through evaporation from reservoir surfaces of 106 mcm and 82 mcm per year, respectively. The Muela site produces the highest hydropower rates in the basin (502 GWh/year), having an associated small reservoir surface of only 0.18 km^2 at the same time. Hence this hydropower facility is characterised by the best ratio of energy production versus water loss in the basin. Neusberg (15 GWh/year) is the smallest hydropower production site in the basin, with relatively small reservoir surface. Uncontrolled spillway is reported for Katse, Mohale, Gariep and Van der Kloof dams, causing elevated flood risk in the Caledon subbasin (ORASECOM, 2008). Large and stable reservoir surfaces could be used for additional solar energy production from floating photovoltaic systems, contributing to the reduction of water losses through evaporation from reservoir surfaces at the same time (Gonzalez Sanchez et al., 2021). Produced solar energy could be directly fed in and distributed by the existing power grid infrastructure.

The Orange basin belongs to the South African Power Pool (SAPP). The Eastern part of the basin, where major cities are located (e.g., Pretoria, Johannesburg and Bloemfontein), is connected to the high voltage power grid (> 66kW), same as the Windhoek area (northwest of the basin limit; World Bank, 2022). A new high voltage power line is planned from Serowe to Windhoek via Gabarone, to bridge the existing high voltage power hubs and provide better energy access to Botswana. The Namibian regions of the basin (southeast of Windhoek) are mainly connected to the low and medium voltage power grid.

Water and Energy – issues and challenges

- Solve transboundary water disagreement (e.g., between South Africa and Namibia).
- Develop short- and long-term capacities to adapt to changing climatic conditions, particularly in Botswana and Namibia.
- Reduce evaporation rates from large reservoirs surfaces, e.g., by implementing floating photovoltaic panels for additional solar energy production.
- Reduce flood risk from dam overspill by improved dam management.

5.7.3 Summary map and priorities

In this section, a map on key challenges and a list of priorities are reported. Feedback and ranking of priorities have been provided by EEAS-Maseru (Lesotho), ORASECOM, GIZ, and Stellenbosch University (SU).

Addressing changes to hydrological regime

- *Improve a physically based water accounting estimation*. The volume of water currently reaching the mouth of the Orange–Senqu is estimated to be approximately less than half of the annual natural flow.
- *Assessment of agreed environmental flow regime.* Environmental flow requirements need to be adequately addressed and specifically an agreement among riparian countries is needed.
- *Improve knowledge about aquifer system*. Improve knowledge for quantification of groundwater to mitigate reduced groundwater recharge (research and HCD).

- *Enhance hydrological and groundwater modelling*. Need for improvement of surface and groundwater quantity and quality monitoring networks. Hydrological and groundwater modelling at river basin scale.
- *Enhance knowledge on CC*. Climate change impacts on stream flows are highly uncertain and are expected to be unevenly distributed (runoff increase in the upper part and reductions in the rest of the basin).
- *Joint annual water resources modelling to manage allocations among sectors.* Decision making on water allocation is key to operation of water infrastructure, in a river system with as many storage dams as the Orange-Senqu. Agreement on modelling tools and joint operation of such on an annual basis will foster cooperation towards equitable water allocation.
- *Assessment of basin wide impacts of future transboundary water transfers.* The impacts of the LHWP (Lesotho Highlands Water Project) Phase 2 and possible Lesotho - Botswana transfer on water resource development potential in Lesotho, and on the Orange River System is not fully understood.

Management of increasing demand on water resources

- *Monitoring and open data of water demands and abstraction*. Demands are steadily growing, with little surplus water to allow for increased abstraction: the sharing of water has become a particularly urgent issue for Namibia and South Africa.
- *Water accounting estimation.* Develop (improve) a physically based water accounting estimation at river basin scale: more reliable information about crop specific water uses, water divergence schemes, water allocation between sectors and effective use of water.
- *Identification of optimal water conservation practices* is a key priority (research and HCD).
- *Agricultural (and urban) water tariffs.* Current tariffs are not sustainable and do not provide incentives towards water conservation. Studies on willingness to pay and environmental services to be provided with the extra income generation as well as redistribution that can be linked to equity concerns.
- *Promoting water re-use.* Campaigns and education on the treatment of used water to safe levels. Establishing standards for reclamation of used water.

Addressing water quality issues due to pollution

- *Improve monitoring and assessment of chemical pollution* (Mining, agriculture, etc.). Chemical pollution is increasingly observed, due to the important role of the industrial sectors of mining, production and agriculture: nutrient surplus; increased salinity; microbial contamination; sediment loads.
- *Develop inventory of contamination hotspots*. Localised hotspots of heavy metals, persistent organic pollutants, radionuclides and polycyclic aromatic hydrocarbons; acid mine drainage, microplastic, etc.
- *Enhance research and surveillance*: groundwater monitoring network for all cited contaminants and, specifically, of water quality monitoring in upper and lower Orange.
- *Mitigation option*: environmental management and control in mining sites; improvement of sewage treatment and urban and industrial waste management; enhanced access to WASH services in Lesotho and Namibia; control of domestic and industrial emissions.
- *Enhancing monitoring and management of incremental pollution and control of emissions*. Promoting monitoring of increases in pollution (pollutants) as a result of several approved developments that produce "limited" pollution" individually - throughout the river basin. Strengthening ESIA procedures.

Land degradation

- *Improve monitoring of degradation of wetlands*. Degradation of aquatic ecosystems, such as wetlands or protected areas located in the river mouth.
- *Management of loss of species and increase of alien invasive vegetation*.
- *Soil degradation*. Decrease of land productivity, soil salinisation, poor land management, overgrazing.

- *Improve monitoring and assessment specifically in Lesotho area.* The Lesotho highlands are particularly sensitive to land degradation, which causes critical impacts on runoff and damages the water sponges and sediment loadings. An assessment of the scale and scope of land degradation at river basin scale, particularly in the Upper and Lower Orange, is needed.
- *Exploring alternative livelihood for communities in the upper catchment*. Identifying and promoting alternative livelihoods for communities that depend on Wetland resources to minimise long term impacts on the ecosystems.

Addressing socioeconomic issues

- *Reduce the heterogeneity of resources exploitation*. Reduce the heterogeneity of economic activities importance and distribution, as well as differences regarding the level of development of the riparian countries. Concretely, the Vaal basin is the most important sub-basin in terms of GDP contribution.
- *Reduce inequality specifically for food security*. A big issue particularly for food security at household level, as poor households are more vulnerable for example to price shocks in the staple food markets. South Africa is the most unequal country in the world (according to the Gini index) and, even if Botswana has one of the highest per capita levels of income in Africa, more than 18% of its population lives below the poverty threshold.
- *Identification of key limiting factors for development*. Several factors limiting development: high incidence of HIV/AIDS in Lesotho (which reduces the available labour force), absence of incentives in the case of Botswana, etc.

Adaptation to climate change and variability

- *Improve knowledge and assessment of CV*. Develop short- and long-term capacities to adapt to changing climatic conditions, particularly in Botswana and Namibia.
- *Explore alternative management solutions for big reservoirs*. Assess and reduce evaporation losses from large reservoirs surfaces, e.g., by exploring new management solutions such as the implementation of floating photovoltaic panels for additional solar energy production (research).
- *Improve climate forecasting for mountainous river source areas*. Conduct further research and promote on appropriate modelling techniques to downscale global CC models for the source areas of the Orange Senqu River Basin where current techniques seem to produce widely non-converging results.

Governance/Institutional

- *Improve transboundary management*. Solve transboundary water disagreements (e.g., between South Africa and Namibia)
- *Sharing of data, tools and methods among riparian countries*. Coordinated basin water use monitoring, data collection and management as the basis for effective basin operations and management, including at riparian state national levels (a key aspect to enable the implementation of integrated programmes such as IWRM, WEFE, Circular Economy and overall Green Transition).

- Summary from stakeholder consultations:

The key priorities highest ranked (also considering the number of feedback provided) are:

- *Assessment of agreed environmental flows*; According to GIZ this lack of knowledge seems to be a big gap and it translates in lack or poor environmental reserve. The estimation can be a first step towards practical measure and basis for new legislation. In addition transboundary environmental flows can only be set in the context of a basin wide water sharing agreement which include other uses ii) *Improving monitoring and assessment of chemical pollution*. According to GIZ suggestion, the information on water quality are already available. The underlying issue is not monitoring rather management of water quality through improved capacity and availability of financing. Maintenance of sewage treatment plans is key too. Mining (mine drainage) especially mines closure is a big contributor to the issue perhaps a shared solutions working with mines should be conceptualised. Legislation might also be a weakness hampering rehabilitation efforts iii) *Improving pollution mitigation strategies*; iv) *Improving monitoring of wetland and land and soil degradation*. GIZ suggests to assess the importance of assessing and understand the role of wetlands ecosystem as potential mechanism of adaptation to climate change.

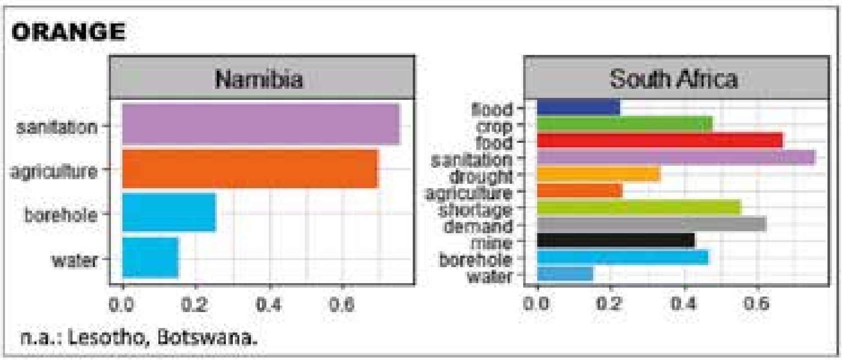
- And with highest score, but with just one ranking value provided as corresponding to priorities added to the original list by Stellenbosch University: i) *Improving climate forecasting for mountainous river source areas*; specific issue identified by SU is about the need to downscale global CC models and scenarios ii) *Enhancing pollution monitoring and management as part of EIA*. SU suggest here the promotion of monitoring of increases in pollution (pollutants) as a result of several approved developments that produce "limited" pollution" individually iii) *Agricultural and urban water tariffs*, iv) *Joint annual water resources modelling for sectoral water allocation*.

Concerning other important issues, with lowest ranking it is important to highlight here:

- *Water accounting estimation system* need to be improved.
- *Hydrological modelling at RB scale and assessment of CV and CC impacts*. Indeed as highlighted by GIZ the most recent ORASECOM IWRM Plan is already based on revised hydrological modelling; Strategy and implementation should be the focus as modeling exercises have been carried out in the past and are available. Concerning CV analysis GIZ points out the importance of mainstreaming Climate Change adaptation strategy into ongoing Water Resource Management Strategy rather than as stand alone studies. The research should be tailored to action.
- *Optimal water conservation practices*. Even if identified as important, GIZ recommends to consider that several research exists and maybe the focus should be on the adaptation and in the development of HCD to ensure the implementation of research's outcomes. An important aspect to be considered maybe also on water tariffs as a strategy to improve water optimal use and allocation across sectors.
- Concerning *aquifer system and groundwater quantification*, even if it is ranked lower, it is anyway identified as an important issue specifically by EEAS-Lesotho and SU. Groundwater is identified as untapped and unexplored sector in South Africa and this is not anymore acceptable in the context of growing pressure and need for sustainability (GIZ).
- *Identifying and promoting alternative livelihoods for communities* that depend on Wetland resources to minimise long term impacts on the ecosystems. This is a new Key priorities suggested by SU as very important.
- Improving transboundary management and more specifically the *sharing of data, tolls and methods among the riparian countries.* According to GIZ this is specifically relevant during times of floods and draught. Currently there is no real time data exchange at river basin level that could support the mitigation of negative impacts of floods and draughts.

- Most recurrent water related keywords per country in the river basin:

Figure 57. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



RIVER BASIN 6

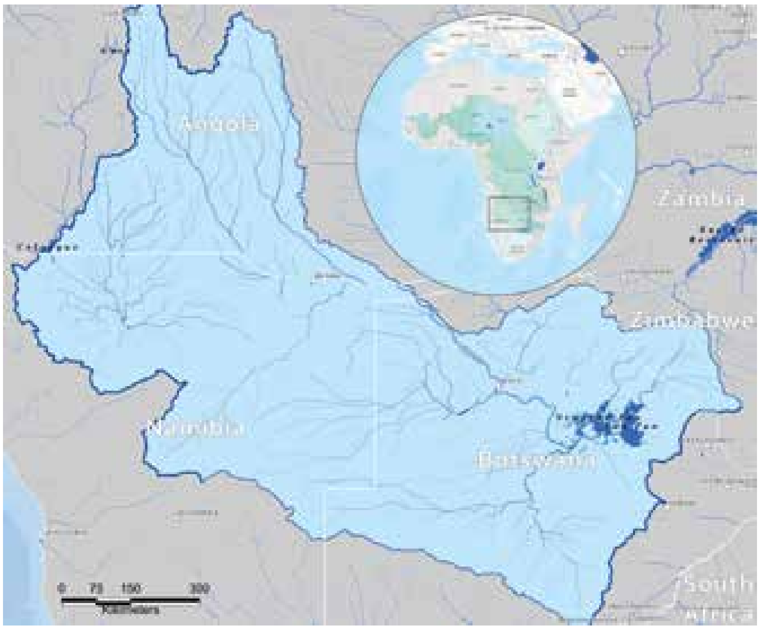
OKAVANGO

5.8 River Basin 6 – Okavango

5.8.1 Introduction

The Cubango-Okavango River Basin (CORB) is a transboundary basin that serves as an important source of water resources for three riparian Southern African states, namely Angola, Botswana, and Namibia. It comprises a network of rivers whose headwaters are in the Angolan highlands, where the Cuito and Cubango rivers originate. The topographic extent of the basin is approximately 700,000 km^2, but derives its principal flow from an area of 120,000 km^2 of sub-humid and semi-arid rangeland in the Cuando Cubango Province of Angola. The Cubango-Okavango River (COR) stretches for approximately 1,100 km and is drained by the Cubango (referred to as Kavango in Namibia and Okavango in Botswana). The COR forms the boundary of Namibia and Angola and, on this stretch, is joined by the main tributary (the Cuito) before entering Botswana and spilling into the Okavango Delta in Botswana.

Figure 58. The CORB river basin.



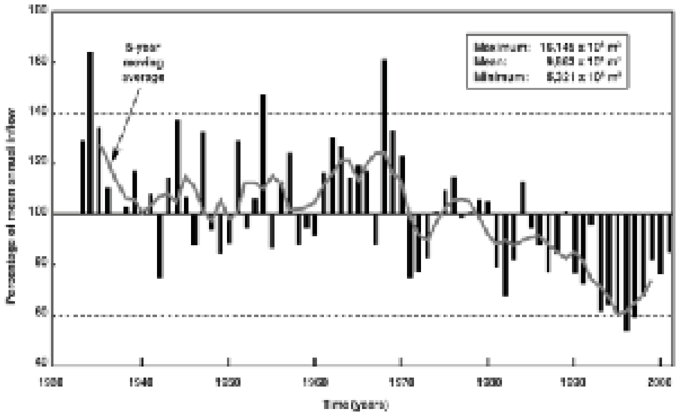
The Okavango Delta is the best-known feature of the CORB. It is one of the largest Ramsar Sites in the world and is a globally important wetland oasis for a myriad of bird species. Half a million people depend on it for their livelihoods. It was declared a World Heritage site under the UNESCO convention in 2014. With its high variety of habitat types, which support a high diversity of biological life forms, it remains one of the most important areas for biodiversity conservation in the world (Inman et al., 2021). However, the entire CORB is under threat from pollution, excessive water abstraction, deforestation, climate change, and potential oil drilling. The basin supports predominantly rural communities, most often located either adjacent to the river or along roads. Relative to capital cities and main centres of economic activity in the basin, as most people live in remote areas, social development indicators in the basin are generally lower than those reported at national scale. In general, the basin is still relatively underdeveloped, the people of the basin are poorer, less healthy, and less educated than other groups in their respective countries. Fortunately, the riparian countries recognise that economic and social development within the basin is essential for the improvement of the socio-economic status and livelihoods of communities within the basin. Moreover, if this basin is not properly managed, it could entail a potential source of conflict between the three countries (Gondwe et al, 2021).

There is limited knowledge on the contribution of the various parts of the CORB to the available water resources due to the lack of comprehensive, consistent, and sustainable water resources monitoring in some parts of the basin. For example, groundwater resources have never been quantified at the basin level. Similarly, assessments of sediment provenance and transport do not exist for the CORB. Significant socio-economic development is likely to occur in the next few decades, due to population increase and the prevailing political stability in Angola. Although the overall water quality in the basin is currently in a desirable state (based on recent survey results), socio-economic developments such as agriculture, construction of dams, mining and urbanisation are likely to negatively affect both water quality and quantity in certain parts of the basin. To manage the allocation of these activities and detect their potential impacts on water management, there is a need for a basin-wide comprehensive water resources monitoring program. The development of surface water, groundwater and water quality monitoring systems will enable the collection of data, necessary for effective water resources management.

5.8.2 Key issues and challenges

5.8.2.1 Hydrology

Figure 59. Annual variations from mean annual flow (100%) in the Okavango River, compared with the 5-year moving average. Source: Ashton, P. and Neal, M., 2003.



The CORB is one of the world's relatively undisturbed transboundary river basins, with unique hydrological and ecological features. It is endowed with a diverse natural resources base that supports the socio-economic development and livelihoods of an estimated 1.2 million people living within the basin (Mapaure, 2021). The Okavango Delta is currently stable and it is continually being shaped by complex interactions between natural processes. However, if the balance of these processes is disrupted, the system could be highly destabilised. The most important dynamic for the basin is inflowing water into the delta. The two main rivers in Angola, the Cubango, and the Cuito, join to form the Okavango River, which feeds the delta. These two rivers are hydrologically different: the Cubango, which is to the west, first flows rapidly down steep, narrow paths characterized by incised valleys, rapids, waterfalls, and valley swamps, while the Cuito, which is to the east, with shallow valleys and large floodplains, gets its water from groundwater seepage.

Benjamin Mapani (2012) reported that the manipulation of these rivers in the forms of both dams and irrigation may potentially affect the water flow and change its annual distribution, even though these developments form part of current and future planning in Angola and Namibia. Besides, a decrease in water supply will affect the vegetation growth and the wildlife, while an increase of water flows would inundate the islands (thus potentially dissolving their salts deposits and releasing chemical elements impacting water quality). In addition to declines in water flow induced by climate change and human activities, ground deformation is also happening because of shifting continental plates. This could change the paths of the water flows by changing the ground slopes. Measurements of ground deformation with Global Positioning Systems (GPSs), as found in a study by Pastier et al., (2017), reveal changes in local slopes that albeit very slight can modify the paths of the water flowing to the delta. To effectively sustain the Okavango Delta, system management strategies must definitely consider all the components, involving the governments of the riparian countries. Besides, scientific expertise, specific knowledge and data from upstream catchment to downstream Delta should be integrated.

Hydrology – issues and challenges

- Monitoring and data collection programmes are required throughout the basin. No comprehensive study has been done in the Okavango basin regarding hydrology, surface water and groundwater. Therefore, knowledge should be improved in terms of surface and groundwater interactions.
- Potential high groundwater demand sites/areas must be identified and analysed. Management protocols must be established for aquifer systems. Even if no major issues affecting groundwater supply can be reported, a great and growing demand for groundwater exists, especially in areas not serviced by perennial streams.
- The CORB is a highly sensitive and biodiverse region whose climate, vegetation and river discharge characteristics are not well understood. There is a need to analyse flow dynamics and the implications of different hydrological and flow regimes on the CORB.
- The Okavango Delta is shaped by complex interactions of natural processes. Key and system critical interactions which could pose a risk to the equilibrium in the CORB must be identified, together with mitigation and offset mechanisms should these risks materialise.

To date no comprehensive study has been done in the transboundary Okavango River basin on groundwater resources (OKACOM, 2022). A few studies agreed that no major issues of groundwater supply can be currently reported in the basin, however, groundwater demand is on the rise, especially in areas that are not serviced by perennial streams. The users of groundwater are generally village communities who utilise traditional wells, thus subjected to contamination. The Namibian side of the basin still depends on hand pumps, provided and installed by the Ministry of Agriculture, Water, and Forestry. On the Angolan side of the basin, most residents depended both on hand-dug wells and perennial rivers. Even though these demands are not large, they are crucial to sustain through all the year people's wellbeing. There is no clear information to confirm if these practices still exist to date.

5.8.2.2 Agriculture and food security

In the Okavango Delta of Botswana, there is a limited capacity for rainfed agriculture due to poor precipitation volumes. Most of the rural crop production takes place through flood recession farming, locally known as *molapo* farming. Other agricultural activities include livestock farming and subsistence fishing. Flood recession farming involves growing crops along the alluvial flood plain within the Okavango Delta and is typically carried out by rural communities (Kolawole & Kashe, 2019). The crops (sorghum, millet, maize, beans, pumpkin, and watermelon) are reliant on the residual soil moisture and nutrient deposits from annual flood pulses, which are fed by the upstream Cuito and Cubango-Okavango rivers (Kashe et al., 2015; Motsumi et al., 2012). There is a lag time of several months between the summer rains (which occur in Angola during November to March) and the occurrence of floods in the northern region of the delta (Vanderpost, 2009). From there on, the floods only start to rise from June to August. This is due to the geology of both the Cuito and Cubango-Okavango rivers, as well as the generally high infiltration rate and water holding capacity of the delta (Bauer et al., 2006). The flood pulses are not predictable enough to determine reliable planting times, which creates uncertainties for smallholder subsistence farmers (who rely on the residual moisture left by flooding of the delta). However, evidence by Kolawole & Kashe (2019) indicates that these farmers show resilience to the change in flooding times, either by adapting planting or by selecting drought-resistant crops, such as millet, should the alluvial floods not suffice.

Agriculture and food security – issues and challenges

- Focus on the Delta: flood pulse prediction and support to subsistence agriculture. There is a significant lag time from the first rains upstream of the Delta, to the point when the flood pulse occurs. Crops are primarily irrigated through annual flood pulses. Due to the variable annual arrival of the floods, resilience practices among subsistence farmers include decisions on crop selection.
- The improved prediction precision of the flood pulses could contribute to a more stable and reliable agricultural economy, particularly in the lower CORB.
- Flood pulses support a localised and underdeveloped fishing industry, characterised by harvests dependent on dissolved nutrients in the water and water levels. These are poorly understood, except through local practices and indigenous knowledge.
- To further develop the fishing industry, developmental programs should be put in place by national governments, based on a clearer understanding and predictability of flood pulses on fish populations.

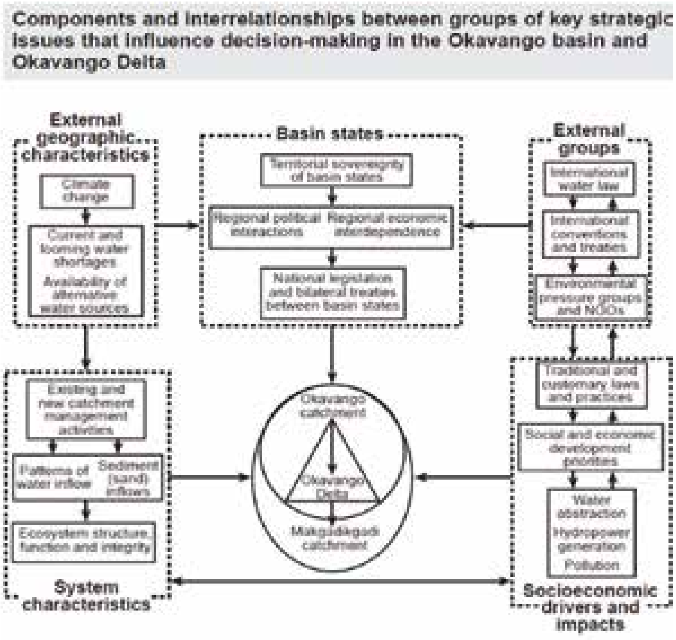
The primary livestock raised in the Okavango Delta is cattle, which is either used for meat production, bartered in exchange for other goods, or used as a transaction method for marriage (Kolwole et al., 2015). Due to the annual flooding of the delta, livestock-related diseases such as foot and mouth disease are a common occurrence, which hinders meat export activities due to fear of outbreaks.

The seasonal flood pulses in the delta allow for the existence of localised fisheries, important for the food security and economic livelihoods of rural communities (Mmopelwa et al., 2009). The location of these fisheries is influenced by the time of year and extent to which the floods take place (typically from November to May), and the surrounding animal activity. The concentration of fish populations is negatively correlated to flood extension: if flow levels are low, the concentration of fish increases due to their more confined swimming area. Therefore, the reduction in floodwater is viewed as advantageous, as it allows for greater ease of harvesting. In addition, the surrounding animal activity also influences the concentration of fish. For example, livestock dung deposited within the floodplain can increase the fertility of the fishery lagoons, hence promoting fish productivity.

Key challenges in the subsistence fishing industry include the requirement of a fishing license for gill-net fishers (Mosepele & Kolawole, 2017), which is viewed as a hindrance for subsistence fishing. Additional challenges within the subsistence fishing industry are the lack of local and national legislative framework, concretely around enabling the development of fisheries and the hazards associated with subsistence fishing (Kolawole & Bolobilwe, 2019).

5.8.2.3 Socioeconomics

Figure 60. Okavango river basin: framing schema (from Ashton and Neal, 2003 – amended in 2017).



The CORB is underdeveloped, and economic transformation in Angola, Namibia, and Botswana has put strain on it. A significant fraction of the population, notably in Angola, still lives below the line of poverty (Matlosa et al., 2002). Most people in the basin rely on natural resources freely available from the river and nearby areas to maintain their livelihoods. These authors state that water is being used for irrigation in the agricultural industry and tourism-related activities in semi-arid Botswana and Namibia, where water is also key for the preservation of native wildlife. The demand for the river and its natural resources are likely to increase in the coming years, owing to demographic shifts and rising socioeconomic needs in the basin, as well as the Angolan peace process and numerous development projects throughout the basin nations.

According to OKACOM (2011), the Okavango Basin economy is a component of the broader mineral-based economies of Angola, Namibia, and Botswana, whereby diamond mining contributes substantially to the tax base of all three states. The basin is seen as a potential source of development prospects by all three states. For example, the Namibian government has now outlined the fishing and tourism sectors as means of diversifying their tax base away from diamond mining (OKACOM, 2011). Similarly, the Botswana government views the wildlife tourism and agricultural sectors as a potential driver for economic growth but notes that there may be adverse impacts (nevertheless not quantified by the authors) on the water resources of the delta.

Although the water quality and river discharge of the Okavango Delta are primarily governed by the upstream activities in Angola and Namibia, Vushe et al. (2014) observed that water quality indicators (such as pH, dissolved oxygen, phosphate, and nitrate levels, dissolved organic carbon and total dissolved solids) were all within an acceptable range along the Okavango River, Guma Lagoon, Maun and several other sites within the delta. A higher concentration of the DDT pesticide was stated as a cause for concern in borehole water in the Xakanaxa region.

Socioeconomic – issues and challenges

- Impact of activities related to economic development on the CORB. Extraction of the basin's natural resources is putting pressure on the natural environment and its associated ecosystems.
- A thorough analysis of the different economic activities and their current and projected impacts on the CORB is an area requiring further analysis and investigation.
- There is a high rate of population growth in the basin and, should this trend continue, the environmental sustainability of the Okavango River's water and resources is likely to be jeopardised, which could have a negative impact on social sustainability.
- Further investigations on demographic trends and their potential impacts on the natural resources of the CORB will provide better insights into the approaches needed to effectively plan and manage for sustainability and to mitigate potential negative outcomes.
- Tourism development and its impact on other sectors which support local livelihoods require a specific assessment and monitoring.

The Okavango River is mostly used for tourism development in Botswana, and it is primarily used for substantial agriculture in Namibia, thus enabling a consistent water monitoring program during periods of peak water demand is essential to ensuring that the tourism, mining, and agricultural sectors have access to water that meets the requirements of the respective industries.

Arable farming, management of livestock, veld, basket manufacturing, fishing, and tourism are the principal natural resource-based livelihood activities in the Okavango basin. OKACOM (2011) states that public welfare benefits, formal program occupation, repatriation, drought relief operations and bartering in rural communities are examples of non-natural resource-based livelihood activities. A combination of natural resources accessible in the area, principally water, land, and living biological resources such as livestock, has resulted in significant livelihood prospects for people in the basin.

More people in Angola are more dependent on agriculture than in the inhabitants of other areas of the basin (Mendelson and al.; 2003). According to their estimates, there are 60,000 small-scale arable and animal farmers in Angola, compared to 18,000 and 8,500 farmers in Kavango and Ngamiland, respectively. Ngamiland (located in Botswana) has progressed further in the development of tourism than Kavango and the Angolan part of the basin. The Okavango Delta is a major tourist attraction in Ngamiland, and tourism is Botswana's second most important economic industry after diamonds. Tourism contributes 5% of the country's GDP (or 7% of non-mining GDP).

5.8.2.4 Water use and demands

Figure 61. Current and planned abstractions in the CORB. Source: World Bank (2019).

The CORB is a co-managed basin between the three riparian countries, therefore water management should be effectively addressed to ensure water sustainability in the basin (Mapaure, 2021). Growing population is triggering a high competition for water among the riparian countries, which should commit towards the achievement of peace and prosperity while protecting the environmental assets of the basin. The presence of a large variety of wildlife, including the African Bush Elephant, zebra, African buffalo, hippopotamus, giraffe, rhinoceros, birds, fish, and many others (King and Brown, 2021), also puts pressure on water resources. In this context, water and other natural resources are threatened by multiple drivers, including climate change, growing populations (not only human, but also those of elephant and hippo) and development expectations (e.g., improvement of living standards)..

A study by Hambira and Kolawole (2021) analysed climate change actions and water demand management approaches conducted by companies listed in the Botswana Stock Exchange (BSE). Concretely, fourteen of the twenty-four domestic companies were reviewed using self-completed, open-ended questionnaires and secondary data. According to the results, main water demand management practices and strategies included water reclamation and reuse, water-efficient fixtures and appliances, knowledge creation strategies and risk management.

The Transboundary Diagnostic Analysis carried out in 2011 concluded that natural systems in the basin are under substantial threat. In particular, freshwater resources are the component most at risk, since there is no substitute for the basin's rivers, watercourses, swamps, and aquifers. Even though the current water demand in the basin is less than 1% of the current total discharge, the basin is drying up and there is limited information on groundwater recharge (Mapani, 2012). As projected demands over the next 10 year are also below the total water discharge of the basin, climate change remains as the highest risk factor, potentially affecting the water flow and levels in the basin.

Another study was reported by Wang and Nuppenau (2021), which aims to resolve a potential water conflict between the upper catchment communities of the CORB and the downward communities in the Okavango Delta. A model of payment for ecosystem services is developed at the basin level, recognising spatial diversity and water flows. It addresses four objectives: i) to assess relationships between water consumption and land use from a spatial perspective; ii) to estimate water availability under current land use as a reference without any water policy intervention; iii) to optimise water flow generation as intended for getting ecosystem services, and; iv) to compensate farmers for economic losses due to upstream land-use changes.

Water demand – issues and challenges

- Impact riparian state water allocations and quotas. There is a need to meet the high competition of water from each country to ensure that the water demand for both the fauna and flora is met especially with the growing human population while committing to peace and prosperity among the three countries. The modelling and scientific based determination of optimal objective, fair and reasonable water allocation to each of the riparian states could address and mitigate any potential for conflict among the basin states.
- Lack of a comprehensive basin-wide water management plan. There is a dire need to manage water, especially upstream of the Delta (to ensure an adequate flow regime in the river mouth).
- Biomonitoring and ecosystem health monitoring at basin level. Botswana has the third highest hippo population in Africa, reflecting the importance of the Delta. Reductions in rainfall and river flow, arising from climate change and water resource development, would threaten these hippo populations by impacting grazing availability, lagoon sizes, and seasonal swamps.
- Ongoing monitoring of hippos should continue, as they represent a good indicator for the entire floodplain ecosystem.

The study suggests that an integrated approach should consider payments for ecosystem services to incentivise forest conservation. The annual payments of US$28.7 million could encourage farmers upstream to deforestation dynamics to forest conservation. With compensation, approximately 8.7 million hectares of forests would be maintained in the basin, securing 3,656 million m^3 of water during the rainy season and subsequently benefitting the delta in the dry season.

5.8.2.5 Water quality, health and environmental issues

The delta is reliant on water supply from Namibia and Angola. As per OKACOM (2011), the main threats posed to the basin by these countries are increased upstream water exploitation and pollution. Due to increased commercial and subsistence use of the delta and its resources, local uses (agricultural, fishing, resource collection and usage) may affect the resource base and biodiversity.

Variations and reduction in hydrological discharge, changes in sediment dynamics, changes in water quality, and changes in the richness and distribution of biota are some of the important transboundary management topics of concern recognized by OKACOM. Population trends, a change in land-use, poverty, and climate change are the primary drivers of these concerns. The main multilateral risk, according to OKACOM (2011), is that rising population in the basin would raise demand for food crops, putting strain on land and, in turn, causing changes in water quality.

Water quality and environment – issues and challenges

- Climate change and development impacts on water resources. Water management in the Okavango will face considerable challenges, as a result of climate change and general development (industrial or in farming).
- There is an imminent increase in water consumption in the basin, which can result in the degrading quality of water. The potential impacts of these water quantity and quality changes (surface and groundwater) in localised areas and at basin scale are very poorly understood.

Based on OKACOM (2011) a lengthy water quality monitoring program and an outreach book for stakeholders and decision-makers were utilised in the Okavango Delta. A freshwater biodiversity baseline has been constructed, which will be maintained using a biological integrity index that is currently being piloted and will provide management-oriented data for the years ahead.

5.8.2.6 Climate change and climate variability

Located in the subtropics climate region, the inflow into the Okavango Delta has largely been influenced by water flows from upstream of the river basin in Angola, which travels along the Cubango-Okavango and Cuito Rivers (Todd et al., 2003), and to a lesser extent, by the contribution from the seasonal rainfall pattern from November to March. The hydrologic functioning of the Okavango Delta region is inextricably linked to the climate variability of the region (Moses et al., 2022).

On a global scale, the influence of the El Niño-Southern Oscillation [ENSO] cycles have been seen to be responsible for the wet and dry cycles in the Okavango Delta. Generally speaking, the El Niño conditions are associated with below-average rainfall/ drought conditions, and La Niña cycles are associated with above-average rainfall/ frequent floods in southern Africa. Moses et al. (2022) highlighted the positive relationship between the rain-bearing La Niña cycle and high values of the Normalised Difference Vegetation Index (NDVI) in the summer rainfall months over Angola, during the wet cycle of 2006 to 2013. This wet cycle over Angola, brought about by the warmer sea surface temperatures in the south-eastern Atlantic Ocean in addition to the La Niña event, led to increased river discharge in the Okavango River Basin (Moses et al., 2022).

Considering a scenario of little to no mitigation (Engelbrecht et al., 2015), temperatures in subtropical Africa are forecasted to rise by almost twice the global rate average. In this context, evapotranspiration rates in the Okavango River may rise, hence contributing to reduced discharge within the basin (Hughes et al., 2011; Moses & Hambira, 2018).

Climate – issues and challenges

- Management plan/framework to address climate change impacts in the CORB. Climatic changes will be critical to the functioning of the Okavango Delta. There are concerns that a warmer climate may result in increased evaporation rates of the lagoons/ lakes within the delta area. This entails severe impacts on the communities that rely on ecosystem services provided by the delta. There is a lack of a legislative framework, surrounding the proactive measures to deal with the potential impacts of climate warming on the delta. The development of such a framework will have immense benefits for all the basin states.
- Drought interventions. An increase in surface temperature, associated with climate change, will worsen the impacts of droughts in the Okavango River Basin. Temperature and hydrological models show a reduction of water flow towards the delta in the latter half of the 21st century. The identification of potential drought hotspots and interventions to mitigate their impacts - in the WASH, agriculture, economic sectors - will enhance the resilience of communities to these shocks in a proactive manner, rather than the reactive approach currently followed.

Reduced streamflow may have an adverse impact on water availability for subsistence farmers, who rely on the annual floodwaters to irrigate their crops. Taking into consideration a climate warming scenario, similar results using the Global Water Availability Assessment Model [GWAVA] (Folwell et al., 2006) indicate that an increase in annual evaporation in the southwest basin may occur. Therefore, water resources in the delta area could decrease due to a reduction of river discharge and increased water abstractions to sustain the economic development of the region. Unless proactive strategies are implemented to prevent this outcome, the communities relying on flood recession agriculture will face negative impacts on their livelihoods.

Despite the existing knowledge about these potential issues, a legislative framework on how to mitigate water shortages is still lacking in the case of Botswana (Crawford, 2016). Regarding the impacts of climate change on economy, policymakers have already recognised the likelihood of adverse effects (Hambira et al., 2020), identifying nature-based tourism as the most vulnerable sector to climate change.

5.8.2.7 Water and energy

The CORB is acclaimed worldwide for its biodiversity and biological production (OKACOM, n.d.). The Okavango River is still one of the world's most distinctive, near-pristine free-flowing rivers. Water is a vital resource for many socioeconomic sectors, such as agriculture or hydropower generation.

According to OKACOM (2011), 28 potential hydropower projects have been identified in the basin. All of them are located in Angola. The installed capacity of these facilities' ranges from 80 kilowatts to 105 megawatts. The 12 primary projects have a total capacity of 391 megawatts and are expected to produce 1,864 gigawatt-hours of energy per year.

The aggregate potential of these projects is significant, given that the largest city of the Angolan part of the basin, Menongue, has a maximum demand of under 5 megawatts. Providing electricity for domestic use, as well as for some industrial facilities, would roughly take a tenth of the total hydropower capacity. However, future energy demand is expected to increase along with household incomes. In any case, significant hydropower projects can only be constructed if the generated electricity is exported out of the basin. According to OKACOM, the average flow of the river system will not be considerably affected by the identified schemes, as hydropower generation is a non-consumptive water use (even if uncertainties remain for the estimation and consideration of evaporation losses from reservoirs, that can be high and of impact to water cycle in high temperature climate). On the other hand, the operational regime of hydropower plants and dams is projected to alter flow timing and rate, reducing peak flows and increasing low flows.

Water and energy – issues and challenges

- Detailed feasibility assessment of new proposed potential hydropower projects is a key requirement, primarily to determine ecosystem and socio-economic development impacts and affordability. Building a dam and a reservoir to provide hydroelectric power involves a great deal of money, time, and labour. Besides, most of the potential places to establish hydroelectric facilities have some degree of occupancy, either by humans or the already existing natural ecosystems.
- Hydrological regime analysis for hydropower. Hydroelectric facilities are particularly sensitive to climate change and its consequences. Dams are built with specific precipitation in mind, allowing them to contain water during floods or, conversely, provide electricity during droughts.

5.8.3 Summary map and list of priorities

In this section, a map on key challenges and a list of priorities is reported. Feedback and ranking of priorities have been provided by EEAS-Maseru (Lesotho), ORASECOM, GIZ, and Stellenbosch University (SU).

- Management of increasing water demand
    - *Improve the development of a water management strategy to ensure agreed and equal resources allocation*. A Working Water Management Strategy to ensure and agreed and equal resources allocation between the riparian countries, especially focused on the upper basin to assure enough water downstream (even during the dry season.
    - *Monitoring and data on water demands and abstractions*. Such a strategy would also entail arrangements among the riparian states on water sharing and abstractions. It is important that Angola, Botswana and Namibia collaborate to derive accurate estimates of the volumes of water that each state may justifiably require.
    - *Water quality*. Water quality management strategy is necessary to secure effective water and food security availability downstream to satisfy increasing water demand.
    - *Identify and agree on transboundary water resource and environmental trade-offs*. As part of the management strategy, assess scope for tourism benefit sharing as a mechanism to compensate for constraining upstream irrigation development.

- Adaptation to climate change and variability
    - *Develop a climate strategy at river basin level.* Need for a Climate Change Response Framework/Strategy at basin level.
    - *CC and CV impact on water availability.* Improve knowledge of climate variability and change which impact on the increasing unreliability of water availability and rainfall variability. Research to reduce high uncertainty on predicted climate change impacts.
    - *Research on improving productivity (soil fertility, water productivity, flood pulses, mixed systems).* In relation to agriculture and food security, there are limitations to the scale of agricultural development which in turn stunts local economic development.
    - *Improve assessment and knowledge of agricultural sector.* Deforestation along the Okavango River leads to an augmentation of the inflow to the Delta, mitigating the local effects of climate change. Global Climate Models (GCMs) are highly uncertain in this region, hence the development of Regional Climate Models (RCMs) may reduce the uncertainty of climate change projections.

- Addressing changes to hydrological regime
    - *Improve the analysis of river management and impacts on the Delta (Data and modelling).* The hydrology of the delta area, where community farming is highly sensitive to changes in climate conditions, requires more intensive investigation and analysis, particularly as an indicator of the overall health and functioning of the basin. The current hydrological model shows that water inflow into the floodplains of the delta will be negatively affected by: i) increased abstraction upstream of the delta, ii) removal of floating vegetation (which will change the distribution of flow within the delta) and, iii) future construction of reservoirs.
    - *Improve the assessment of impacts of river flow decrease*. The natural flows in the Okavango River have experienced variation between -45% and +65% of the mean annual flow. In this context, a key issue is the absence of sufficient information regarding the scale, significance and resilience of ecosystem responses within the Okavango Delta to decreased inflows. Thus, the extent and consequences of river flow decrease must be fully evaluated.
    - *Improve monitoring and assessment of loads of sediments*. The Okavango Delta is dependent on inflowing loads of sediment, in the form of sand transported as bed-load along the river

channels. If this sand load is reduced (e.g., by being trapped within an upstream impoundment), the river channels would incise into the surrounding terrain and the flooded area would be greatly reduced. Any attempts to impound water or alter river flows in the catchment upstream of the Okavango Delta should be very carefully evaluated, to ensure that such schemes do not alter the patterns of sediment (sand) transport.

  - *Improve assessment of impacts of forest loss.* Deforestation along the Okavango River leads to an augmentation of the inflow to the Delta, mitigating the local effects of climate change. Global Climate Models (GCMs) are highly uncertain in this region, hence the development of Regional Climate Models (RCMs) may reduce the uncertainty of climate change projections.

- Addressing socioeconomic issues
  - *Assessment of tourism development.* Improve the assessment of tourism development and its impact on other sectors.
  - *Improve knowledge and monitoring of fishing sector.* Improve subsistence fishing industry.

- Water and energy issues
  - *Improve renewable energy contribution (Research and HCD).* Explore solutions using renewable energy: bioenergy, PV–hydropower, floating photovoltaic system.
  - *Enhance cost-benefit assessment for new hydropower plants.* Increase consideration of ecosystem and socioeconomic aspect in feasibility assessment of new dam and reservoirs.

- Governance/Institutional
  - *Improve the development of a framework strategy at river basin level.* The basin management strategy needs to proactively respond to changing climate conditions, to prevent adverse impacts on the communities that rely on the water resources provided by the CORB. Currently, such a framework/strategy is not fully available, although an Okavango Delta Management Plan was developed by the Botswana Government in 2008 (due to the importance of the delta for the country). Such a strategy would also entail arrangements among the riparian states on water sharing and abstractions.
  - *Engagement of local community.* Community engagement for socio-economic development and governance. In a situation of rapid development in the CORB, water management must ensure that governance procedures are inclusive, fair and dynamic. When community members are actively participating in the decision-making process, they perceive benefits from self-management.
  - *Need for a Climate Change Response Framework/Strategy at basin level.* It is important that Angola, Botswana and Namibia collaborate to derive accurate estimates of the volumes of water that each state may justifiably require.
  - *Financing and resources (Financing mechanism & longer terms sustainability of RBOs).* Having access to funds to maintain water management implementation is a key issue. Potential funding mechanisms and models must be investigated, as the failure to do so would have dire consequences for the implementation of an effective water management plan or programme. Mature RBOs need to be financially sustainable a clear plan on what the country contribution is necessary. For implementation of larger projects and pilots the improvement of financing mechanisms is crucial for the future particularly linked to the risks of climate change.
  - *Capacity & institutional assessment.* IWRM is a highly dynamic field. For RBOs to be relevant and deliver upon their mandates it is crucial to have the right people with the right skills. An assessment of the services of the RBOs and corresponding HRs might be useful.

- Summary notes from stakeholder consultation:

The key priorities highest ranked (also considering the number of feedback provided, see *Annex: ANNEX_I_TAB_06.OKAVANGO*.xlsx) are:

- *Develop a water management strategy for water resources allocation.* A Working Water Management Strategy to ensure an agreed and equal resources allocation between the riparian countries, especially focused on the upper basin to assure enough water downstream (even during the dry season). GIZ points out how competing activities could benefit from such strategic plan, but it is essential that such a plan should carefully presents issues of benefit sharing, to be negotiated among the countries. Indeed OKAKOM prompts that no allocation agreement is currently applied.

- *Improve knowledge and monitoring of fishing sector.* OKAKOM mentions the importance of this priority as it directly addresses livelihoods issues of communities living in the basin: a fisheries management plan was developed but requires to be unrolled and implemented across the basin.

- *Research for potential funding mechanisms:* Having access to funds to maintain water management implementation is a key issue. Potential funding mechanisms and models must be investigated, as the failure to do so would have dire consequences for the implementation of an effective water management plan or programme. OKAKOM emphasizes that *CORB* fund is already there as funding mechanism but still the lack of funding sources limits its functioning.

- *Improve the impact assessment of river flow decrease* (*a key issue is the absence of sufficient information regarding the scale).* OKAKOM notes: The basin has now developed a Decision Support System and carried out a number of joint hydrological surveys across the basin. Improved data collection, processing and sharing has be partly addressed with additional monitoring stations. Nevertheless there are still discrepancies about future climate and management scenarios, thus a combined and agreed to future outlook is needed to support this area of focus.

- *Impacts of CC and CV on water resources and CC strategy.* A Climate Change Response Framework/Strategy at basin level is needed. GIZ highlights the need to go a bit further in action proposed with more practical ways to implement, i.e. mainstreaming in water resources management plans for active response to risks and addressing existing vulnerabilities. OKAKOM arises the lack of monitoring of relevant parameters to inform about CC and even if the CC impact is well known in the scientific community, still little transboundary agreement and little inter-sectoral agreement is recognised and also there is not enough governance and private sector recognition of impacts.

- *Ensure water quality:* highlighted specifically by OKAKOM as necessary step to secure effective water and food security availability downstream.

Other important issues, with lowest ranking, but nevertheless to be mentioned because of their importance are:

- *Monitoring and data on water demand and abstractions.* In this context OKAKOM has reminded that a basin water allocation strategy was developed and considered by the Commission in 2017, but additional efforts are needed specifically concerning groundwater.

- *Agreement on water needs and allocation among the riparian countries:* GIZ highlights the importance of capacity building, negotiation and research studies to ensure a shared understanding and thus facilitating the agreement. Again benefit sharing should be part of this negotiation backed by studies.

- *Improve assessment of impacts of deforestation and landuse changes.* In this context GIZ points out the importance of consideration of the impact of alien invasive species with regards to deforestation, highlighting also a low awareness of the issue. In addition OKAKOM stress the knowledge gap of the sector.

- *Assessment of tourism sector.*

- *Financing mechanism & longer terms sustainability of RBOs.*

- *<u>Other point of discussion highlighted by stakeholders</u>*:

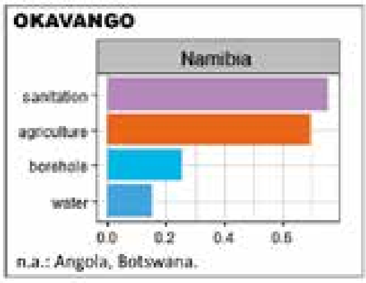
Research in the field agriculture productivity (soil fertility, management, etc.) seems to be ranked as lower priority, as some studies have been already developed and available in the literature. In addition, according to GIZ, Botswana has already started a process to try to increase agriculture intensification to make the country independent from imports. Nevertheless still low importance is given to water supply and real demands. Concerning the analysis of river management and its impact on the Delta system OKAKOM suggests to focus on new aspect, as this issue is rather well known and much academic research is done in this space.

OKAKOM also suggests further studies in the context of sedimentation issue (even if ranked with lower priority).

For the energy sector and specifically for renewable energy, some specific inputs are: some work has already been done in the upper catchment in Angola to explore renewable energy potential especially looking at solar. Solar should definitely be researched and operationalised/implemented as many studies stop at feasibility stage. Also hydropower is highlighted as a solution not to be investigated anymore.

- Most recurrent water related keywords per country in the river basin:

Figure 62. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



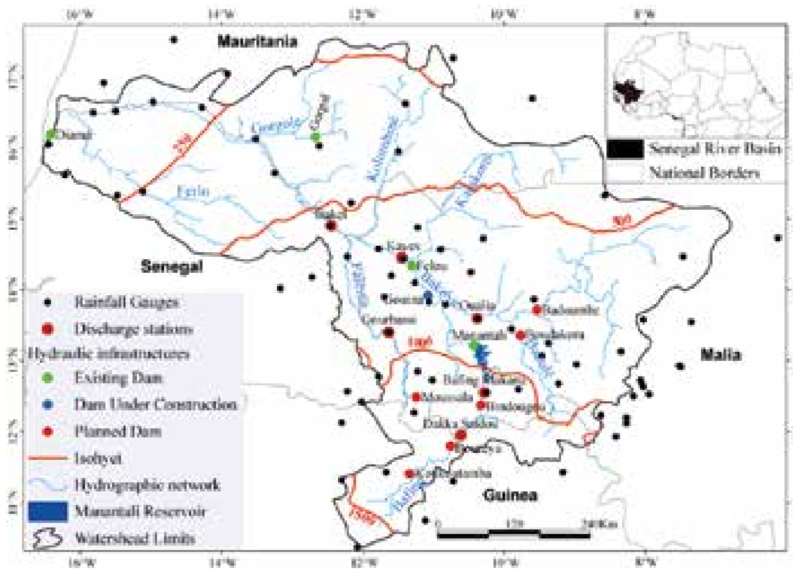
RIVER BASIN 7

SENEGAL

5.9 River Basin 7 – Senegal

5.9.1 Introduction

Figure 63. Senegal basin. Source: Bodian et al. (2020).



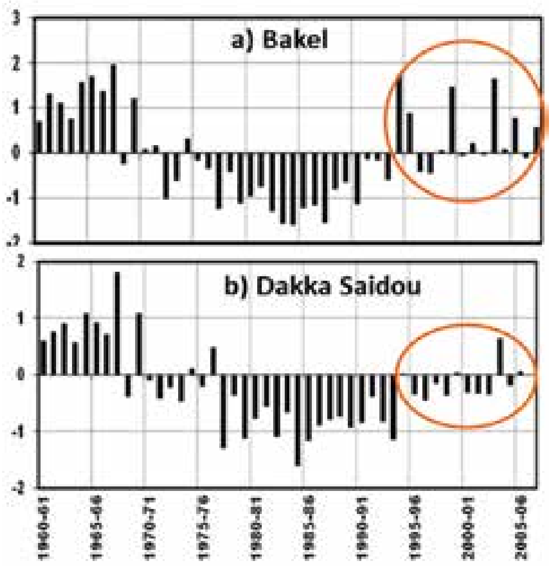
Born in the Fouta Djallon massif in Guinea, after the confluence of the Bafing, Bakoye and Falémé rivers, the Senegal River travels across Guinea and Mali and traces the border between Mauritania and Senegal until it meets the Atlantic Ocean near Saint-Louis in Senegal. The journey of the second largest river in West Africa, through almost 1,800 km and four riparian countries, constitutes a lifeline for the 7.7 million people (in 2018, 16% of the riparian countries' population) that inhabit within the 340,000 km^2 of the Senegal River Basin (SRB). Due to the high dependency of the main livelihoods on water (agriculture, livestock, fisheries), around 85% of the population in the SRB lives close to the river (UN, 2003). In this context, the development of the basin is of vital importance for the four riparian countries, which show values of the Human Development Index (HDI) among the lowest of the world (being listed as Least Developed Countries (LDCs)). Hence, Senegal, Mauritania and Mali decided to join their efforts in 1972 through the establishment of the *Organisation pour la Mise en Valeur du fleuve Sénégal* (OMVS), which is considered as an example of transboundary cooperation due to the effective implementation of the principle of equitable sharing among member states (regarding both the ownership of hydraulic infrastructure and the benefits associated to water resources). In 2006, Guinea joined the OMVS.

5.9.2 Key challenges

5.9.2.1 Hydrology

The SRB can be divided in three main areas: the upper basin (covering 56% of the basin area, from the river source until the Bakel gauging station located 980 km downstream), the valley (35% of the SRB area, extending 600 km downstream of Bakel station) and the delta (from Richard Toll to the river mouth, located 170 km downstream) (Thiam, 2016). Most of the river flow is produced in the upper basin (located in western Mali and Guinea) and provided through three main tributaries (up to 80%): Bakoye, Bafing and Falémé. Nearly half of the discharge of the Senegal river depends on the Bafing river, originating in the Fouta Djallon mountains of central Guinea. The Bakoye river, born in the Manding Plateau in West Mali, contributes nearly a quarter of the entire river flow (Mettrop et al,2019; DeGeorges and Reilly, 2006). After the confluence with the Falémé, no significant flow is added because the contribution of the three tributaries located between Bakel and Diama (the Oued Garfa, the Gorgol and the Guélouar) is less than 5% of the total river flow (Thiam, 2016). Average annual precipitation in the basin ranges from 2,000 mm/year in the Guinean eco-climatic zone (corresponding to the headwaters) to 250 mm/year in the Sahelian eco-climatic zone (northern part) (DeGeorges and Reilly, 2006).

Figure 64. Standardised indices of average annual flows in two gauging stations Source: Cisse et al. (2014).



Flow regime is characterised by two seasons: a high flow season from July to October and a low flow season which extends throughout the rest of the year. However, river discharges during the high flow season are subject to a strong interannual variability, with an alternation of wet and dry periods (wet conditions during the 1950s-1960s, followed by drought during the 1970s and 1980s and then a return to wetter conditions from 1994 onwards; Cisse et al., 2014). For example, at the Bakel outlet in the upper Senegal basin, the period 1955-1967 was characterised by abundant flows (average of 472.5 m^3/s, with flow rates of more than 570 m^3/s in 1955 and 1957), while the average flow rate during the next period (1968-2011) was 216.8 m^3/s (in 1983, 1987 and 1990 flows were less than 150 m^3/s) and from 2011 to 2014 it was 424.1 m^3. The upper part of the basin has undergone significant land use changes during recent years, due to anthropogenic actions (infrastructure development, massive deforestation, degradation of the Baoulé and Bafing wildlife reserves, etc.). From 2007 to 2014, fields and fallows increased by 7.8% and bare soils by 8.8%. However, the forests and savannahs decreased by 10.35% (Faty et al., 2019). In the Fouta Djallon (the headwaters of the Senegal river), it is estimated that 295 km^2 of closed woodlands were lost during the period 2000-2020, although assessing the changes experienced by other land use classes through remote sensing products is challenging (JRC Technical Report - Velasco et al., 2021). Therefore, the debate about how land use changes are affecting the soil water-

Hydrology – issues and challenges

- Strong interannual variability of river discharges, with an alternation of wet and dry periods (wet conditions during the 1950s-1960s, followed by drought during the 1970s and 1980s and then a return to wetter conditions after 1994).
- The debate about how land use changes are affecting the soil water-holding capacity in the headwaters of the basin (Fouta Djallon) is still ongoing, as it is challenging to quantify changes between some land use classes using remote sensing products.
- Importance of dam management regarding flooding, maintenance of ecosystem services, groundwater levels and climate change adaptation. Need of measures to control the progression of the "Langue de Barbarie" breach.
- The coastal areas of the basin have been identified as one of the most vulnerable hotspots worldwide with regard to rising sea levels in a climate change context.
- Suggested further research on: adaptive management strategies for the middle valley under climate change, artificial flood regimes, spatial distribution of flood recession cultures, irrigated areas and flood forests, drought resistant crops or changes in the agricultural calendar.

holding capacity is still ongoing. Trend analysis of flows in the Falémé basin during the period 1954-2014 revealed a significant downward trend, affecting monthly discharges throughout the whole year (during both the high flow and low flow seasons; Faye, 2017).

Recurrent flooding in the city of Saint-Louis and subsequent morphological changes of the "Langue de Barbarie" sandy spit (lower estuary) has been attributed to upstream dam management. In 2003, rapid drainage of flood waters to preserve the city of Saint-Louis opened an initial gap of 4 m in the "Langue de Barbarie", which became the new river mouth. As no measures were implemented afterwards, the breach has progressed due to severe erosion along the coast and now reaches a width of +6 km, hence challenging the daily activities of local communities. The importance of proper dam management in a context of climate change adaptation has been highlighted in a report commissioned by the OMVS. Concretely, the report recommended to allow water levels of at least 3.5 m in the middle valley during the flooding season, in order to guarantee the ecosystem services of the river, keep groundwater levels and protect flood recession cultures, grazing grounds and biodiversity. Additional suggested actions include the development of a hydrodynamic model (to study adaptive management strategies for the middle valley under climate change); the design of an artificial flood regime that mimics the natural one; the need for further insights into the spatial distribution of flood recession cultures, irrigation cultures and flood forests in the entire middle valley and; the initiation of research programs focused on drought resistant crops, changes in planting and sowing dates in the agricultural calendar and the development of pilot studies in the form of experimental test farms (A&W, 2019).

Rising sea levels due to climate change are also a problem in the coastal area of the basin, as it has been identified as one of the most vulnerable hotspots worldwide due to the presence of a large extension of low, plain areas. The first consequence is the exacerbation of coastal erosion, resulting in coastline recession at an estimated rate of about 6 m/year over the entire coastal area. Main initiatives to slow down the progression include reforestation and replenishing the beaches with sand. Other consequences are the salinisation of water and soils (further developed in the section corresponding to water quality) and the increase of the frequency of coastal flooding during storms (the presence of cyclones over the coastal area is a new phenomenon, observed regularly from 2014 onwards) (IAGF, 2018).

Groundwater

Regarding groundwater, the Senegal river can play an important role in restoring the border aquifers of these countries, if the transboundary groundwater component is properly addressed within the broader framework of integrated water resource management in the SRB. According to OMVS (2007), groundwater systems in the SRB can be characterised as follows:

- Guinea: multiple shallow aquifers (1-10 m deep) are located in this part of the SRB, although flow rates are usually low (even less than 1 l/s). Water availability in these aquifers is mainly linked to annual precipitation and local population normally rely on surface water for supply, although some aquifers are used during the dry season. Regarding water quality, as these aquifers generally have a low permeable layer on top, recharge takes place through crevices and hence they could be polluted by domestic wastewater or toxic products used in gold mining.

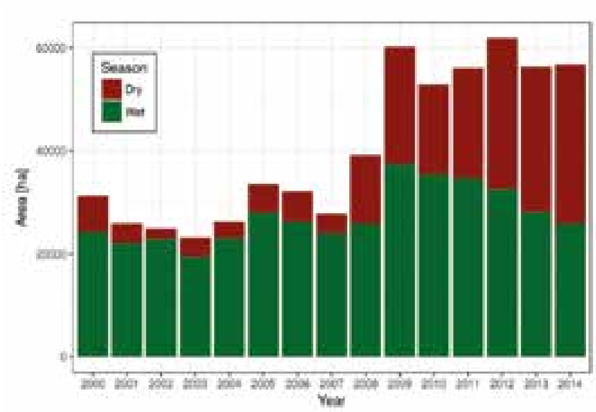
- Mali: aquifers are characterised by a mean depth between 10-15 m and, although groundwater recharge is mainly related to rainfall infiltration, the role of surface water on recharge cannot be neglected. Hence pollution found in surface waters could reach the aquifers below, although Souleymane and Zhonghua (2017) found that the vadose zone was the main parameter which impacts groundwater vulnerability to pollution (while net recharge contributes least to pollution in this area).

- Senegal and Mauritania: three types of groundwater systems have been identified in this part of the SRB: 1) shallow systems (which include dune systems, characterised by low flow rates, and 2-15 m deep alluvial water tables from which multiple villages in the middle valley obtain their water supply); 2) the Continental Terminal system, which comprises the Trarza and Ferlo aquifers (Central-Northern Senegal) and; 3) the Maastrichtian deep aquifer system (depth of 100-350 m), which is located across the Senegalo-Mauritanian sedimentary basin and provides about 40% of the total drinking water in Senegal (Diene, 2012).

Groundwater availability and demands are not equitably distributed in Mauritania and Senegal. Although both countries host significant groundwater resources, overexploitation issues exist mainly in the Diass horst aquifer system (where two aquifers are exploited, the confined/unconfined Palaeocene karstic limestone and the confined Maastrichtian sandstone aquifer underneath). The Diass aquifer system has experienced intensive groundwater abstraction during the last 60 years to meet the increasing water demand of Dakar, and contributes to a significant share of the total water supply distribution to the city (31% in 2019, with an abstraction rate of 174,000 m³/day taking place in nine pumping fields). Sustained increasing abstractions during the period 1958-2019 have led to a continuous groundwater level decline (up to 30 m), a modification of the flow patterns and, to some extent, to a quality degradation through salinisation processes (e.g., in Sébikotane and Mbour). Piezometric depressions and convergent flow patterns have been observed near the pumping fields, where piezometric levels which were above the sea level before 1959 now show negative values (-40 m in some cases) (Madioune et al., 2020). Currently, vulnerable groundwater resources in the basin lack of legal protection and control.

5.9.2.2 Agriculture and food security

Figure 65. Reported irrigated rice area in the Senegal River Valley. Source: Busetto et al. (2019).



Before the development of large infrastructures in the basin, the annual flow supported a rich and biologically diverse ecosystem despite its large interannual variability, enabling the livelihoods of flood recession farmers, herders and fishers along the river banks (estimated at 500,000-800,000 people; DeGeorge and Reilly, 2006). However, in 1973 the Sahel suffered its largest famine of the 20th century, which resulted in more than 100,000 deaths and a massive migration of the rural population towards the cities. The Sahelian states decided to adopt agricultural policies based on the development of large irrigated areas for cereal crop production, to enhance hydroclimatic forecasting and to build large multi-purpose dams in the river valleys. However, the intended objectives are far from being attained in most countries, which still heavily depend on cereal imports to supply the growing demand. Rice consumption in Senegal increased from 163,000 tons in 1960 to 1.5 million tons in 2015 (also because of the increase of annual per capita consumption from 51 to 100 kg; Manikowski and Strapasson, 2016). According to the World Bank, in 2020 Senegal was the second top importer of rice worldwide regarding trade value (broken imports of 416,769.12 thousand USD, only after China) and the first one regarding to quantity (near 1,705 million kg of broken imports).

Rainfed agriculture is still prevalent in the basin, where irrigated cropping systems account for less than 1% of cropland in Guinea and Mali, 15% in Senegal and 25% in Mauritania. Major crops in the SRB are sorghum, fonio, millet and maize (about 51% of the total harvested area). Average productivity of rainfed crops is quite limited, ranging from 0.4 t/ha in Mauritania to 0.9 t/ha in Mali in the case of sorghum and from 0.58 t/ha to 1.62 t/ha in the case of maize. Other important crops are oil crops (16%), pulses (12%), rice (7%) and cotton (6%) (Pastori et al., 2021). In the SRB, irrigation systems were mainly developed since the 1980s on both sides of the river, when the construction of the Manantali and

Agriculture and food – issues and challenges

- The objectives for the agricultural sector are far from being attained. Heavy dependence on cereal imports to supply the growing demand: e.g., Senegal is one of the top importers of rice worldwide. In this context, the rise of cereal prices has the potential to lead to social unrest in West Africa.
- Rainfed agriculture is dominant and its productivity is quite limited. The main irrigated crop is rice, although its production is hindered by multiple issues (e.g., high costs, lack of mechanisation or the liberalisation of irrigated areas during the 1980s).
- Loss of traditional downstream production systems due to alteration of the flow regime (driven by large dams) has had multiple detrimental effects, worsening the situation of the rural population. Besides, salt intrusion into the aquifers and soils (attributed to dam management) is impacting agricultural activities.
- Biodiversity of fish species in the lower estuary has undergone changes due to the breach of the "Langue de Barbarie" and salinisation, although fish landings have increased. Fishing communities are threatened by sea level variations and regular storm surges.
- Traditional pastoral husbandry faces multiple challenges, such as urbanisation, climate crisis, the pressure of the agricultural sector, the extension of protected areas and the presence of public policies oriented towards intensification and sedentary livestock rearing.

Diama dams (the former to develop agriculture, provide electricity supply and make the Senegal river navigable, the latter to prevent saltwater intrusion into the lower valley) allowed irrigation all year round. Irrigated agriculture mostly takes place downstream of Bakel, in Mauritania and Senegal, where the irrigation area in 2011 was around 75,000 ha (Tilmant et al., 2020) out of a total irrigation potential of 402,000 ha and flood recession agriculture covered 55,000 ha (FAO, 2021). According to other authors, irrigated schemes in the Senegal River Valley increased from 10,000 ha in the 1970s to more than 110,000 ha in 2012 (Manikowski and Strapasson, 2016). However, these figures are far below the irrigation potential initially estimated by OMVS for Manantali dam (more than 300,000 ha) and the alteration of the flow regime has had huge detrimental impacts on the environment, the society and the health of the riverine communities. The loss of traditional downstream production systems triggered conflicts between farmers and herders and nearly a war between Mauritania and Senegal, displacing 10-11,000 people behind the Manantali dam with inadequate and less fertile lands. As a result, the situation of the rural inhabitants within the basin worsened, along with undernourishment and malnutrition rates and the prevalence of out-migration and remittances (DeGeorges and Reilly, 2006). In the lower estuary and in the natural region of Gandiolais, salt intrusion into the aquifers and soils attributed to dam management are impacting agricultural activities, hence decreasing the income of traditional communities specialised in market gardening and livestock breeding. Concretely, estimated irrigated agricultural area affected by soil salinisation amounts to 15,000 ha in the entire delta of the river. Despite the efforts of the local communities to adapt to the new conditions (through relocation of agricultural activities and the development of salt extraction as an alternative income source), poverty is rising in the area (Niang et al., 2019).

Except for some large-scale commercial sugarcane states, irrigation schemes are relatively small in size and water is distributed to the fields mainly using electric pumps. The main irrigated crop is rice, and it is either cultivated in the wet season (July-December) or during the dry one (February-July). Besides, tomatoes and onions are also cultivated during the short cold season (December-February) and river flood recession agriculture (watermelons, sorghum, beans) is practised after the floods in August and September (Busetto et al., 2019). However, irrigated agriculture in the Senegal River Valley is hindered by multiple issues, such as the high costs of the irrigated campaigns, lack of mechanisation, liberalisation of irrigated areas during the 1980s or the creation of farmers' organisations within a very hierarchical society (Bruckmann, 2016). In this context, actual rice yields in the SRB are almost half of their potential (5 t/ha in the delta and 5.6 t/ha in the middle valley, while the estimated potential is 9 and 10 t/ha, respectively) (Busetto et al., 2019). However, Tanaka et al. (2015) estimated mean attainable yields of 7.2 and 8.6 t/ha in the delta and the middle valley, respectively.

Regarding fisheries in the lower estuary, the breach of the "Langue de Barbarie" and the salinisation of both surface and groundwater seem to have induced changes in the biodiversity of fish species. While certain fish species have disappeared, an overall increase of fish landings has occurred due to the emergence of new fish species such as *Sardinella*, white carp, cheekfish or tilapia (Niang et al., 2019).

In the Sahelian area, three main forms of animal husbandry have been identified: pastoralism (characterised by its mobility, extensive nature and low integration in the markets), agro-pastoralism (less visible but more valued, able to integrate agriculture and livestock raising to ensure intensification and sustainability) and, finally, intensive urban or peri-urban livestock raising. The dairy sector in West Africa is characterised by a strong demand growth, particularly in the cities, which is mostly fulfilled through imports of milk powder. These imports are encouraged by favourable commercial policies at regional level, which establish weak protection levels and favour the development of a processing industry to provide cheap dairy products to the urban populations (while strongly penalising local production and transformation; Amadou and Magnani, 2020). Urbanisation and its related consumption models (based on imports) are only two of the challenges that traditional pastoral husbandry currently faces up, along with the ones posed by the climate crisis, the pressure of the agricultural sector, the extension of protected areas and the presence of public policies oriented towards intensification and sedentary livestock rearing (Magrin et al., 2011).

5.9.2.3 Socioeconomic

With an annual growth rate of 3%, population in the SRB is expected to double by 2040 (Thiam, 2016). The middle valley of the Senegal river hosts a rapidly growing population of around 3.5 million people (annual growth rate of 3.5%), mostly rural and young (under 20 years old). The region constitutes a hinterland between the capital cities of Mali, Mauritania and Senegal, acts a transit area for multiple goods, hosts several mineral resources (e.g., gold, marble, phosphates) and offers development opportunities for irrigation and energy (presence of Manantali, Félou and Foum Gleita dams). However, this area is still characterised by poverty levels higher than the average ones found at national level. Rural households obtain their livelihoods from multiple activities: agriculture (rainfed and irrigated, cereals and pulses, sweet potatoes and vegetables in peri-urban areas), livestock rearing (cattle and small ruminants), trade (grocery stores), craftsmanship (masonry, carpentry) and money transfers (migrant remittances and seasonal mobility of rural assets) (GRDR, 2014).

Important migratory dynamics have taken place in the riparian countries of the SRB (towards other African countries, such as Democratic Republic of the Congo (DRC), Ivory Coast or Western Europe, e.g., France, Spain, Italy). Besides, seasonal cross-border migrations are also typical in the basin. The diaspora provides an important support for the economy of the SRB, both at the regional and domestic scales and through different channels: infrastructure financing (building and maintenance of schools, healthcare centres, etc.), service maintenance (contributing to the salaries of teachers and health staff) and household economy (supporting expenditures on commodities or access to social services). The role of migrant remittances on enhancing the access to healthcare and water, sanitation and hygiene (WASH) in West Africa was highlighted by Marcos-Garcia et al. (2021), who found that it was more prominent in this region than in other parts of the continent. During the last decades, migrants have mainly invested in urban areas (such as Kayes, Dakar or Nouakchott) and certain sectors (e.g., real estate industry, transport sector), although more recently a reinvesting trend towards the rural productive sector has been observed. Besides, migrants who settle themselves in this region provide skills and know-how in multiple sectors (e.g., construction, agriculture or hospitality; GRDR, 2014).

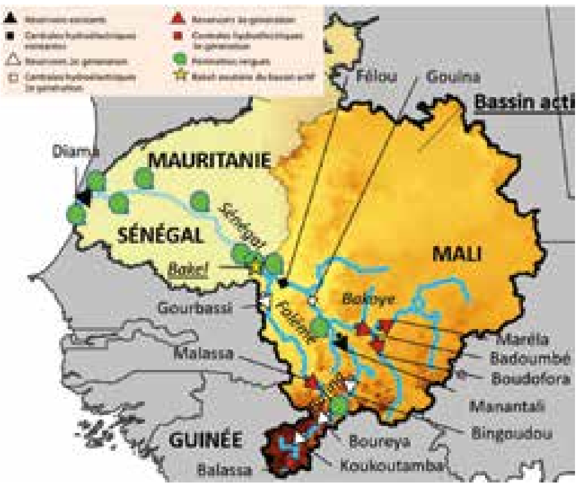
Socioeconomic – issues and challenges

- Population in the basin is increasing at a fast pace (annual growth rate of 3%) and it is expected to double by 2040.
- Main livelihoods of rural households include: agriculture (rainfed and irrigated, cereals and pulses, sweet potatoes and vegetables in peri-urban areas), livestock rearing (cattle and small ruminants), trade (grocery stores), craftsmanship (masonry, carpentry) and money transfers (migrant remittances and seasonal mobility of rural assets).
- The middle valley of the Senegal River is still characterised by high poverty levels (exceeding the average ones found at national level).
- Migrants play a key role in the economy of the SRB. Migrant remittances from the diaspora contribute to infrastructure financing, maintenance of basic services and household economy (e.g., supporting expenditures on commodities or access to social services). Besides, migrants who have settled in the basin provide important skills and know-how in multiple sectors.
- The creation of an international navigation corridor (from Saint-Louis to Ambidédi) would offer new economic perspectives for the SRB, mainly related to the transport of mining products and the encouragement of agricultural production. Mali, as a landlocked country, would be the most benefited one.

Navigation development offers new economic perspectives in the SRB, for example regarding the transport of mining products (e.g., phosphates, iron and bauxite). Besides, navigation can also encourage agricultural production. The creation of an international navigation corridor would mainly benefit Mali, due to the landlocked nature of the country. Two main components are included in the current version of the navigation project: a priority investment programme and a specific part on the transport of mining products.

5.9.2.4 Water use and demands

Figure 66. Location of planned second and third generation hydropower schemes and irrigated areas. Source: FAO (2021).



Currently, main water uses in the SRB are irrigated agriculture (including flood recession), hydropower generation and fisheries, industrial uses (mining) and domestic water supply. Agriculture is the main water use in the basin, accounting for 70% of the total freshwater withdrawals even if irrigated agriculture has a small share of the total agricultural area (Pastori et al., 2021). Both irrigation and hydropower potential are largely untapped in the basin, involving respectively 25% and 30% of the potential (Boinet, 2011). Navigation was as its peak at the beginning of the 20th century and during the 1960s (linking Saint-Louis and Kayes) but it stopped completely during the 1970s, due to both the problematic maintenance of the river bed and the difficulty caused by drought (1973-1975). Currently, only a tourist boat sails upon the river. The OMVS aims to develop a continuous and perennial navigation route from Saint-Louis (Senegal) to Ambidédi in Mali (located 905 km upstream) (IAGF, 2018). Hence in the next two or three decades, development of hydropower and irrigation potential, expansion of mining activities and the transformation of the lower reach of the river into an inland fluvial route are expected to increase the pressure on water resources. Riparian countries exhibit large differences with regard to the availability of water resources and their potential for the development of water-related economic activities. While the Guinean part of the SRB produces more than 50% of the river flow and Mali provides near 40% of the volume registered at Bakel station, Mauritania and Senegal almost lack of local water resources (within the SRB). However, Mauritania and Senegal have the highest potential for hydropower production, irrigation (the two countries account for near 90% of the agricultural developments) and recession agriculture, as well as a good potential for navigation. Mali has the best potential for navigation and a good potential for hydropower production and Guinea, despite being the largest contributor to the river flow, could only benefit of the development of its hydropower potential. Water resource management in the basin has been related to social unrest in the past, specifically related to Manantali dam. At the end of the 1990s, another crisis arose when Senegal proposed a water transfer project to enhance agro-pastoral activities. Facing the strong opposition of Mauritania, the project was finally abandoned (Thiam, 2016).

Water demand – issues and challenges

- Agriculture is the main water use in the basin, accounting for 70% of the total freshwater withdrawals even if irrigated agriculture has a small share of the total agricultural area. Other main water uses are hydropower generation and fisheries, industrial uses (mining) and domestic water supply.
- Both irrigation and hydropower potential are largely untapped in the basin, where current exploitation only involves 25% of the former and nearly 30% of the latter.
- Navigation is no longer a thriving activity in the basin, although the OMVS aims to develop its potential. The development of these activities, coupled with the rapid population growth and the expansion of mining, are expected to increase the pressure on water resources in the next decades (water needs could triple by 2040).
- Riparian countries exhibit large differences with regard to the availability of water resources and their potential for the development of water-related economic activities.
- Senegal is already suffering from water stress, water related extreme events and pollution, while water withdrawals are projected to increase by 30-60% by 2035.
- The trade-offs between water, energy, food and ecosystems (WEFE) are already quite complex in the SRB. Two coalitions of objectives have been identified in the context of future development at basin scale: traditional food production (agriculture and floodplain fisheries) versus hydropower-navigation. However, traditional food production is much more vulnerable to changes in both hydroclimatic conditions and allocation policies.

The trade-offs between water, energy, food and ecosystems (WEFE) are already quite complex in the SRB. For example, Pastori et al. (2021) found that the implementation of alternative irrigation in the Guinea region could increase both energy and food production (+6%), but at the cost of increasing water demand by nine. In a context of fast-pace growing population and infrastructure development (both for hydropower generation and irrigation extension), water needs in the SRB are expected to triple by 2040 (Thiam, 2016). Senegal is already suffering from water-stress (renewable water availability per capita less than 1,700 m^3/capita/day) and water withdrawals are projected to increase by 30-60% by 2035. While surface water represents 90% of the country's renewable resources, groundwater supplies 85% of drinking water and most industrial uses. Besides, the country experiences water-related extreme events and pollution, which cost about 10% of the national GDP each year. In the case of flooding, the Greater Dakar area is especially at risk, due to its socioeconomic importance (hosting near one third of the country's population and 50% of Senegal's GDP production) (World Bank, 2022).

In this context, and from the analysis of trade-off relationships, two coalitions of objectives can be derived regarding the future development of the basin: traditional food production (agriculture and floodplain fisheries) versus hydropower-navigation. However, traditional food production is much more vulnerable to changes in both hydroclimatic conditions and allocation policies (Tilmant et al., 2020). Therefore, future hydroeconomic scenarios envision two different allocation policies and development schemes. Regarding allocation policies, the first one advocates the maintenance of an artificial flooding regime to favour the traditional agricultural production (artisanal fisheries and recession agriculture), while the second one rules out the artificial flooding to enhance hydropower production and navigation. In relation to development, the first scheme represents an intermediate development scenario for the basin (expansion of irrigated agriculture up to 255,000 ha and installation of second-generation power facilities), whereas the second one corresponds to a complete development scenario (expansion of irrigated agriculture to its full potential (402,000 ha) and installation of second and third generation power facilities) (FAO, 2021).

5.9.2.5 Water quality, health and environmental issues

The three leading causes for mortality and morbidity in the SRB countries are: 1) poor microbial drinking water quality and sanitation issues causing diarrhoea; 2) poor indoor air conditions from cooking on open fires causing respiratory diseases and; 3) poor surface water quality causing malaria and other waterborne diseases (JRC Projec Report - Umlauf, 2019). Correlation between the presence of endemic malaria and typha (an invasive plant whose expansion has been favoured by dam developments) has been found in the basin, along with an increase of schistosomiasis (also known as bilharzia) in the basin. Globally, schistosomiasis affects more than 200 million people and causes 300,000 deaths every year. Freshwater snails act as vectors of the disease, and the only biological method to tackle the spread involves the introduction of a crawfish species which predates on these snails (IAGF, 2018). Besides, the prevalence of *Blastocystis* sp. among the children in the SRB was the highest ever observed worldwide (El Safadi et al., 2014). These authors hypothesised that this high prevalence could be attributed to exposure of individuals to animal (zoonosis) and environmental (waterborne) sources coupled with large scale human-to-human transmission. In this context, access to water, sanitation and hygiene (WASH) services is another issue which hampers the effective prevention of disease spread. At national level, the availability at home of a handwashing facility with soap and water is only 17-22% in Guinea, Mali and Senegal (according to the UN Water SDG 6 Data Portal, Home | SDG 6 Data - https://www.sdg6data.org/). Although it is well-known that large dams create conditions that facilitate

Water quality, health – issues and challenges

- Alteration of the flow regime has triggered the proliferation of Typha (an invasive plant), posing a serious threat to biodiversity through eutrophication and water quality degradation and to the development of economic activities (such as fisheries, agriculture, navigation and the access to drinking water in the case of rural populations). Besides, its expansion has been related to the increase of waterborne diseases in the SRB.
- Waterborne diseases such as malaria, schistosomiasis or Blastocystis are a main issue in the basin. Dam development and limited access to water, sanitation and hygiene (WASH) services favour their incidence. Suggested mitigation options include the collection of population-level data on disease prevalence, providing support to measure and monitor the impacts of dam development, coordination of efforts across riparian countries and implementation of new mechanisms to integrate multiple goals regarding policies, assessments and operations.
- Other pressing environmental problems include desertification and bush fires, wetlands degradation and the modification of the estuarine hydrodynamics. The area covered by salinised soils grew during the 1968-1990 drought period.
- Heavy metals: emissions from the mining sector (mainly located in the Falémé and Bafing rivers, although Mali also hosts artisanal gold mining activities) not only affect the mining communities (through direct exposure) but also water quality and the aquatic food chain.

disease transmission and thus increase the burden of water-related diseases, health impacts have been poorly addressed in river basin development and are still a side point (rather than a focal one) within the WEFE nexus paradigm. Lund et al. (2022) conducted a study on the point where health has been overlooked within the planning cycle in the SRB. According to these authors, despite institutions are aware of the health impacts posed by the existing dams, they are not able to manage them properly, mainly in the transition from key areas of decision making (such as impact assessments or basin-wide programs) to dam and reservoir operations. Besides, the efforts of international financing and donors are often limited to sectoral silos which impair a cross-sectoral consideration of health impacts. In this context, it has been proposed to integrate health within the WEFE nexus instead of considering it as an externality to be mitigated post-hoc, although further research is needed to understand how financial safeguards and international standards can support this integration. Besides, it would be necessary to improve the collection of population-level data on the prevalence of dam-related diseases in the SRB, along with further support to measure and monitor the impacts of dam development and the implementation of efforts to coordinate across riparian countries and integrate multiple goals across policy, assessment and operations through new mechanisms (Lund et al., 2022).

The massive presence of invasive species (especially typha) challenges natural resources management and biodiversity conservation in the SRB (OMVS, 2007). Typha is an indigenous plant in the SRB, but its expansion was hindered by salinity until the entry into service of Diama and Manantali dams. Due to the large modifications induced by these infrastructures on the river regime, the typha has invaded the river and replaced the existing vegetation (especially in the delta and the lower valley). The total extension covered by the typha has been estimated at more than 100,000 ha, posing a serious threat to biodiversity through eutrophication and water quality degradation. Besides, the expansion of typha and its modification of the river hydraulics could act as a barrier for the development of multiple economic activities, such as fisheries, agriculture, navigation and the access to drinking water in the case of rural populations. Although riverine populations use the typha for the artisanal production of mats, ceilings or fences, no industrial activity using typha as a raw material has been identified yet. (IAGF, 2018).

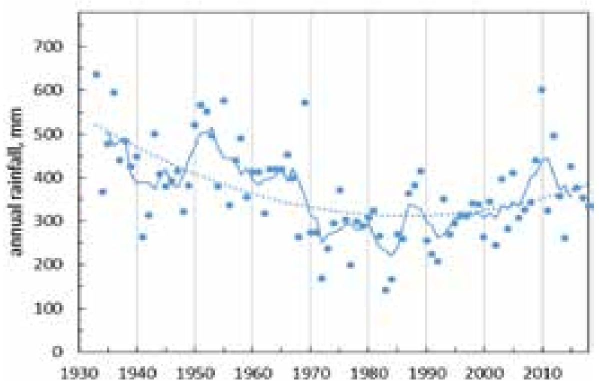
Impacts of the primary sector in the SRB could be related to irrigated agriculture and mining activities. Potential hotspots related to agricultural emissions (namely nutrients and pesticides) are the lower valley and the Delta (due to large scale rice cultivation) and the Lac de Guiers (due to sugar cane production). Monitoring data revealed only few pesticides close to or exceeding existing Predicted Non-Effect Concentration (PNEC)/ Environmental Quality Standards (EQS), e.g., the Endosulfans: and permethrins (a mosquito repellent) in Guinea, partially exceeding the EU EQS. Dimethoate, found in ppb range (µg/L) in the Senegal River, was the only agro-pesticide which clearly exceeded the EU EQS for aquatic ecosystems. The mining sector is mainly located along the Falémé and Bafing rivers, and Mali hosts significant artisanal gold mining activities which cause emissions of mercury. In this context, emissions from the mining sector not only affect the mining communities through direct exposure, but also water quality and the aquatic food chain all along the Senegal river (Umlauf, 2019). Regarding potential water pollution by heavy metals in the SRB, the assessment of cadmium, lead and mercury levels in fishes from the Senegal river in Mauritania revealed that, generally, mercury levels were higher than those found in fishes from other African rivers. However, the target hazard quotient (THQ) did not indicate risk in the case of consumption of the studied fishes three times per week or less (although a rate of consumption of five times per week could pose risk for the consumers) (El Mahmoud-Hamed et al., 2019). Besides, levels of cadmium, arsenic and lead were tested both in rice produced in the Senegal river valley and in rice imported from Asian countries. According to the findings of the study, no significant differences in the risk of exposure to heavy metals were found between the consumption of locally produced rice and imported rice (Ndong et al., 2018). Contamination with mercury and its derivates has been also found in water and sediments within the Falémé catchment, although total mercury concentrations did not exceed the EU EQS. Besides, the maximum lead concentration upstream Diama dam was slightly below EU EQS (Umlauf, 2019).

The secondary sector is not well developed in the four SRB countries (except of the processing of marine fish and some petroleum refining in the coastal area), hence the activities linked to this sector are of little relevance. However, poor management of urban und industrial wastes, together with the lack of wastewater treatment pose a threat to ground and freshwaters in urbanised areas (e.g., the Delta area). As in the case of emissions from the agricultural sector, aquatic and food chain toxicity, pathogens and eutrophication can be expected (Umlauf, 2019). Other pressing environmental problems in the basin include desertification and bush fires, wetlands degradation and the modification of the estuarine hydrodynamics (quick and unforeseen changes concerning the river mouth, following the opening of a breach in the Langue de Barbarie in 2003). Deforestation, overgrazing, erosion and silting (including shoreline erosion), changes in the composition of fish populations and changes in water resources availability should also be addressed urgently. For example, between 1981 and 2005, Senegal lost 800,000 ha of forests, Mali and Mauritania sustained losses of 100,000 and 10,000 ha/year, respectively, and Guinea experienced a deforestation rate of 2.08% during the period 1981-2000. Significant deforestation issues arise in the part of the SRB corresponding to Mali, particularly in the Kéniéba area due to gold mining, near Manantali dam, downstream of Kita due to the expansion of cotton croplands (4,000 ha/year). Besides, use of wood fuel and the expansion of pasture and agricultural lands have resulted in the appearance of deforested areas around cities such as Kayes, Kita, Kolokani or Kati, while the construction of the high voltage line of Manantali (1,500 km) has also triggered deforestation along its path (OMVS, 2007).

Although some environmental problems manifest themselves in an eminently local way (e.g. waterborne diseases or soil salinisation), they could gain momentum if proper measures to protect water quality are not promptly adopted. Regarding salinisation, although nude, salinised soils are naturally present in most of the coastal plains of tropical regions, their area increased during the 1968-1990 drought period. However, drought is no longer the main driver regarding salinity progression in the SRB. For example, in the Guandiol region, after the appearance of the breach in 2003, salinity levels of the water table significantly increased. Villages using motor pumps or hosting important touristic facilities sometimes suffer from salinity problems regarding water supply, which could increase in the future. Besides, inverse estuaries such as Saloum and Casamance can be found in Senegal (characterised by a salinity gradient which increases from downstream to upstream), where saltwater evaporates and hence salinity increases (IAGF, 2018).

5.9.2.6 Climate change and climate variability

Figure 67. Average annual rainfall in Northern Senegal. Source: A&W (2019).



Rainfall in the SRB is related to the displacement of the Intertropical Convergence Zone (ITCZ), from south to north, inducing the penetration of the African monsoon (which is governed by the thermal contrast between the sea and the continent). Four climate zones can be defined in the basin, according to latitudinal distribution of precipitation: Guinea (mean annual precipitation more than 1,500 mm), Southern Sudan (between 1,000 and 1,500 mm/year), Northern Sudan (ranging from 500 to 1,000 mm/year) and Sahel (less than 500 mm/year). The first shift of precipitation in the basin took place in 1969, and a second one was detected in 1994.

From 1994 onwards, an increase of the mean annual rainfall was observed, which indicates a not significant, partial rainfall recovery at the basin level (Bodian et al., 2020). Regarding evapotranspiration, during the period 1984-2017 it is estimated that annual reference evapotranspiration (ET_0) increased in almost one third of the basin area, while annual maximum, minimum temperatures and relative humidity increased in 68%, 81% and 37% of the basin area, respectively. However, a "paradox of evaporation" was observed in the Sahelian part of the SRB: the decrease of wind speed, coupled with an increase of relative humidity, led to the decrease of ET_0 (Ndiaye et al., 2020).

Climate change and variability – issues and challenges

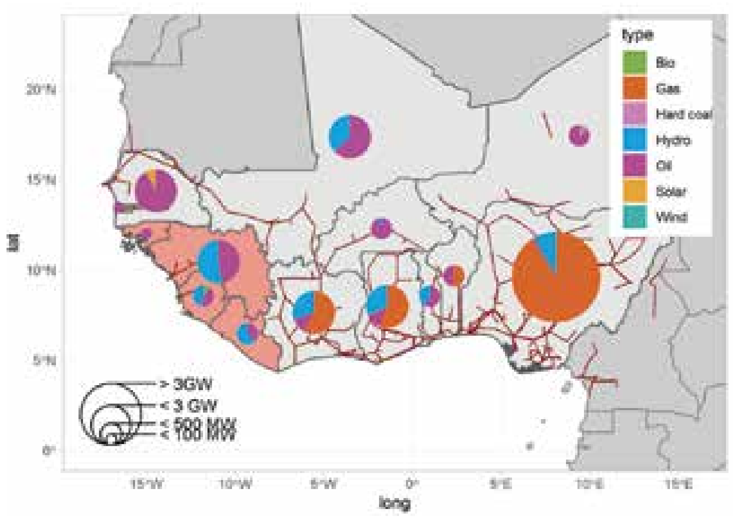
- Rainfall distribution is uneven across the basin. Accordingly, precipitation deficit variability shows a large gradient from the northern part of the basin (sub-desertic and desertic areas) to the Guinean part of the basin (where the headwaters of the Senegal River are located).
- Rainfall in the SRB is subject to a large interannual variability. Main shifts in annual precipitation during the last decades took place in 1969 (beginning of a multidecadal drought) and in 1994, when an increase of the mean annual rainfall was observed (not significant, partial rainfall recovery at the basin level).
- The analysis of precipitation trends in the upper part of the basin shows a significant, decreasing trend during the month of July (wet season). However, positive precipitation trends are detected in the central and northern part of the basin.
- High exposure and low adaptive capacity render the SRB highly vulnerable to climate change. No consensus has been reached regarding changes in average rainfall (except for the headwaters, where a decrease is probable).
- Expected changes in rainfall include an increase of inter-annual variability, intensification of rain events and changes in the duration and timing of the rainy season.

Precipitation deficit variability shows a large gradient from the northern part of the basin (sub-desertic and desertic areas) to the Guinean part of the basin (where the headwaters of the Senegal river are located). Upstream Manantali dam, the deficit variability is lower than 30% when a 5-year return period is considered (Cordano and Cattaneo, 2022). The analysis of precipitation trends in the upper part of the basin shows a significant, decreasing trend during the month of July. However, positive precipitation trends are detected in the central and northern part of the basin.

The SRB has been reported to be highly vulnerable to climate change, due to its high exposure and low adaptive capacity. Temperatures in West Africa are expected to increase by +3ºC to +6ºC at the end of the 21st century. However, no consensus has been reached with regard to an average increase or decrease of rainfall for any term or scenario (except for the Guinean highlands, where a decrease of precipitation is probable). Expected changes in rainfall across the basin include the increase of interannual variability, intensification of rain events and changes in the duration and timing of the rainy season (A&W, 2019). Projections for the upper Senegal basin show a general decrease of river discharge, runoff, actual evapotranspiration and soil moisture at the end of the 21st century, when available water resources could decrease by more than 50% under the RCP 8.5 scenario (Mbaye et al., 2015).

5.9.2.7 Water and energy

Figure 68. Current types of electricity sources available in the national power systems of the West African Power Pool for WAPP. Source: De Felice et al. (2019).



Currently, there are two operational hydropower plants in the SRB: Manantali (a 200 MW power station supplied by an 11 km^3 multipurpose reservoir) and Félou (a 62 MW run-of-river power plant) (Tilmant et al., 2020). Energy production in Manantali is estimated at 800 Gwh/year and in Félou at 350 Gwh/year (Bodian et al., 2020). However, as Manantali alone is only able to cover up to 18% of the total demand in the basin (estimated at 4,400 GWh/year), the OMVS has set the objective to expand the installed hydropower to reach 1,050 MW in 2025. By 2040, energy needs in the basin could reach 15,000 GWh (Thiam, 2016). Guinea has a low electrification rate and current hydropower exploitation is less than 2%, hence the OMVS plans to implement three new infrastructures by 2025 to ensure an installed capacity of 625 MW: Koukoutamba and Boureya dams and Balassa run-of-river hydropower plant (Thiam, 2016).

Besides, the country lacks cross-border transmission infrastructures, although they are currently under development (JRC Technical Report - De Felice et al., 2019). Mali is potentially expected to host other seven hydropower facilities (in addition to Manantali) to reach an installed hydropower capacity of 600 MW. Most of them are planned upstream of Manantali, on the Falémé and Bakoye rivers. The goal is to regulate the river flow (ensuring a minimum flow of 500

Water and energy – issues and challenges

- More than half of the population of Guinea, Mali and Mauritania lack access to electricity (in Senegal this percentage is near 30%). Manantali dam only covers a small part of the energy needs in the basin (18%). By 2040, energy needs in the basin could reach 15,000 GWh.
- Large development plans. The OMVS has set the objective to expand the installed hydropower capacity to reach 1,050 MW in 2025. Currently, hydropower is an important part of the energy mix in Guinea and Mali and further developments are under way, but this is not the case of Senegal and Mauritania (although a new hydropower plant is intended in the Falémé river in Senegal).
- The Banda Gas-to-Power project has the potential to change Mauritania's incentives to cooperate and invest in the subregional hydropower sharing mechanism of the OMVS (as the country will be transformed from a net consumer into a net producer).
- Bioenergy could be an interesting support energy source, specifically in rural areas, although the trade-offs between the different components of the WEFE nexus should be carefully considered.

m^3/s at Bakel) while producing hydropower for Mali, Mauritania and Senegal. As Félou and Gouina are intended as run-of-river facilities downstream Manantali, they do not contribute to river regulation (Thiam, 2016). The discovery of offshore gas in Mauritania and Senegal (Banda Gas Fields) has the potential to alter the regional energy distribution. The Banda Gas-to-Power project will turn Mauritania from a net consumer into a net producer. Therefore, the project can change Mauritania's incentives to cooperate and invest in the subregional hydropower sharing mechanism of the OMVS. Mali is already buying electricity to Mauritania, even if it also exports part of the production of the Manantali dam to Mauritania (due to an intergovernmental agreement under the OMVS) (Medinilla et al., 2019). In Senegal planned Gourbassi dam, which will be located in the Falémé river, will support the development of irrigated agriculture, navigation and energy production. However, its future capacity (2,100 Mm^3 and 30 MW) is limited by the morphological and geological conditions of the Falémé river (Thiam, 2016). According to the World Bank, access to electricity in 2019 ranged from 70.40% of the population in Senegal to 42.42% in Guinea (in Mali and Mauritania, it was 48.02% and 45.81%, respectively).

Guinea, Mali and Senegal belong to the West African Power Pool (WAPP) (Mauritania is integrated within the North Africa Power Pool, NAPP). In Guinea, main installed capacity corresponds to hydropower (310 MW) and oil (281 MW), while solar has less than 0.1 MW installed. Mali has 374 MW of installed capacity regarding to oil, 219 MW of hydropower and 1 MW of solar. Senegal lacks of hydropower capacity and mainly relies on oil for its energy supply (installed capacity of 511 MW). Solar in Senegal has 44 MW of installed capacity and a small share of biomass (less than 0.1 MW). Mauritania's energy mix is mainly dependent on oil (71%), followed by renewable energies (28%). Concretely, bioenergy is the main renewable energy source in Mauritania (95% of the share of renewable energies in the total primary energy supply in 2018, while solar and wind accounted for 3% and 2%, respectively). In this regard, bioenergy could be an interesting source of energy in the basin. According to Pastori et al. (2021), 7 million tons of crop residues were generated in the SRB in 2016, resulting in an electricity potential of 4.4 million MWh/year. However, trade-offs between the different components of the WEFE nexus should be carefully considered, as promoting bioenergy could result in an increase of the water demand (hence detrimental for other water users).

5.9.3 Summary map and list of priorities

In this section, a map on key challenges and a list of priorities are reported. For the SRB ranking scores are available currently only from NEPAD/UCAD. Given just one direct feedback on ranking scores it is important to point out that all issue identified are in general important and the choice of the different stakeholder would results always in different rankings. Stakeholder involved in the process were: EEAS-Dakar/Bamako/Conakry/Nouakchott and CoEs and experts (mainly from OMVS and UCAD).

- Management of alterations of the water cycle and increasing water demand
    - *Enhance multi-purpose usage of existing dams and improve hydro economic modelling and optimisation (Research and HCD).* An important development of the hydropower capacity is foreseen and planned by OMVS and the riparian countries. This will require an impact assessment of climate change, growing demands and navigation services. In this context, a focus in multi-purpose usage of existing and future dams must be enhanced.
    - *Assessment of current and future hydropower sites.* Consider efficiency of current and future hydropower sites: often located in dry regions, causing high water loss from reservoirs through evaporation
    - *Improve a concerted management among irrigation, natural flooded and rainfed systems: ensure flood recession agriculture and improve knowledge and mapping of recession cultures.* Fully control irrigation system (rice and big schemes) vs natural flooded area (recession agriculture) need a concerted management of river flow. Besides, demands should be carefully assessed in the context of new hydropower developments. Importance of dam management regarding flooding, maintenance of ecosystem services, groundwater levels and climate change adaptation. There is a need to enhance hydroeconomic modelling and optimisation knowledge and capability.
    - *Assessment of CC impact on coastal areas*. The coastal areas of the basin have been identified as one of the most vulnerable hotspots worldwide with regard to rising sea levels in a climate change context.
    - *Research for improving productivity and improve multi sectorial assessment*. Suggested further research on: adaptive management strategies for the middle valley under climate change, artificial flood regimes, spatial distribution of flood recession cultures, irrigated areas and flood forests, drought resistant crops or changes in the agricultural calendar (poor soil fertility management, moisture retention, improve mixed agricultural system and agroforestry, etc.).
    - *Improve groundwater monitoring and knowledge (Research and HCD)*. Monitoring of groundwater withdrawals and impact. Need to enhance knowledge of groundwater resources potential and modelling.
    - *Improve assessment of water demand and abstraction*. Shared data among riparian countries, spatial and temporal variability of demands.
    - *Improve assessment and monitoring of fishing sector.* Improve subsistence fishing industry and assessment of impact of decrease of biodiversity of fish species in the lower estuary.
    - *Enhance assessment and consideration of the navigation sector* on the river. Develop (improve) impact assessments regarding planned hydropower developments, considering climate variability and change, growing demands or competing uses (e.g., navigation).

- Adaptation to climate change and variability
  - *Reduce uncertainty among precipitation trends*. The analysis of precipitation trends in the upper part of the basin shows a significant, decreasing trend during the month of July (wet season). However, positive precipitation trends are detected in the central and northern part of the basin. Uncertainty remains high also for Global and Regional Climate Change modelling. High exposure and low adaptive capacity make the SRB highly vulnerable to climate change. No consensus has been reached regarding changes in average rainfall (except for the headwaters, where a decrease is probable).
  - *Improve knowledge of cropping system suitability and vulnerability to CC*: *soil fertility management, water productivity, mixed systems (crops, livestock, pasture, forest, fruit trees)*. The agricultural cropping systems are generally below expected productivity levels, even when irrigation developments are introduced: This can be associated with low nutrient and fertility management and loss of soil production capacity: increase knowledge of agriculture sector and about the identification of most suitable cropping system: more resilient and adapted to food security of local farmers (e.g., focus on recession agriculture and limitation of big irrigation schema, enhance the consideration of local mixed agro forestry system, etc.).
  - *Improve irrigation efficiency and soil moisture capacity*. Improve irrigation efficiency (specifically for bigger scheme) and develop supplementary irrigation for rainfed agriculture farming, along with the enhancement of crop fertility management to increase soil moisture capacity.
  - *Improve knowledge and agreement on landuse change and impacts*. Deforestation issues in the upper basin still require an agreed assessment. Uncertainty remains high and the debate about how land use changes are affecting the soil water-holding capacity in the headwaters of the basin (Fouta Djallon) is still ongoing. Concretely, quantifying changes between some land use classes using remote sensing products is challenging.
  - *Improve assessment of fishing sector***.** Improve subsistence fishing industry and assessment of impact of decrease of biodiversity of fish species in the lower estuary
  - *Improve protection of pastoral husbandry.*

- Addressing environmental and water quality issue
  - *Improve monitoring of water borne diseases, mining impact and of chemical pollution at river basin level.* Water quality is affected by (heavy metals) pollution and specifically by a rapid increase in the prevalence of water borne diseases, as impacted by river flow alteration (reservoirs mainly). Mining impact on water quality, specifically in the Falémé.
  - *Enhance standard monitoring of bacteria, parasites, nutrients and pesticides in the Delta*. Monitor the presence of faecal bacteria, parasites, nutrients and pesticides in the Delta region.
  - *Improve data collection, data sharing (Open data) and coordination at RB level.* Develop mitigation options to reduce the growth of water-borne diseases (integrate health issues within the WEFE Nexus framework): collection of population-level data on disease prevalence, support to measure and monitor the impacts of dam development, coordination of efforts across riparian countries and implementation of new mechanisms to integrate multiple goals regarding policies, assessments and operations.
  - *Assessment of environmental issues such as desertification, bush fires, wetland degradation, soil salinization.* Other pressing environmental problems include desertification and bush fires, wetlands degradation and the modification of the estuarine hydrodynamics. The area covered by salinised soils grew during the 1968-1990 drought period.

- Water and energy
    - *Improve transboundary water agreement*. Assessment and identification of solutions to solve transboundary water disagreement.
    - *Enhance renewable energy development and use.* Explore solutions using renewable energy: bioenergy - PV – hydropower - floating photovoltaic system.
    - *Enhance inclusion of socio economic aspect, specifically for hydropower management.* Increase consideration of ecosystem and socioeconomic aspect in feasibility assessment of new dam and reservoirs.

- Governance/Institutional
    - *Improve transboundary collaboration*. A key need is for the development of a Basin-Level Strategy Response Framework (specifically for water demand and hydropower development). River basin authority needs tools and methods to proactively respond to changing climate conditions to prevent adverse impacts on the communities that rely on water resources provided by the SRB.
    - *Data and knowledge sharing at river basin level*. It is important that all countries collaborate and share data and knowledge to derive accurate estimates of the volumes of water that each state may justifiably require in the coming decades. Coordinated and harmonised water use monitoring, data collection and management as the basis for effective basin operations and management, including at the national levels of the riparian states.

- Summary of first stakeholder involvement:

The key priorities highest ranked (extremely important) are:

- *Improve multi-sectorial assessment*, specifically in the context of adaptive management strategies for the middle valley.
- *Improve monitoring of water borne diseases.*
- *Improve transboundary collaboration, data and knowledge sharing at river basin level.*

Other important priorities ranked as very important by *NEPAD/UCAD* are:

- Enhance multi-purpose usage of existing dams (improve for example concerted management of irrigation, natural flooded and rainfed areas); Improve soil fertility management and awareness; assessing impact of mining activities: assessment of wetland and land degradation (including soil salinization, erosion, bank erosion, etc.).

More specifically NEPAD-UCAD points out the importance to distinguish key issues that address and impact in the whole catchment (and links with riparian's countries strategies and environmental policies) from other more specific to local or regional conditions.

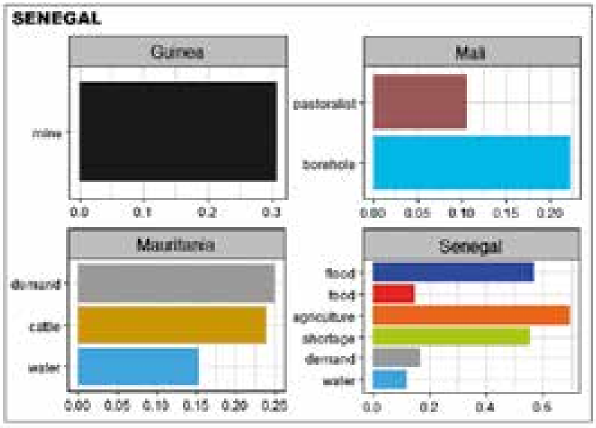
The ones linked and impacting the whole basin may be summirised as: the data and knowledge sharing at River basin level; the improvement of Transboundary collaboration; the improvement of the waterborne disease monitoring; the Coordination of the water use monitoring, research in improving productivity: it is quite urgent to tackle those issues in priorities although the gap between populations understanding and strategies needed or undergone can be considered as very important in many cases. Research at the catchment level should work out the relationship or nexus of water, energy, food security and environment both at the upstream and downstream Senegal river basin.

On the other side researches can be conducted on more specific and local issues, for example on the mid valley and the estuary area and could focused on the following themes: the assessment of the impact on climate change and attention could be made on the enhancement of the MULTI-PURPOSE USAGE OF EXISTING DAM; the Improvement of the management irrigation, researches could find issues to facilitate the co habitation on the artificial irrigation with the natural flooded and rainfed agricultural system;

enhance hydro economic modelling and optimisation knowledge and capability (research can be set up to find out the relationship between the Importance of dam management regarding flooding, maintenance of ecosystem services, groundwater levels and climate change adaptation. Accents need to be developed for the restauration of the environment in the mid and low valley.

Most recurrent water related keywords per country in the river basin:

Figure 69. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



RIVER BASIN 8

LIMPOPO

5.10 River Basin 8 – Limpopo

5.10.1 Introduction

The Limpopo River Basin (LRB) is situated across four riparian countries (namely Botswana, Mozambique, South Africa and Zimbabwe). The LRB supports 18 million people in total and has a catchment area of approximately 408, 000 km^2.

The Limpopo River starts at the confluence of the Marico and Crocodile Rivers (in the Limpopo Province of South Africa) and flows north to form the border with Botswana. Later, it arcs east and is joined by the Shashe River to form the border with Zimbabwe. From here it flows down the Great Escarpment and east into Mozambique at Pafuri, across the coastal plateau to the Indian Ocean at Xai Xai. The Olifants River, which originates near Witbank and then runs east across the southern portion of the basin, joins the Limpopo River in Mozambique just after Massingir Dam.

Figure 70. Limpopo river basin.

Many of the people who reside in the LRB depend primarily on rainfed agriculture for food and income. The challenge of variable rainfall in the basin and unreliable water availability makes rainfed farming difficult for these subsistence and livelihoods purposes, which are further threatened by increasing temperatures, unstable rainfall patterns and growing water demands from agriculture, industry and urbanisation. In this context, it is necessary to work with smallholder farmers and find sustainable ways to diversify their agricultural production and strengthen their livelihoods (Nyikadzino et al., 2020).

Chisanga, et al. (2022) have stressed that, while increasing trends in rainfall will likely result in an augmentation of water in the basin, rising demands from population growth and associated activities put constant pressure on water resources. Seibert, et al. (2017) pointed out that historical inequalities in the basin have further removed smallholder farmers from policy processes and hampered equitable access to natural resources, including land and water.

The main challenges in the LRB were most recently summarised in the Resilience in the Limpopo Basin (RESILIM) Program 2019 Evaluation Report (Hellmuth, et al., 2019) and are stated to be:

- climate change;
- water quality;
- water supply deficits;
- agricultural productivity; and,
- ecosystem health.

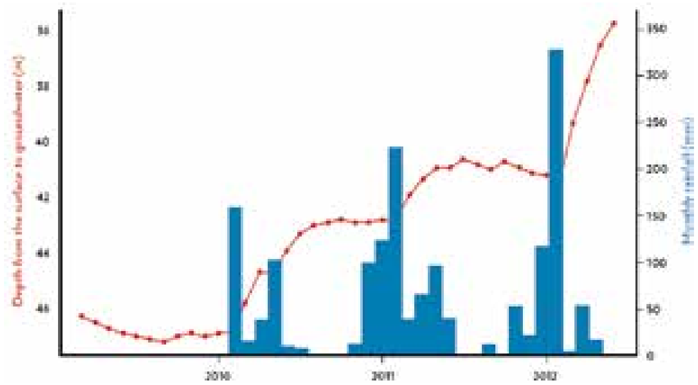
The report, which covers the period since the commencement of the RESILIM program in 2012, states that almost a decade later these challenges are still seen as a threat to the development of the basin and its residents. This is evident, because rural poverty generally remains widespread and persistent. There have been several attempts to improve the basin conditions by different institutions, with a paradigm shift focus from expecting more water supplies to instead, manage the available water better.

5.10.2 Key issues and challenges

5.10.2.1 Hydrology

The Limpopo River basin is located in a region classified as arid to semi-arid, where water resources are under huge pressure from the environment alone, even before human development demands are factored in. The water resources of the LRB are shared by four countries, with significant portions of each country and national populations contained within the basin boundary. The water resources support a large population and significant economic activities, such as agriculture, all of which depend on water for survival and growth (Fallon, *et al.*, 2019; Mothapo, 2020).

Figure 71. Groundwater levels respond dramatically after heavy rainfalls, indicating that most groundwater recharge takes place after these rainfalls. Source: USAID Report, 2014.



Like several other river basins in Southern Africa, no natural, perennial lakes exist within the LRB. There are numerous dams (impoundments) of various sizes distributed across the basin, serving a variety of purposes. The building of dams in the basin has led to an increase in the interaction between groundwater and surface water. This is a huge change of course for most periods of the year, with the lower and some middle reaches in the LRB running dry while the water instead flows into the alluvial aquifer of the riverbed. While there are some proposals related to hydroelectric power generation, all the dams located within the LRB are utilised for water storage for domestic, agricultural and industrial (mining) use (Mothapo, 2020). Each country in the LRB has its own surface water monitoring infrastructure and procedures, which vary to some degree in extent and timeframes, but follow similar methods. The resources in the LRB are shared as follows: South Africa (45%), Zimbabwe (15%), Mozambique (21%) and Botswana (19%). According to the Limpopo River Awareness Kit, the foundation of the analysis of the surface water resources of the LRB is incorporated in a monthly catchment modelling package (the Water Resource Simulation Model). The river basin has 24 distinct main tributaries, although there is the proposal for a further subdivision to create 27 more equally sized and geographically homogenous sub-basins (Mosase et al., 2019).

Hydrology – issues and challenges

- Groundwater management, including poor groundwater quality. The overexploitation of groundwater, especially in the South Africa region, highlights the need for effective monitoring and management of groundwater resources (including the implementation of policies addressing the protection of groundwater resources, while accounting for the rights of Limpopo residents to water).
- Recharge issues. Decreased soil moisture (due to weather and climate change) results in slower recharge of aquifers.
- Data and monitoring systems and methodologies. Lack of adequate and consistent surface water monitoring infrastructure and procedures to generate high-confidence data.
- Governance. Need for an integrated basin approach to improve data collection, validation and overall basin water resource management (surface and groundwater).

Most of the surface water flow originates in the Drakensberg Mountains and South African highveld, feeding the Crocodile, Marico and Olifants Rivers. The contributions to the overall flow of the Limpopo River are, to a lesser extent, determined by rainfall in the river basin (Botai et al., 2020).

The rainfall in the basin is heterogeneous, with some sub-basins receiving less than 400 mm on average and other downstream sub-basins in Mozambique receiving over 750 mm annually. Even meteorological stations located in close proximity to one another demonstrate substantial spatial variation within sub-basins. The basin has experienced severe droughts in the last decade. In addition to the variation in the amount of rainfall, the timing, especially the start of the growing season, also varies significantly. However, there remain many questions about the reliability of rainfall data and other water measurements, due in part to the infrequent calibration and validation of field site measurements. The limited confidence in these data, combined with the substantial variation through time and space, necessitates an integrated approach to improve data collection, validation and overall basin water resource management (Sharp and Kahler, 2022).

Groundwater is used extensively throughout the LRB, supplying a large percentage of water for irrigation and rural water supply schemes (Mustafa, et al., 2021). Approximately 37% of people living in the Southern African Development Community (SADC) region rely on groundwater. This is the predominant source of water in rural areas located away from surface water resources. Groundwater is also used extensively by the mining industry in the basin (Nhassengo, et al., 2021). It plays an important role in water supply in rural areas of the South African portion of the LRB, providing domestic and irrigation water in the order of approximately 850 Mm^3/year, and many of the rural communities of this region are located on or near marginal aquifers with potential yields of 2 l/s (Mosase, et al., 2019). It is estimated that 117 million m^3 water is abstracted a year by rural communities in South Africa alone (CSIR, 2003).

Groundwater quality is relatively poor due to high salinity. The major issue of concern regarding groundwater resources in the LRB is overexploitation, especially considering the relative slow recharge rate of groundwater. Groundwater is primarily abstracted through boreholes and the actual number of boreholes may vary significantly (as many boreholes are not registered when drilled, or were drilled prior to the creation of national inventories).

5.10.2.2 Agriculture and food security

Farming is the most significant economic activity in the LRB, with a substantial portion of the people reliant on it for survival. One of the most difficult tasks faced by the Limpopo Watercourse Commission (LIMCOM) and the member states' national water management agencies, is balancing the water requirements for irrigation with water supplies for household and industrial usage while sustaining river environmental flows. Agricultural contributions to GDP in the LRB range from 4 to 5% in Botswana and South Africa, 15% in Zimbabwe, to 40% in Mozambique. Aside from monetary contributions, the significance of agriculture in terms of food security, income production, poverty alleviation and employment are critical for the well-being of many people in the basin (FAO 2004). Because of the biophysical features of the LRB, there are various obstacles to overcome regarding agriculture as a source of income. The region is mainly semi-arid, with little arable land and a low agricultural potential.

In Botswana, despite the fact that agriculture only accounts for 4% of the country's GDP, 65% of the population in the LRB lives on farms and relies on agricultural activities for a living (FAO 2004). The majority of agricultural operations in the basin are small-scale, with average farm sizes of 1-3 hectares (LBPTC 2010). According to the 1993 agricultural census, traditional or subsistence farming accounted for 99% t of arable agriculture (1993 census, GOB-MOA-CSO 1995; FAO 2004). This translates to 80,000 households engaged in arable agriculture, with the LRB accounting for 74%. With the growing population of the basin, the size of farm holdings has shrunk. Smaller holdings have compelled cattle farmers to change their methods. Ruminants range from typical cattle to tiny ones. In 1993, Botswana had 253 commercial farms, with 122 (48%) of them located in the basin. According to FAO (2004), these farms accounted for 43.5% of commercial livestock holdings and 69% of commercial arable agriculture holdings.

Figure 72. Subsistence agriculture in the Oliphants River sub-basin, South Africa. Source: Sitoe 2004.

In Mozambique, agriculture is the most important industry, employing 80% of the country's working population, 60% of whom are women (LBPTC, 2010). Small-holder farming, also known as family farming, accounts for 95% of all agricultural land. Almost every family in the Mozambican part of the basin engages in subsistence agriculture, with average farm sizes ranging from 1.1 to 1.4 hectares (LBPTC, 2010). In Chokwé, agriculture for food crops is the major farming system, with several modest and large-scale irrigation facilities. Because of the basin's biophysical features, agriculture in Mozambique is extremely vulnerable to drought and flooding, rendering those who rely on agriculture vulnerable and food insecure.

In South Africa, the LRB is partitioned into four water regions (water management areas - WMAs). In the Limpopo WMA, any land with potential for horticulture has already been established (DWAF, 2004a). Farming exercises generally happen in the focal and southern pieces of the WMA and are rainfed; notwithstanding, there are a few water system improvements in the WMA. The WMA is covered by vegetation utilised for animal feed, prompting overgrazing in certain areas. In the Luvuvhu and Letaba WMA, serious inundated agribusiness happens in the upper part of the Klein (Little) Letaba River sub-basin, downstream of the Middle Letaba dam and in the upper Luvuvhu River sub-basin (DWAF, 2004b). Farming is a significant wellspring of business to many people living in the Crocodile West and Marico WMA, however it does not contribute a lot (7%)to the generally speaking GDP (DWAF 2004c and DWAF 2004d).

In Zimbabwe, land use in the upper Mzingwane River basin (the part of Zimbabwe situated in the LRB) is generally related to business agriculture, while collective land and subsistence cropping system are located in the lower basin. Common land plots range in size from 0.5 to 14 ha (LBPTC, 2010). The mutual terrains are viewed as helpless, due to dryness and the presence of unsuitable soils to sustain rainfed agriculture. Their reliability is mostly beneath the food security limit. A large group of domesticated animals, including dairy cattle, goats, sheep and jackasses, is found in the basin.

Agriculture depends heavily on water, as it is a key factor in its success in the LRB (Gashu et al., 2019). Water scarcity has a direct effect and influence on food production. Irrigation is a restricting component in crop yields, and water for food is one of the most pressing challenges (Laura, 2016). Furthermore, because most people residing in rural communities work in the agriculture sector, they receive food and wages to support their families. This is reinforced by evidence from a variety of studies that show a substantial link between greater farming activities and reduced poverty (Njoko, 2014). Accordingly, the link between agriculture for food production (food security), as well as employment, is an important factor for rural socio-economic stability.

Although there is a scarcity of information on water for agriculture (concretely on its distribution and management, along with its implications on economic hardships), there is rising evidence of links between water used for agricultural activities and some indicators for economic hardship in the countries of the LRB, such as Botswana and South Africa (Beekman et al, 2003).

Agriculture and food security – issues and challenges

- Balancing the water requirements for irrigation with water supplies for household and industrial usage while sustaining river environmental flows.
- Agriculture and socio-economic well-being. Agriculture contributes to socio-economic stability through food production (food security) and employment generation. Rising evidence of links between water used for agricultural activities as an indicator for economic hardship in the countries of the LRB. However, information on water distribution for agriculture and its management thereof is scarce, notably regarding its implications on economic hardships.
- Education and capacity building. The food industry and production channels drive food production, thus these and other entities must be involved in solving food security challenges at the most basic level. To achieve maximum cooperation on production and sustainability, institutions, small - scale farmers and communities must increase awareness and training.
- Implementation of policies. Increase participation. State agencies, local governments, farmers' associations, and other agricultural stakeholders should be involved. Water scarcity may be addressed internationally by bringing together a variety of parties and state entities.
- Estimations of projected changes in water demand at river basin level.
- Diffusion of alternative practices and capacity building: for example, regenerative farming practices to improve the land's moisture retention and drought resistance.

Water shortage is a severe problem in the province of Limpopo (Maponya and Mpandeleni, 2016). Since the province is in a semi-arid region with inconsistent rainfall, it has a detrimental impact on the agricultural sector, resulting in decreased agricultural operations, livestock losses, a lack of drinking water, low yields, and a scarcity of seeds for following agricultural production. This was further confirmed in 2015 by the South African Limpopo Province Department of Agriculture, which declared it a drought disaster area. Although Limpopo is a drought-prone province that experiences drought on a regular basis, it experienced limited water supplies for irrigation were available during the severe 2015 drought, which had a significant impact on the agricultural industry (Maponya and Mpandeli, 2012).

Population expansion and lifestyle changes in the basin contribute substantially to water and agricultural demands in the LRB (Daus, 2019, Nephawe, et al, 2021). By taking care of the land, farmers can assist to lessen the likelihood of water shortages. Farmers can utilise organic matter in soil through regenerative farming practices to improve the moisture retention of the land and drought resistance. The soil is much more stable and less prone to be washed away by storms. Lastly, farmers can encourage organic and conversional farmers to participate in regenerative agricultural approaches.

5.10.2.3 Socioeconomic

Figure 73. Summary of socio-economic conditions and activities. Source: adapted from: LBPTC (2010).

Indicator	Botswana	Mozambique	South Africa	Zimbabwe
Population	69 % (1,21 M)	7 % (1,39 M)	22 % (10,72 M)	10 % (1,14 M)
Agriculture	65 % of the population.	80 % of the population	Rainfed subsistence farming	64 % of the population
	Mostly rainfed subsistence	coastal zone of Gaza province is favourable for agriculture	irrigation farming in the Limpopo, Luvuvhu and Olifants	55 % of these are subsistence farmers
	Small scale irrigated commercial farming in the Tuli	subsistence rainfed agriculture	Natural vegetation (livestockgrazing) and game farming in the Oliphants and Crocodile WMAs.	Irrig. Comm. farming in Upper Mzingwane
		Some irrig.comm.farming in Chokwé District		
Tourism	Games reserves, game farms and cultural sites.	Beach tourism	Kruger National Park.	
		National parks and game reserves.	Eco-tourism activities in the Olifants WMA.	
Mining/ Industry	A number of mines in Botswana.	Area within the basin endowed with natural gas.	All WMAs have mining activities.	
Source of income	Remittances. Rainfed agriculture(unreliable).	Remittances. Rainfed agriculture (unreliable).	Remittances. Rainfed agriculture (unreliable).	Remittances. Rainfed agriculture (unreliable)
	Livestock sales	Selling of cane, charcoal and firewood.	Irrigated commercial farming. Formal employment.	Livestock sales.

The LRB is a sophisticated multilateral system that currently sustains 18 million people in Botswana, Mozambique, South Africa, and Zimbabwe, which are all riparian republics. It is a major agricultural region with abundant mineral resources and a varied biodiversity. It also includes parts of South Africa's major urban and industrial centres. This river basin system is made up of diverse biological and social sub-systems that work together to create a hybrid snapshot of overall adaptability levels. In other words, the condition of these relationships reveals the basin system's ability (or inability) to withstand crises, which is a key indicator of its response.

Local sources of water are critical for rural development, employment creation, income extraction, and increased food security in South Africa. Consequently, agricultural productivity improvements do help to alleviate rural poverty by ensuring a stable food supply, lowering food prices, producing export income and thus increased income for farmers, increasing employment in the rural agricultural sector and farm salaries, and establishing links between farming and other rural economy drivers.

The LRB has a variety of socioeconomic activities, ranging from mining in rural areas to government, commerce, and retail in more developed and larger urban areas. Mining is present throughout the basin and with its expected increase this may result in the betterment of the economic conditions in the basin.

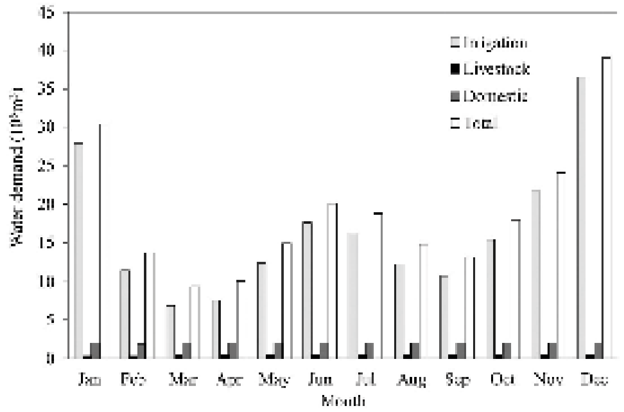
Macroeconomic conditions also vary across the riparian countries, with GDP (PPP per-capita GDP) ranging from $9 in Zimbabwe (inflation adjusted), $938 in Mozambique, $9,961 in South Africa, and $13,491 in Botswana (IMF, 2009). There are socio-economic disparities along the river from its source to its mouth. According to the 2007 Human Development Index values (HDI), the upstream countries of Botswana and South Africa are classified as Medium Human Development countries, whereas Mozambique is classified as a Low Human Development country (UNDP HDR, 2009). For Zimbabwe, there is insufficient data to establish a ranking. Since the HDI was first evaluated in 1980, all the riparian countries have improved their rankings: Botswana (0.94% yearly), Mozambique (1.34% annually), and South Africa (0.14% annually). Other metrics of human development, such as GDP and life expectancy, are higher in upstream riparian countries than in downstream ones, and literacy levels are high (above 82%, except for Mozambique, all countries average is 44, 4 %).

Socioeconomic – issues and challenges

- Assessment of the system condition (river health/ecological status). The diverse biological and social sub-systems of the LRB work together to create a hybrid snapshot of overall adaptability levels. The condition of these relationships reveals the basin system's ability (or inability) to withstand crises, which is a key indicator of its response.
- Research, communications and reporting. Continued research on water uses, conservation and protection of water resources. Information and results should be made available to all stakeholders.
- Moreover, research on water shortages should be conducted with the goal of informing academics, governments and the commercial sector about the findings, so that they can address the identified issues.
- Economic assessments. A cost-benefit analysis of water uses for different economic sectors is necessary, to understand the contribution of these sectors to development and socio-economic stability in the basin. In particular, manufacturing, mining and small-scale water use must be considered.

5.10.2.4 Water use, abstraction, demands

Figure 74. Monthly trend of water demand in Lower LRB based on the statistical information in 2015.Source: Nhassengo et al., (2021).



The LRB is characterised by water scarcity and a growing demand, arising from both rapid population and economic growth. Agriculture is the most important economic sector in the LRB, and irrigation is the greatest water user overall (about 50% of the total water demand). Because of its massive population (see table below) and consequently high agriculture and mining sector water requirements, South Africa is the main water user among the riparian countries. Although Zimbabwe's demands are nearly half of those of South Africa, urban supplies and irrigation dominate the allocation. Mozambique and Botswana are the countries that consume the least amount of water. Irrigation is the primary demand in Mozambique, while urban and rural water supply is the primary need in Botswana (LBPTC 2010).

The major cities of Gaborone, Francistown (Botswana), Pretoria, parts of Johannesburg and Polokwane (South Africa) and Bulawayo (Zimbabwe) are major water users, demanding water for their industry, power stations and municipalities. Outside of the cities, water is drawn from boreholes, wells, sand pits and dams to be used in agriculture. Rainfed subsistence agriculture is widely practised in the basin but, because of the unpredictable climate, this is often an unreliable source of food and income (LBPTC, 2010).

According to the Limpopo River Awareness kit, the current water demand in the South African portion of the Limpopo River basin is predominantly from the irrigation (49%) and urban sectors (22%), transfers to other basins (0.3%), and all other remaining water demands (such as rural, mining, power generation and afforestation) account for the remaining percentage. The general projections for future water use include increases in urban and rural supply, due to increased population and levels of service, and no other significant demand in water was expected from other sectors in the base year 2010.

Years later, water demand is still a concerning issue in the LRB. Nhassengo et al., (2021) summarised the monthly trend of water demand in Lower LRB based on the statistical information in 2015. Irrigation remained the highest water demand in all months, while livestock remained the lowest. Further findings suggest that the water demand within each of the national water management areas increased and varied based on land use. Currently, the Limpopo dominant water demands are based on irrigation, urban, industrial, mining and power generation.

According to RESILIM (Anon, 2016 and Anon 2017), the LRB is one of the most vulnerable transboundary basins in the Southern African region, because of water scarcity and climate-related risks, as well as its limited capacity to adapt. To date, the LRB is still categorised under basins characterised by higher water demand than supply. This led to paradigm shift from looking into ways to increase water supply to looking into ways to manage the available water.

Water demand – issues and challenges

- Poor current water use management. High vulnerability of the basin to water scarcity and climate-related risks, with a limited ability to adapt.
- Projected changes in water demand. Water demand higher than supply, due to growing population and poverty (which forces people to exercise farming).
- Increase of sectoral demands. Dominant water users (such as irrigation, urban, industrial, mining and power generations) are increasing their water demand.
- Required management approach. Paradigm shift: from looking into ways to increase water supply to looking into ways to manage the available water (e.g., increasing the use of recycled wastewater, implementing drip irrigation versus flood irrigation methods, improving end-use efficiency of water and/or the availability of water per capita, through enforcing catchment protection and ecosystems conservation.
- Water balance. Management of sub-basin water transfers.

A cost benefit analysis (CBA) of Water Demand Management (WDM) options for the LRB was undertaken, with the goal to understand households and farmers preferences in adopting and using WDM options in the basin, and to assess their ability and willingness to make trade-offs and adapt when faced with reduction in water supply. The results suggested that there will be continued increase in water scarcity. In an effort to mitigate that, eight WDM interventions were proposed (of which the focus was mainly on four):

- Increase the use of recycled wastewater,
- Implementing drip irrigation versus flood irrigation methods,
- Improving end-use efficiency of water, and
- Improving the availability of water per capita, through enforcing catchment protection and ecosystems conservation.

5.10.2.5 Water quality, health, and environmental issues

The most fundamental human needs or uses of water are drinking, cooking and sanitation. To meet these needs, the quality of the available water must pose no risk to human health. The quality of water also affects the condition of ecosystems upon which all living organisms depend.

The amount of water available is limited due to several variables, including a semi-arid environment, water pollution and international sharing obligations among riparian states. This is exacerbated by the strain on the water supplies caused by long-term population expansion, high evaporation rates that surpass rainfall, and economic development (Hedden and Cilliers, 2014).

A study by Hattingh and Claassen (2008) indicates that water quality has been largely ignored, especially in terms of policy instruments to enable and empower authorities to protect and manage this critical aspect of freshwater. The first movements in this direction in Southern Africa occurred in 1961, when the South African government implemented effluent guidelines and eventually special effluent standards in 1991.

According to Hughes et al. (2011), climate variability and change are predicted to exacerbate current water stress in many parts of Africa. Various human activities, such as mining, coupled with the lack of good administration practices in the riparian countries, have an impact on the basin. This could have a considerable influence on other users, as well as on the health and integrity of aquatic ecosystems (Ashton et al, 2001).

In the LRB, reduced water supply owing to pollution, inefficiencies in water management interventions, poor governance, water that is unaccounted for, and lack of infrastructure maintenance must be successfully handled (Department of Water Affairs, 2013). Accordingly, a comprehensive water resource management strategy is required, considering all elements or activities that have the potential to influence water quality. Pollard and du Toit (2011), who have intensively studied the LRB over a number of years define this as "a practice-based understanding of policy, the role of leadership and communication, effective governance, collective action and regulation, self-regulatory procedures, and feedback to all concerned".

Water quality – issues and challenges

- Governance and management. Effective execution of relevant laws and treaties in order to further improve long-term environmental protection.
- Monitoring, compliance and enforcement. By improving monitoring of discharge impacts and compliance enforcement, other land uses that may pose a serious threat to natural resource protection and the cultural landscape can be effectively regulated.
- Monitoring programme for the water system. Water resources in this catchment must be monitored on a regular basis (biomonitoring, chemical, physical, biological and microbiological).
- Land use impacts assessments on water quality. Carry out research to discover the most effective strategies to execute socio-economic activities, while maintaining the quality of the environment.

According to a study by Ashton et al. (2001), water resources in most of the sub-catchments of the LRB are impacted by:

- Mining and minerals processing.
- Landfills and solid waste disposal sites.
- Disposal of liquid and effluent.
- Non-point domestic effluent via soak-aways in rural areas.
- Non-point impact of irrigation and redistribution of river waters.
- Non-point impact from commercial or subsistence agriculture.
- Fuel loss and litter on roadways.

In fact, the Olifants River in the South African portion of the LRB has been described as one of the most polluted rivers in Southern Africa. This is the subject of a study being undertaken by the CSIR (South Africa) in the Upper Olifants River.

5.10.2.6 Climate change and climate variability

Studies across the basin areas of all four riparian countries confirm that significant warming has occurred over the last few decades. Extremely hot days have significantly increased and extremely cold nights have become fewer. The most recent analysis of rainfall trends for the South African part of the LRB (SANBI, 2019) shows that there is a tendency for reductions in rainfall at most stations in autumn, and fewer rain days in summer and autumn. Increases in high rainfall events suggest a possible increase in rainfall intensity.

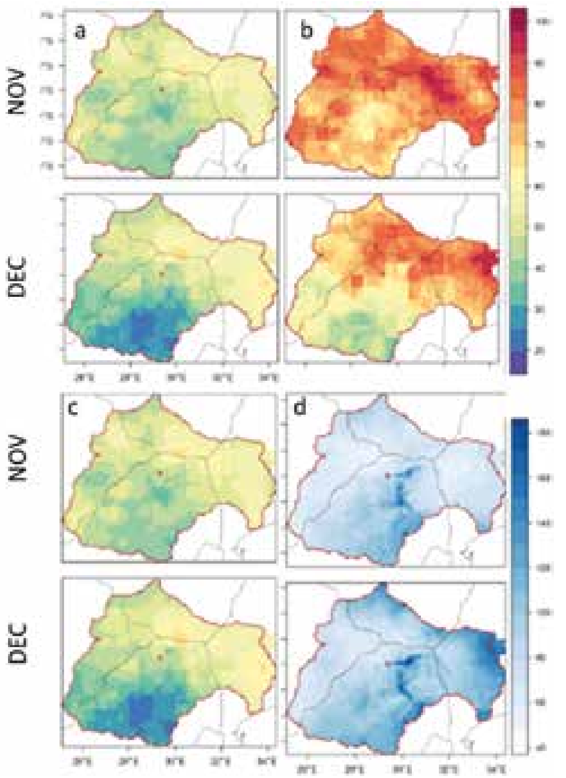


Figure 75. Precipitation Deficit in Dec. and Nov.: (a) 5 yr return period (b) 20 yr return period; (c) variability; d) Mean Monthly Precipitation. Source: Cordano et al., (2021).

In the core interior regions of Southern Africa, temperatures have risen by around 1.6 degrees Celsius over the previous century. In the summer months, maximum temperatures in the LRB climbed by 1 to 1.4 degrees Celsius, with the southern and western parts experiencing the greatest increases. Climate in the LRB varies from tropical rainy in Mozambique's coastal plain to tropical dry savannah and tropical dry desert further south of Zimbabwe. The annual rainfall ranges from 250 mm in the hot, dry western and central areas to 1,050 mm in the high-rainfall eastern escarpment areas. The rainfall is very seasonal and unevenly distributed spatially, with nearly all of it falling between October and April and being concentrated in a few isolated rain days in isolated areas. Because yearly rainfall occurs mostly during a brief summer rain season with substantial inter-annual variability, rainfall features limit crop output.

Several studies have been conducted in the basin to evaluate the impacts of climate change. Mosase (2018) conducted a study to evaluate annual and seasonal variations of rainfall and temperature in time and space from 1979 to 2013 in the LRB. Average annual rainfall varied between 160 and 1,109 mm, generally from west to east of the basin during the study period. In terms of temperature, minimum annual and seasonal temperature means gradually increased from west to east and from south to north of the basin, ranging from 1.9 in winter to 22.8 ◦C in summer. Overall, the analysis of minimum temperatures on an annual basis and for the winter and spring seasons show upward trends during the study period, while minimum temperatures for summer and autumn showed decreasing trends.

Similar results were observed in a study by Botai et al. (2020) who evaluated the projected future climate and anticipated impacts on water-linked sectors in the transboundary LRB. The study showed that the basin is likely to experience frequent dry and wet conditions, which can result in drought and flash floods. Projected rainfall and runoff trends for the LRB in

Climate change and variability – issues and challenges

- Current and projected temperature changes. Extremely hot days have increased significantly, and extremely cold nights have become fewer. This has resulted in increased dryness of the land due to decreased rainfall, increased temperatures and increased evaporation.
- Rainfall trends. The most recent analysis of rainfall trends for the South African part of the LRB shows that there is a tendency towards rainfall reduction at most stations in autumn, and fewer rain days in summer and autumn.
- Rainfall projections. Increases in high rainfall events suggest a possible increase in rainfall intensity. Droughts and flash floods may become more frequent (hence management strategies for these events are needed).
- Required interventions. Need to enhance transboundary water and biodiversity management, within the constraints of climate change, to enhance the resilience of the ecosystems and people in the LRB.

the study by Nyikadzino et al. (2020) show that the basin is experiencing frequent dry conditions, which include decrease in streamflow under the current climatology. The conditions are projected to continue in both the near future and towards the end of the century, with the prolonged dry conditions translating into potential droughts in the basin. The average annual precipitation ranges from 200 mm in the hot, dry regions of the basin (near the junction of the Limpopo and the Shashe rivers) to 1,500 mm in heavier rainfall places like the Drakensberg escarpment. Because of the orographic effect, where wet air is pushed to cool quickly when air masses pass over areas of greater relief, this area receives a lot of rain. Rain falls on the windward side of the relief area because of the rapid cooling. In these situations, the leeward side of the relief often receives less rain than the rest of it, which is referred to as a rain shadow.

5.10.2.7 Water and energy

Conventional electricity generating sources, such as coal, utilise a lot of water, whereas hydropower allows the water to be reused downstream. Several vast hydroelectric projects, on the other hand, necessitate the construction of dams, which dramatically modify the flow and flood extensive amounts of land, including wildlife habitat and flora, resulting in significant environmental repercussions. Small-scale hydro projects, such as run-of-river, divert only a section of a river, avoiding flooding and the need for reservoirs, resulting in lesser environmental consequences.

As per the World Bank World Development Indicators, the source of energy within every country in 2006 was as follows (World Bank 2010):

- Botswana - 99 % coal
- Mozambique - 99 % hydropower
- South Africa - 93 % coal, 5 % nuclear, 2 % hydropower
- Zimbabwe - 43 % coal, 57 % hydropower

Botswana and South Africa rely largely on coal for their energy, whilst Mozambique is entirely dependent on hydroelectricity, and Zimbabwe is evenly split between coal and hydropower.

From 2004 to 2008, a policy reform was implemented in Botswana to improve energy self-sufficiency and regulate efficiency and access. The government's goal included encouraging renewable energy policies, such as employing solar for electricity generation and water heating when cost-effective.

Despite the fact that Mozambique has the world's largest hydroelectric project (the Cahora Bassa dam on the Zambezi River), there are no known renewable energy power generation sources in the Mozambique portion of the Limpopo River basin.

> **Water and energy – issues and challenges**
>
> - Status quo. Issues arising from the dependence of hydropower on water availability and the semi-arid nature of the LRB.
> - Ecological impacts. Destruction and rehabilitation of natural ecosystems and effects on the already existing social and natural habitats.

South Africa has a lot of renewable energy resources that it may tap into to fulfil future energy demands. The government released a paper on Renewable Energy Policy in 2003, setting a goal of 10,000 GWh of renewable energy contribution to final energy consumption by 2013. Biomass, wind, solar, small-scale hydro, and non-grid technologies such as biofuels and solar water heating will be used to meet this goal. South Africa's good to exceptional hydropower potential is concentrated in the southeast, but potential in the LRB is limited to the east side of the basin, with mediocre to acceptable potential.

5.10.3 Summary map and list of priorities

From the number of various studies and analyses undertaken in the LRB over the last two decades, the priorities listed below have consistently emerged as ongoing ones requiring concerted attention. Climate change projections have now sharpened the focus on these priorities and heightened concerns about the impacts which are most severe and evident for most of the rural population in the LRB at the subsistence and small livelihood socio-economic levels.

Past interventions have not proven to be effective in addressing these priorities and their impacts to date have been enduring. The key priorites identified in the assessment and integrated by stakeholder of the river basin specifically consulted (EEAS-Gaborone (Botswana), EEAS-Maputo (Mozambique), GIZ and CSIR (Sethal)) are:

- Management of the increasing water demand especially for agricultural purposes (commercial and subsistence), due to increasing population in the basin and for the export market:
    - *Enhance groundwater exploitation and improvement of groundwater infrastructure.* Groundwater exploitation need to be increased due to lack of enough suitable surface water supply; and because of limited development of groundwater infrastructures.
    - *Improve data collection and validation.* Improved data collection and validation and overall management of water resources at river basin level and with the coordination and collaboration of all riparian countries.

- Addressing water quality issues.
    - *Assessment of groundwater quality and salinity issues* Groundwater resources are extremely important to support development and water requirements but they are mainly affected by a poor quality due to the overexploitation and increasing salinity.
    - *Improve data knowledge, collection and monitoring.* Build a comprehensive water resources management strategy to address pressures on water supply that affect water quality. Water quality monitoring system to study elements or activities that more influence water quality are needed. Also supporting data for drivers of pressure and contamination need to be improved at river basin level (such as population growth and density, economic development indicators, water abstractions and sectorial uses, etc.).

- Climate change impacts
    - *Improve knowledge of CC and CV impacts.* Improve knowledge of climate variability and change which impact on the increasing unreliability of water availability and rainfall variability.
    - *Improve crop productivity and sustainability.* Contribute to a detailed analysis of the balance that must be struck between water needs for irrigation and water supply for households and industry, while sustaining environmental river flows.
    - *Improve water infrastructure resilience.* Contribute to address the disaster risk reduction, improve water infrastructure while improve the water storage.
    - *Natural hazard assessment in Mozambique.* Adaptation strategies to reduce impact of natural hazards in Mozambique (cyclones, floods, droughts).

- Assessment of socioeconomic aspect and sustainability
    - *Improve knowledge and assessment capacity of socioeconomic and sustainability indicators.* In Zimbabwe for example: no Human Development Index (HDI) and no data supporting capacity building, tools and methodologies.
    - *Support climate-smart agricultural practices to strengthen rural livelihoods and food security in the basin.* Water security requires investments in livelihoods of rural communities in the basin. Next to irrigation, climate-smart agricultural practices that help small-holder farmers adapt to global warming and rainfall variability, are key.
    - *Ensure sustainable management and support to transfrontier conservation areas.* The basin includes important transfrontier conservation areas (incl. *Kruger*) that are key for the biodiversity, wildlife and livelihoods of the population through tourism-related jobs (see also Chobe RB report).

- *Enhance assessment of social impact of subsistence agriculture.* Social management of negative impacts on subsistence agriculture, as resulting from recurrent droughts, increasing fertiliser prices and degradation of agricultural land.
- *Environmental degradation.* Environmental degradation (deforestation, inappropriate land use practices) in the upper basin causes erosion, sedimentation and changes in environmental flows downstream.
- *Reduce inequality across riparian countries.*

- *Water and energy*
    - *Enhance renewable energy contribution.* Explore solutions using renewable energy: Bioenergy - PV.

- *Coordinated basin water use monitoring, data collection and management*
    - *Improve transboundary collaboration.* Coordinated water use monitoring, data collection and management as the basis for effective basin operations and management, including at the national levels of the riparian states.
    - *Improve policy instruments to manage water governance at river basin level.* Missing policy instruments to enable and empower authorities to protect and manage critical aspects of freshwater.
    - *Development of an effective basin-wide water allocations and management plan.* To support socio-economic development in the sovereign riparian states and basin, focusing on economics - and cost-benefit analysis of sector uses and benefits.

Water Governance and Basin Water Use Monitoring, Data Collection and Management are cross-cutting enablers for all the basin priorities as both provide a basis for a coordinated and proactive approach to basin planning, management and key interventions implementation for integrated programmes such as IWRM, WEFE, Circular Economy and overall Green Transition.

Figure 76. Framing Schema (green = opportunities; red = risks; black = ongoing attention; orange = need).

- Summary of notes from stakeholders.

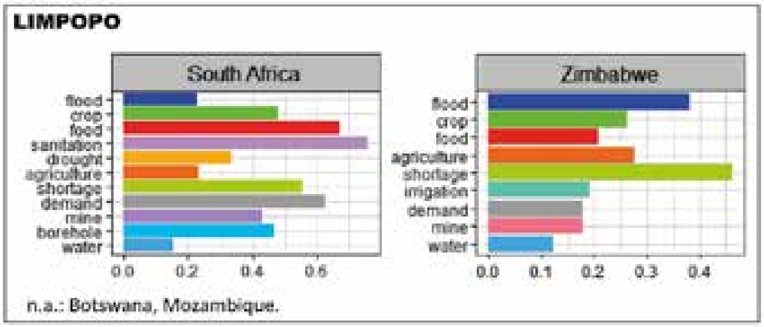
The key priorities highest ranked (extremely important) and pointed out by several stakeholders are:

- *Improving data collection and validation (including groundwater, water quality);* According to GIZ indeed a basin-wide Data and Monitoring System that will aid evidence-based decision-making is a key investment under any transboundary water management /governance approach. This should ideally integrated all relevant aspects, including socioeconomic data, ground- and surface-water as well as water quality indicators. Concerning pollution GIZ highlights the importance of assessment of industries and mining impact specifically in the basin's urban areas. This should form the second priority area for key investments of the TEI (the other one being rural livelihoods).
- *Improving transboundary collaboration* and development of a *water allocation plan* at basin level. GIZ note: a basin-wide Data and Monitoring System that will aid evidence-based decision-making is a key investment under any transboundary water management /governance approach.

- *Some key priorities added by EEAS-Maputo: Environmental degradation* (Critical, in view of ecosystem services provided by the basin, on which large part of population depends , and key importance for biodiversity , and economic sectors (tourism)); *Assessment of social impacts on subsistence agriculture* (Livelihood dependence of majority of rural population on agriculture, highly vulnerable to weather events and low productivity, results in food security very high , vulnerability , poverty trap.); *Reduce inequality across riparian countries* (Unequal access to services and public investment and infrastructure is a key driver, as well as private investment concentrated in capital-intensive sectors, contributing very little to diversification of agriculture or the development of value-chains.). *Natural hazards in Mozambique* (Droughts are particularly frequent and cyclones are common); *Improve water storage*. *Improve water infrastructure resilience* (Lack of funds to invest in water infrastructures);
- *Some key priorities added by EEAS*-Gaborone*: Support climate-smart agricultural practices* to strengthen rural livelihoods and food security in the basin (Water security requires investments in livelihoods of rural communities in the basin. Next to irrigation, climate-smart agricultural practices that help small-holder farmers adapt to global warming and rainfall variability, are key). *Ensure sustainable management and support to transfrontier conservation areas.*

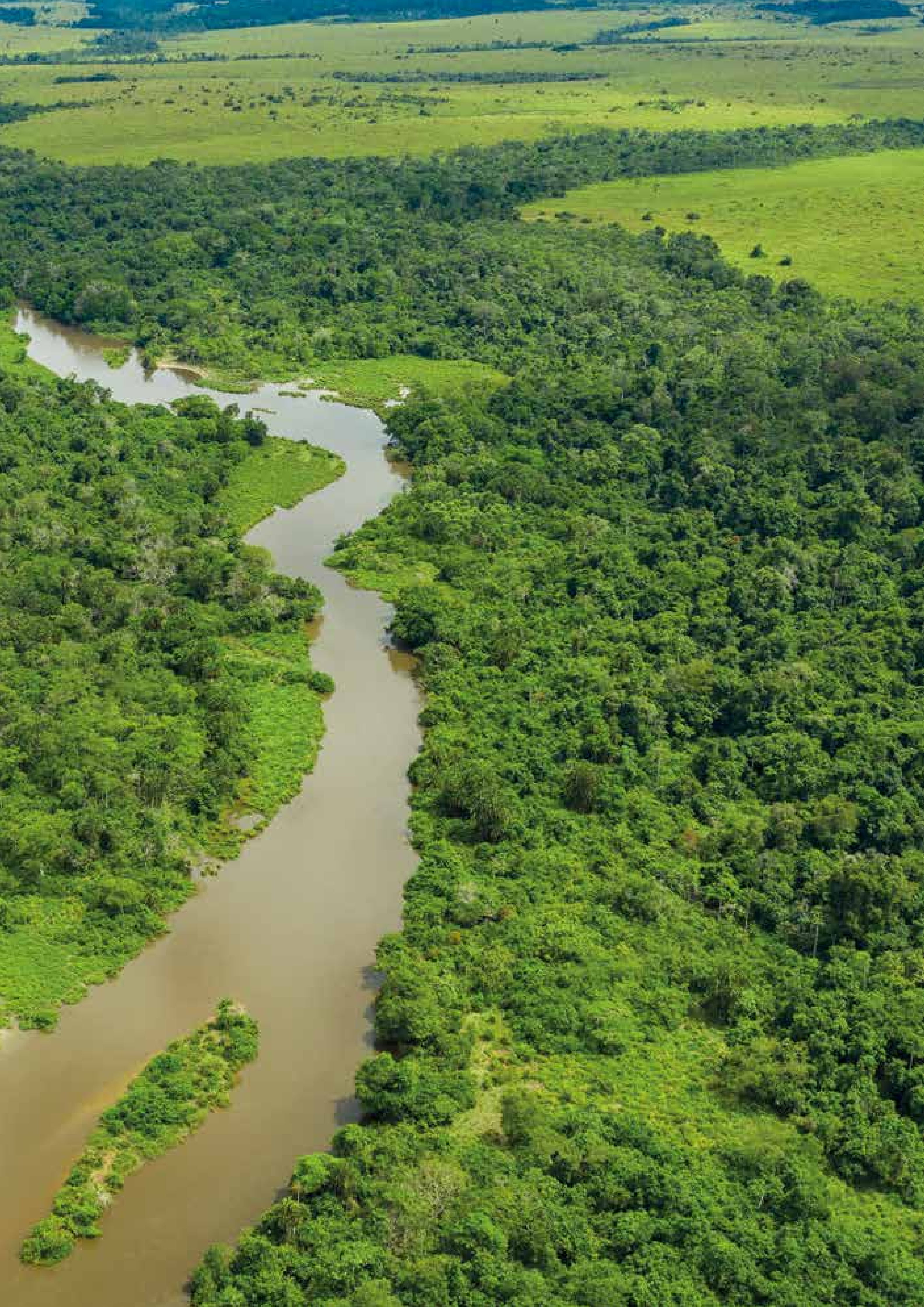
- Most recurrent water related keywords per country in the river basin:

Figure 77. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



RIVER BASIN 9

TANGANYIKA



5.11 River Basin 9 – Tanganyika

5.11.1 Introduction

Global significance of Lake Tanganyika is undoubtedly justified: it is the world's longest lake (673 km); the deepest lake in Africa (maximum depth of 1,470 m) and the second deepest one in the world (after Lake Baikal). Besides, Lake Tanganyika holds approximately 17% of the world's unfrozen surface freshwater, which makes it the largest lake in Africa by volume (it is the second lake in Africa by surface area, after Lake Victoria). The lake is also one of the most diverse freshwater ecosystems worldwide, as almost 1,500 species of fish, invertebrates and plants (out of which 600 are endemic) inhabit it (Masi et al., 2016). However, only 6% of its coastline is protected by four national parks with different levels of protection: Rusizi (Burundi), Nsumbu (Zambia) and Gombe Stream and Mahale Mountain national parks in the Kigoma region of Tanzania. Concretely, the latter ones aim at the conservation of both the lakeshore Miombo woodland and littoral zone, and about 93% of Tanzania's endangered chimpanzees live in Mahale; Britton et al., 2017; Future Water, 2015). In 2017, the Global Nature Fund declared Lake Tanganyika as the "Threatened Lake of the Year", due to the multiple challenges it faces as a result of its rapidly expanding human population and poverty (overexploitation of biological resources, pollution, and destruction of natural habitats or proliferation of invasive species such as the Water Hyacinth).

Figure 78. Tanganyika River basin.

The Lake Tanganyika Basin (LTB) covers an area of around 231,000 km^2 and it is shared by five countries: Tanzania (67%), Democratic Republic of the Congo (DRC) (16%), Zambia (7%), Burundi (6%) and Rwanda (4%). In 2003, all the riparian countries (except for Rwanda) adopted the Convention on Sustainable Management of Lake Tanganyika and the Lake Tanganyika Authority (LTA) was established in 2008. The LTB has a low population density (near 43 inhabitants/km^2, although it is much higher in the northern part). About 1.5 million people are concentrated in the main cities of the basin (Bujumbura in Burundi, Kigoma in Tanzania, Mpulungu in Zambia and Kalemie and Uvira in DRC) and agriculture is the main economic activity, followed by fisheries, commerce and light industries (such as food processing). In this context, although land use changes have not been significant at regional level, they have been drastic around the major towns (especially in the northern area, where a farming hinterland around the cities of 6 km in width and more than 40% of arable land density has been observed; Xu et al., 2020). Woodland clearance and agricultural practices in the catchment are believed to be the main drivers of the current increase of suspended solids entering the lake (when compared with historical rates), which is reducing its biological diversity and productivity and causing port access difficulties (Future Water, 2015; Serrat Capdevila et al., 2018). Besides, in the North Tanganyika-Kivu rift region, landslide erosion grew by a factor 2 to 8 during a period of 15 years due to deforestation; (Depicker et al., 2021).

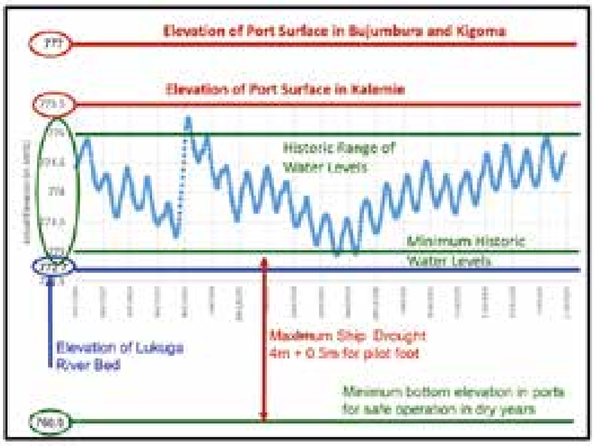
5.11.2 Key challenges

5.11.2.1 Hydrology

The lake was a closed basin until 1878, when high water levels overflowed and eroded the Lukuga Outlet (which was further widened in 1941 to increase its outflow capacity). The flows of the Lukuga River depend on the lake's water level and they constitute only between 6 to 18% of the lake's losses (82-94% of water losses are due to evaporation; Serrat Capdevila et al., 2018). Concretely, evaporation losses were estimated between 1,559 to 1,721 mm/year (Nicholson and Yin, 2002). Three main rivers feed Lake Tanganyika: The Rusizi River flowing from Lake Kivu, the Malagarasi River from Western Tanzania (which drains approximately 62% of the total basin) and the Lufubu River in the south. Annual inflow to the lake from the drainage catchment is estimated in 955 mm/year, whereas annual total precipitation over the lake is higher (1,090 mm/year; Bergonzini, 2002). The most important inflow contribution is from the Rusizi, which also is contributing to about 50% of the dissolved salts input. Precipitation on the lake surface and surface runoff represent about 63% and 37% of water input, respectively (UNEP, 2004).

The five largest lakes in the basin (year 2020) are Lake Tanganyika (32,675 km²), Kivu (2,378 km²), Sagara (306 km²), Nyagamoma (78 km²) and Igombe (9 km²) (EC JRC/Google, 2021). Lake Tanganyika and Lake Kivu are bounded by the flanks of the Great Rift Valley, which naturally limits the lake to the west and east resulting in almost no change in lake extent during the last four decades (EC JRC/Google, 2021). Lake Sagara has notably shrunken in extent since the 1980s but replenishes again since 2008. While Lake Sagare shows remarkable areas of lost permanent water and a transition from permanent to seasonal water, Lake Nyagamoma has lost notable areas of seasonal water (Pekel et al., 2016a, 2016b). A slightly growing trend of water surfaces can be observed at Lake Igombe with newly formed seasonal water areas especially in the northern part of the lake.

Figure 79. Lake levels, the Lukuga riverbed and other elevations of interest. Source: World Bank 2018.



Lake level variations are both seasonal and interannual. Seasonal water level variations in Lake Tanganyika (on average, about 70-80 cm depending on the year) are due to the marked seasonality of rainfall, with highest water levels at the end of the rainy season (October – May) and lowest water levels at the end of the dry season in September/October. The inter-annual variation of lake levels is due to the variability of annual rainfall, depending on wetter or dryer years. There are limited diversions of water flow for irrigation purposes, which currently do not seem to have significant impact on the river flow and neither on the lake level. Nevertheless, a localised loss of wetlands because of water flow shrinkage is reported in some areas in Burundi. Existing hydroelectric production in the Rusizi tributary has limited impact on the water balance of Lake Tanganyika.

Climate and lake levels are particularly interlinked as the water balance of the lake is dominated by rainfall and evaporation, while river contributions are minor. For example, the hydrological cycle has been reported to be specifically linked with precipitation trends and changes: during El Niño events, river discharge tends to be high and may result in flooding events, affecting the livelihoods of the population living and based nearby the river. All elements or activities that have the potential to influence water quality.

Hydrology – issues and challenges

- Lake level variations are both seasonal and interannual. Seasonal water level variations in Lake Tanganyika are due to the marked seasonality of rainfall.
- A localised loss of wetlands, linked to water flow shrinkage is reported in some areas in Burundi.
- Climate, the hydrological cycle and lake levels are particularly interlinked, thus the lake is particularly sensitive to climate variability and change.
- Siltation issues appear as a result of erosion and poor soil management (deforestation), specifically in the northern sub-basins.
- Groundwater potential to supplement surface water use is recognised, but some issues still hinder its effective exploitation: inadequate data on both water quantity and quality, limited mapping and assessment, or the need for financial resources and technical capacity to improve transboundary water governance in the riparian countries.

Groundwater

Groundwater is a major source of drinking water (estimated at 2/3 of the total) in the Tanzanian sub-basins. A multi-layered hydraulically connected transboundary aquifer (IGRAC, 2022) spanning through Burundi, Tanzania and Congo is mostly confined, with an average thickness (in Tanzania) of 50 m. Studies on groundwater are limited and generally focused on Tanzania and other basins rather than on the LTB.

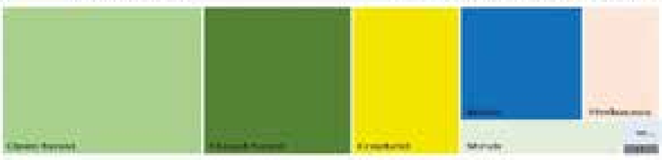
Groundwater potential to supplement surface water use is recognised, but inadequate data on both water quantity and quality, limited mapping and assessment, the need for financial resources and technical capacity to improve transboundary water governance in the riparian countries, are highlighted (Ministry of Water, 2021). Groundwater abstraction may complement surface water shortages for smallholders to continue irrigating crops (Seeteram et al., 2019).

5.11.2.2 Agriculture and food security

Fisheries are a key element of food security in the LTB, as they are the livelihood of 100,000 fishermen and about one-tenth of its 12 million inhabitants are dependent on the annual fish production of the lake (which supplies 40-60% of the animal protein consumption to the four riparian countries; World Bank, 2018; Brehm et al., 2019). It is estimated that 1.09% of the global catch takes place in the Lake Tanganyika (FAO, 2020), generating an estimated annual turnover of USD 732 million and creating 1,600,000 jobs (AfDB, 2004). However, fish stocks are undergoing a drastic reduction due to the combined effects of sedimentation and human encroachment, overfishing in the littoral zone, use of illegal fishing gear and dynamite, pollution and rising water temperatures (World Bank, 2018). While annual fish production in the late 1990s was estimated between 165,000 and 200,000 tonnes, it is believed to have decreased to 110,000-120,000 tonnes in 2012 (Van der Knapp, 2018). From 2016 to 2018, collapse of the wild adult pelagic fish stocks was reported to Lake Tanganyika Authority from all over the lake, even at places where fishing was not intensive. While the 2016 collapse was probably caused by the proliferation of active abnormal fish nets (illegal modified gillnets of unlimited length), it was further aggravated when fishermen adopted irrational fishing practices to compensate economic losses (capturing juveniles of low essential value in the absence of high value, adult fish; Marwa, 2019). The decline of fisheries is expected to impact negatively on regional food and economic security, increasing societal stress and state fragility (Werrell and Femia, 2017). Ecosystems could also suffer the consequences, as people might turn to wild animals for alternative protein sources (putting additional pressure on natural areas, such as Gombe and Mahale National Parks in Tanzania) and fishermen are likely to take agricultural activities as an alternative livelihood (e.g., increasing deforestation and land use change rates; Kitula et al., 2015).

Figure 80. Landcover dominant classes. Source. Copernicus Global Land Service: Land Cover 100m 2019: Globe (Version V3.0.1). DOI: 10.5281/zenodo.3939050.

			SUB-TOTALS
Shrub	5.70%		
Herbaceus	8.91%	14.61%	
Cropland	16.49%	16.49%	
Urban	0.39%	0.39%	
Bare-sparse vegetation	0.00%	0.00%	
Water	14.39%	14.39%	
Herbaceus wetland	0.89%	0.89%	
Closed forest, evergreen broad leaf	1.18%		
Closed forest, deciduous broad leaf	19.33%		
Intact forest	1.98%	22.50%	
Open forest, evergreen broad leaf	0.00%		
Open forest, deciduous broad leaf	12.74%		
Open forest	17.99%	30.73%	53.22%



Riparian countries are extremely vulnerable to climatic shocks regarding food security, as they predominantly depend on rainfed agriculture. In the case of Burundi, food insecurity is aggravated by several factors, such as floods and droughts, rising water levels of Tanganyika Lake, recurrent population moves and consequences of the COVID-19 pandemic. As a result, staple food prices have reached their highest levels in the past 5 years (in a country where 65% of the population lives below the poverty line). Burundi depends heavily on agriculture (which provides livelihoods for 90% of its population), it is already the second country in the world most affected by chronic malnutrition and 56% of children under 5 are stunted (WFP, 2021a). In Zambia, smallholders (mainly women) produce up to 90% of the national food (especially maize, in which the country over-relies) but, during the last decade, their activity has been threatened by prolonged dry spells, extreme high temperatures and floods. Currently, it is estimated that 48% of Zambia's population is unable to meet their minimum calories requirements and stunting affects 35% of children (even if food production at the national level routinely exceeds domestic needs; WFP,

Agriculture and food – issues and challenges

- Overexploitation. Fish stocks are undergoing a drastic reduction due to the combined effects of sedimentation and human encroachment, overfishing in the littoral zone, use of illegal fishing gear and dynamite, pollution and rising water temperatures. From 2016 to 2018, collapse of the wild adult pelagic fish stocks was reported.
- The decline of fisheries is expected to impact negatively on regional food and economic security, increasing societal stress and state fragility.
- Food security in the basin is extremely vulnerable to climatic shocks, due to its dependence on rainfed agriculture for food production (90%).
- Recurrent population displacements, triggered by extreme events (floods and droughts) and changes on the water levels of Lake Tanganyika.

2021b). Tanzania is considered mostly as a food secure country, although the poorest households and refugees still suffer food shortages (e.g., funding shortfalls prevent the supply of minimum required calories ratios for refugees and forecasted funds for 2022 are extremely low). Besides, while Tanzanian population is expected to double by 2050, its agricultural production is currently stagnated and the country's rapid urbanisation rates pose additional future challenges for food security (WFP, 2021c; Hugh Wenban-Smith and Grote, 2016). Finally, after 25 years of armed conflict and subsequent displacements (which have also affected Tanganyika province in recent years), DRC is considered as one of the largest hunger crises in the world (27 million of acutely food-insecure people, 5.5 million people losing their livelihoods due to displacements, 900,000 people living as refugees in neighbouring countries (e.g., Tanzania, Zambia); WFD, 2021d).

5.11.2.3 Socioeconomic

Figure 81. Socio-economic indicators for the riparian countries. Source: Jorgensen et al., 2006.

Item	Burundi	DR Congo	Tanzania	Zambia
Population growth rate (%)	2.0	3.2	2.4	2.2
Population density (persons/km²)	250	21	36	13
Adult literacy (%)	48	59	74	76
Per capita GNP (US$)	120	110	240	320
School enrolment (% of school age population)	51	28	67	89
Life expectancy (yr)	42	51	47	43
Percent of population without access to:				
Safe water	48	32	34	62
Health service	20	NA	7	25
Sanitation	49	NA	14	29

According to the Human Development Index (HDI), Burundi, DRC and Tanzania are classified as low developed countries (Burundi ranked 184th out of 189 countries in 2019). Although Zambia is within the Medium Development group, it is necessary to note that the Mpulungu and Nsama districts (located in the Lake Tanganyika's basin) are considerably poorer than other districts in Zambia (the annual income per capita in those districts is USD 285, far below the national average of USD 1,400; AfDB, 2014). Population in the riparian countries is predominantly rural (urban population ranges from 14% in Burundi to 46% in DRC) and generally lacks a proper access to basic services (only 1% and 3% of the rural population in DRC and Burundi, respectively, have access to electricity). In the LTB, people are mainly dependent on natural resources to cover its growing needs (estimated population increase rate of 2-3.2% per year). Besides, refugees fleeing from conflict zones (DRC, Burundi) travel via the lake and settle along its shores (UNDP-GEF, 2011). Three of the largest Tanzanian refugee camps are located within the basin (Nyarugusu, Nduta and Mtendenli, although the last one was officially closed in 2021). In December 2021, the Kigoma region alone hosted more than 227,000 refugees according to UNHCR. In this regard, environmental degradation around the camps is a source of conflict between refugees and local host communities, as thousands of refugees rely on locally-fetched wood for cooking and heating. Besides, the strict regulation that prevents refugees from farming in Tanzania, rather than eliminating it, has made it informal (hence driving down the salaries of agricultural labourers; Masabo et al., 2018).

Socioeconomic – issues and challenges

- Occasional fish kills due to spills have significant, but short-lived, impacts.
- While commercial fisheries are based on only six species, catches in the artisanal and subsistence fisheries cover over 100 species and take place in varied habitats along the rocky and sandy shoreline, where biodiversity tends to be concentrated.
- Possible impacts of biodiversity loss include: loss of traditional food sources, fuel wood energy sources, medicinal plants, and tourism. However, research is required to quantify the biodiversity loss rate in the lake and its catchment, along with its impact on the local, regional and global communities.
- Overfishing and fishing with destructive methods have led to loss of jobs and livelihoods even at country scale.

Lake Tanganyika is a key trade corridor between central and east Africa, with millions of people dependent on it for transport, livelihoods and food security. However, the deterioration of the infrastructures (which in some cases date back to colonial times) and the competition from other transport corridors have reduced its once important role in (as the link between Eastern Congo/Burundi and seaports in East and Southern Africa), limiting most of the lake's trade to the domestic or regional scale. Concretely, while small-scale or informal trade takes place on small wooden boats along the lake shore and covers a wide range of goods and products (from fish to second-hand clothes), formal trade mainly occurs through large ports and involves the transportation of cement, sugar and maize in larger bulk carriers (ECORYS, 2019). Lake Tanganyika's four major ports are Kalemie in DRC, Kigoma in Tanzania, Bujumburu in Burundi and Mpulungu in Zambia. In this context, the current Lake Tanganyika Transport Corridor Development Project aims to take advantage of the geostrategic location of the lake, unlocking its potential as an inland waterway and providing a multimodal platform to link the Northern (Mombasa in Kenya), Central (Dar-es-Salaam in Tanzania) and Southern (Mpulungu in Zambia/Durban in South Africa) Road Corridors. The rehabilitation of the Bujumbura port (first phase of the project and with the involvement of the EU External Investment Plan) will allow to replace the current road transport of maize from Zambia to Burundi, reducing transport costs from USD 230-287 per tonne to about USD 74 per tonne and hence improving the security of the supply and the humanitarian response to emergency situations (AfDB, 2019).

5.11.2.4 Water quality, health and environmental issues

Health statistics from the basin countries reveal, apart from the important issues of malnutrition, HIV, and indoor air quality problems (inefficient fuel efficiency also leading to deforestation/erosion), that the biological water quality (a traditional hazard) is an important human health issue in all basin countries.

The biological quality risks concern microbial diseases as well as vector borne diseases such as malaria, schistosomiasis, Zika fever, dengue, West Nile fever, Crimean-Congo haemorrhagic fever, Chikungunya, yellow fever, and Rift Valley fever. Their emergence and re-emergence, are closely related to human-induced ecological changes (urbanisation, dams, irrigation, alien species, global change, etc.).

Figure 82. Quality and environmental issues.


- **Research and surveillance:**
  - Assess Environmental impacts from mining activities, including oil exploitation.
  - Monitoring the emergence of waterborne disease in the context of hydropower/irrigation projects.
  - Mapping of ground water resources for geogenic pollutants.
- **Mitigation:**
  - Improve waste-water treatment, waste management and access to (chemically and biologically) safe drinking water.
  - Training on safe management of Pesticides.
  - Erosion protection.

In contrast, land use data from the basin countries, together with the few field data available, suggest that anthropogenic chemical pollution of the environment (a modern hazard), is currently not a priority for human health and the environment at basin scale.

The focus of surface water research in the basin is currently on the densely populated part in the north of the basin (Burundi), where anthropogenic pollution is most likely to occur.

For nutrients, generally good water quality is reported. Only in some small rivers at the northern end of Lake Tanganyika, which cross densely populated areas enhanced concentrations of nitrates, phosphates and ammonium are observed. They are associated with the close-by release of untreated urban wastewaters, but concentrations do not exceed the Quality Standards for surface waters. Nutrient concentrations in the important Rusizi River and iLake Tanganyika itself are distinctively lower.

The oxygenation in the lake and its northern tributaries displays a good or very good ecological status.

Studies of persistent organic pollutants (POPs) and industrial chemicals (such as polychlorinated biphenyls, PCBs) in various fish species, again from the northern part of the basin, revealed very low concentrations (never exceeding the standards for edible fish), and which currently do not pose a general risk to the aquatic ecosystem. However, soil pollution hotspots with pesticides because of bad stockpile management and the ongoing use of banned POPs (such as some pesticides) can locally be a significant threat to man and the environment.

Studies on heavy metals in fish and sediment point to a geogenic origin and display concentrations that are commonly not exceeding food standards. Only for mercury, a few of the investigated fish species approached or slightly exceeded guidelines for vulnerable populations with high rates of fish consumption. Although mercury in surface waters seems to originate predominantly from long-range transport, a contribution from artisanal gold mining is suggested.

Oil pollution so far observed is mainly a natural phenomenon. Spillages from future shore oil and gas exploitation may become a problem tough.

The concentration of suspended solids, partially resulting from soil erosion/improper land management, is high in all river tributaries. Although not toxic from the chemical point of view, they may physically affect aquatic life.

Generally, water quality issues in the lake itself appear only locally, in a close vicinity of the shore. This is due to a limnological particularity of Lake Tanganyika, where the higher density of the river water entering into the lake results in a discharge of riverine pollutants into the deep bottom layers, which do not recirculate to the surface. This, together with the potential dilution in the tremendously large water volume of the lake, provides a particular robustness against anthropogenic pollution of the lake's surface waters.

A study of geogenic groundwater pollution revealed the presence of fluoride in northern Tanzania, which can lead to serious health effects on humans such as dental, skeletal, and crippling fluorosis. Arsenic is reported as a serious pollutant for drinking water in the north-west parts of Tanzania.

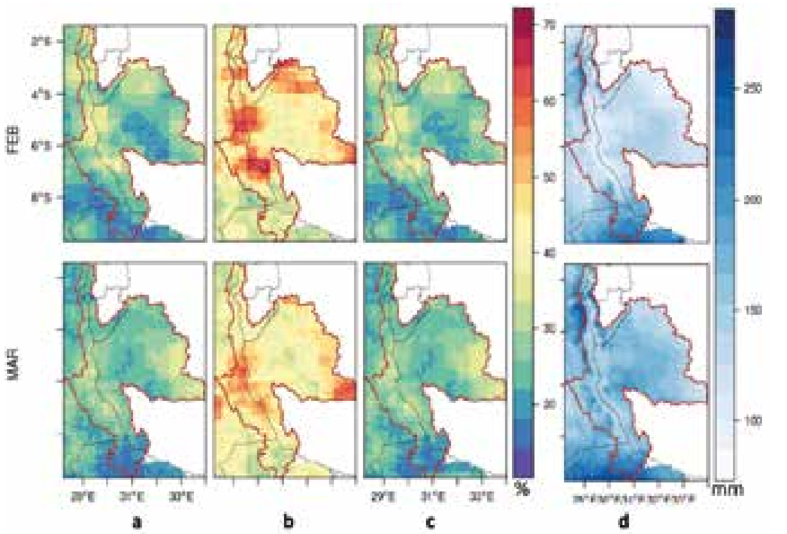
Wide occurrence of invasive, fast growing water hyacinths (*Eichhornia crassipes*) on basin's water surfaces, coupled with the reduction of light and air in the water, not only threaten aquatic animals and plants, but also may negatively affect water supply systems, drainage canals, inflows to hydropower turbines, movement of ships and river flows. Moreover, they impede access to water for domestic use and fishing. Hyacinths can also host human diseases transmitted, for instance, by snails and larvae (bilharzia) and mosquito pupae (malaria) (Lake Tanganyika Authority, 2022). Deforestation and removal of natural vegetation has occurred mainly in the northern Lake Tanganyika region, which represents the south-eastern fragmented edge of the Congo rainforest. Areas around the Virunga and Kahuzi-Biega National Parks show endangered ecosystems of low conditions due to significant biomass loss and forest cover loss (Shapiro et al., 2021), mainly due to changes from forest to arable lands (Xu et al., 2020). Major basin areas west and east of Lake Tanganyika are dominated by grassland and cropland (Mushi et al., 2019). Changes in vegetation structure through anthropogenic activities caused an increase of chemical and physical weathering intensity and enhanced soil erosion in the region (Ivory et al., 2021), exacerbated by climate change. Sheet erosion (loss of topsoil by water erosion) is the dominant degradation type in the basin, triggered by overgrazing and inappropriate agricultural activities. Especially, north-eastern and south-eastern lakeshore areas suffer from severe chemical soil degradation through nutrient loss. Specific sediment yields from soil degradation in the basin are overall estimated at 7.61 t/km² year (Mushi et al., 2019). Eroded soil material from deforested and agricultural areas is flushed to the receiving water courses, causing high sedimentary deposition and pollution in the littoral zones (Niyoyitungiye, 2020) with pronounced effects on fish, mollusc and ostracod diversity and quality (Ivory et al., 2021). Industrial and mining activities and their impacts on water quality are still relatively low, although an increase of these activities can be expected in the near future.

Water quality, health and environment – issues and challenges

- Biological quality risks concern microbial diseases as well as vector borne diseases such as malaria, schistosomiasis, Zika fever, dengue, West Nile fever, Crimean-Congo haemorrhagic fever, Chikungunya, yellow fever, and Rift Valley fever. Flooding and climate change may also lead to an increased incidence of water-borne diseases.
- Untreated wastewater discharges from industrial and domestic wastewater, specifically for large cities around the lake. Improve treatment/management.
- Water quality issues in the lake itself appear only locally, in a close vicinity of the shore. The localised pollution has not compromised the overall quality of the water supply, due to the large size of the lake.
- Arsenic is reported as a serious pollutant for drinking water in north-western parts of Tanzania.
- Reduce sedimentary deposition and pollution in littoral zones by active soil (sheet) erosion control, through reforestation and appropriate agricultural practices.
- Protect areas around the Virunga and Kahuzi-Biega National Parks from further degradation.
- Develop strategies to effectively remove water hyacinths from water surfaces.

5.11.2.5 Climate change and climate variability

Figure 83. **Precipitation deficit with 5 and 10 years return period (a,b); precipitation** variability (c) and average (d). Source: Cordano and Cattaneo, 2022.



The basin area is characterised by a North-West to South-East rainfall gradient, from over 1,500 mm/year to under 1,250 mm/year (the highest precipitation rates are normally registered in the Nyiragongo, Karisimbi and Mitumba mounts). The presence of the lake influences the regional rainfall distribution (isohyets are parallel to the lakeshore) and, over the lake, rainfall exceeds catchment rainfall by 20%; Nicholson and Yin, 2002). Most of the basin area shows a well-defined rainy season (from October to May, with maximum monthly precipitation in December and March), although it is more persistent in the northern part of the catchment than in the southern one (where it is more concentrated; Bergonzini, 2002). Respect to other areas of the Congo River Basin, precipitation deficit variability in the LTB is estimated to be around 30% or 50%, with a precipitation deficit of 50% which may occur averagely every 20 years (Cordano and Cattaneo, 2022). Some areas in the eastern of the basin and in the central part (the latter near Katavi National Park in Tanzania) are most prone to precipitation deficit than the rest of the basin. In this regard, local people in the Katavi area have reported a decrease of agricultural productivity in recent years, due to delayed rainfall and temperature increase (Mwingira et al., 2011). Interannual rainfall variability in East Africa is modulated by multiple factors, including the Inter-Tropical Convergence Zone (ITCZ), the Sea Surface Temperature (SST) over the global oceans (e.g., the Indian Ocean Dipole (IOD) and the El Niño-Southern Oscillation (ENSO)), and tropical cyclones, among others. During the last years, the region has suffered an increased frequency and intensity of extreme events (heavy rainfall and droughts). During the period 1960-2017, although the number of consecutive wet days decreased (along with an increase of consecutive dry days), the number of heavy rainfall days (associated to frequent flash floods in some regions) showed a positive trend (Ojara et al., 2021). Besides, while most of heavy precipitation episodes normally took place from March to May (long rain season), their incidence from October to December has increased in recent times (Chang'a et al., 2020). These episodes have devastating socioeconomic impacts: in 2019, heavy rainfall triggered flash floods, mudslides and landslides in Burundi, affecting thousands of people in one of the twenty countries most vulnerable to climate change and natural hazards worldwide (OCHA, 2019). Climate change could lead to wetter conditions in Lake Tanganyika region by the end of the century, arising from dramatic increases of extreme event intensities coupled with a decrease in the number of rainy days (particularly in the case of RCP 8.5 scenario). The impacts on rainfed agriculture are not clear: wetter conditions could suggest a favourable environment for its development, but as they are associated to a limited number of intense events, they could also be detrimental for yields (Pohl et al., 2017). Regarding the effects of climate warming, there is evidence that the rise of lake-surface temperature is

Climate change and variability – issues and challenges

- Respect to other areas of the Congo River Basin, precipitation deficit variability in the Lake Tanganyika Basin is estimated to be around 30% or 50%, with a precipitation deficit of 50% (which may occur with a return period of 20 years).
- Some areas in the eastern and central parts of the basin are most prone to precipitation deficit: e.g. local people in the Katavi area have reported a decrease of agricultural productivity, due to delayed rainfall and temperature increase.
- Climate change: while most of heavy precipitation episodes normally took place from March to May (long rain season), their incidence from October to December has increased in recent times, with devastating socioeconomic impacts (in 2019, heavy rainfall triggered flash floods, mudslides and landslides in Burundi).
- The impacts on rainfed agriculture are not clear: wetter conditions could suggest a favourable environment for its development.

already decreasing the lake's primary productivity, as it increases the stratification of the water column and prevents nutrient recharge from below (e.g., O'Reilly et al., 2003; Tierney et al., 2010). Future variability of the ENSO system is a major concern, as Lake Tanganyika's food web is largely influenced by interactions between global climatic controls and ENSO teleconnections (McGlue et al., 2020).

5.11.2.6 Water and energy

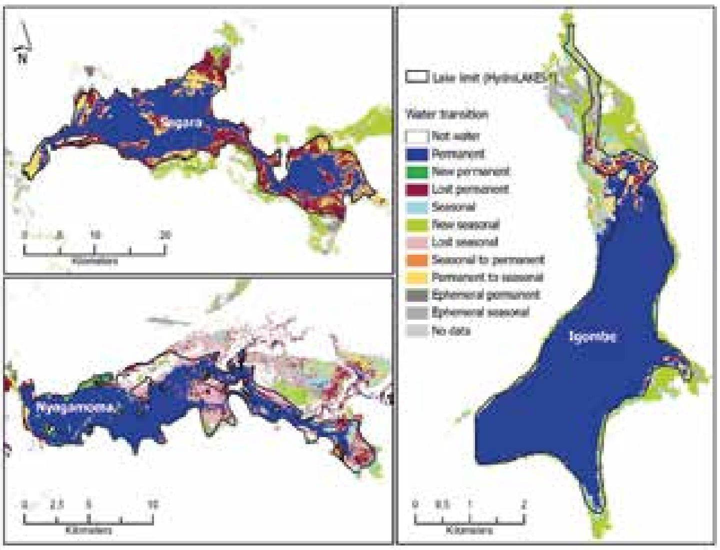


Figure 84. Water transitions (JRC Technical Report - Pekel et al., 2016b) of Lakes Sagara, Nyagamoma and Igombe with significant water extent change from 1984 to 2020. Source: taken from Messager et al. (2016).

The three major hydropower plants in the basin are Ruzizi (102 GWh), Ruzizi 2 (159 GWh, located in DRC) and Rwegura (96 GWh, located inBurundi) with a total hydropower production of 357 GWh (Gonzalez Sanchez et al., 2020). These dams have only caused a small increase of water surfaces and associated water losses through evaporation compared to waterbody extents prior to dam construction. These three dams are complemented by Mpanda, Kabu 16, Jiji 03 in Burundi and Ntaruka in Rwanda (FAO, 2016; Gonzalez Sanchez et al., 2020).

Largest parts of the Tanganyika basin belong to the Eastern African Power Pool (EAPP), only the Zambian part in the south of the basin is located in the Southern Africa Pool (SAPP). East African countries rely mainly on an energy mix of biomass (wood, charcoal), hydropower, oil and gas and geothermal energy. Favourable conditions for geothermal energy exploitation exist in the Eastern African Rift System (EARS) (JRC Technical Report – ACEWATER II Project. Battistelli et al., 2021). To cope with the rapidly growing population and strong economic growth, the focus is set on increasing electric power production, extending the access to the electric network (transmission) and using renewable indigenous energy sources. Densely populated areas north of Lake Tanganyika (Burundi and Rwanda) are increasingly interconnected to the high and medium voltage African power grid. This will particularly support Burundi to overcome its low national electrification rate (11%, as the country has only a total installed capacity of 80 MW). Sparsely populated regions in the east of the basin have no access to the African power grid, except for the Tabora district (connected to the high voltage power grid). Sumbawanga in the south and Kalemie in the west of the basin are also connected to the high voltage power grid.

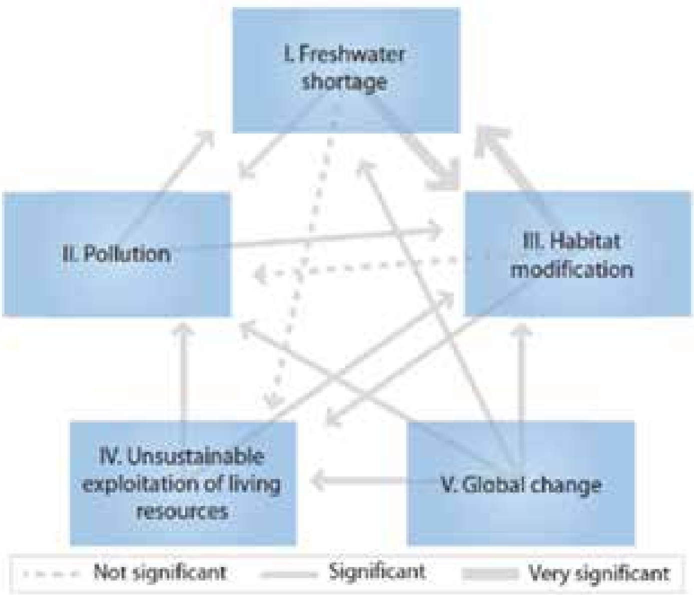
Water and energy – issues and challenges

- Reduce dependency on biomass (wood, charcoal), increase the electric power production, extend access to electric network (transmission) and use renewable indigenous energy sources.
- Sparsely populated regions in the east of the basin have no access to the African power grid.

5.11.3 Summary Map and Priorities

Concerns at river basin level have been identified and shortly summarised and prioritised as follows:

1. Unsustainable exploitation of fish and other living resources
2. Habitat and community modification
3. Pollution
4. Freshwater shortage
5. Global change



As a result of the previously described bibliographic and document assessment, and with the support and input provided by stakeholders and experts in the river basin (EEAS-Bujumbura in Burundi and ICPAC) the following key issues have been identified:

- Improve knowledge of hydrological regime and lake water balance
  - *Improve knowledge and monitoring of lake water balance and variability of levels*, related to rainfall seasonality. Especially as a result of global change, increasing demand from population and development sectors (energy, irrigation, livestock, and fishery). Improve knowledge and monitoring of lake water balance and variability of levels, related to rainfall seasonality.
  - *Enhance hydro economic modelling at river basin scale*.
  - *Implementation of risk reduction policies and development of early warning systems*.

- Management of the increasing water demand
  - *Assessment and mitigation of wetlands shrinkage*. Assessment and mitigation of wetlands shrinkage as impacted by CC, water demand and land degradation.
  - *Improve monitoring data and assessment of ground and surface water resources*. Improve long term monitoring data on groundwater and surface waters, for the assessment of exploitation potential and quality.

- Address impacts on water resources, biodiversity and livelihood
    - *Improve knowledge of fishing sector*. Assessment of over exploitation of fishing system and development of more sustainable lake management practices.
    - *Enhance monitoring and control systems for the fishing sector*. Fish stocks assessment and monitoring required to identify potential mitigation options and limit the drastic reduction up to now observed.
    - *Reduce of illegal or not regulated fishing catches*.
    - *Assessment of biodiversity loss issues*. Assessment of biodiversity loss and of its impact on food, medicinal plants, tourism sectors among others.
    - *Sedimentary deposition and pollution of littoral zones*. Reduce sedimentary deposition and pollution in littoral zones (reforestation and identification of alternative agricultural practices).
    - *Ensure protection of wetlands*. Ensure protection of wetlands and areas close to the National Parks. Improve assessment, knowledge, monitoring and HCD. Invasive species management.

- Climate change and variability impacts
    - *Water balance modelling system*. The hydrological cycle of the basin is particularly sensitive to climate change and variability. Improve of modelling capacity is key.
    - *Improving data knowledge* to facilitate the transboundary governance and equitable allocation of water and natural resources is urgently needed, as highly impacted by climate change and climate variability (incidence of heavy precipitation is increasing, with impact on flash floods, mudslides and landslides).
    - *Improve assessment of CC and CV impacts on agricultural systems*. Rainfed agriculture systems may be impacted, but still there is no agreement about the type of impacts and consequences of different precipitation changes (i.e. for the impact of heavy precipitation).
    - *Enhance research and HCD on soil fertility management, water retention practices*.

- Addressing water quality
    - *Improve monitoring of faecal bacteria and biological risk*. Ensure monitoring and mapping of bacteriological water quality and assessment of locally specific issues (such as arsenic in Tanzania).
    - *Improve wastewater and solid waste management*.
    - *Improve assessment of mining and oil exploitation*.

- Coordinated water use monitoring, data collection and management
    - *Improve transboundary collaboration*. Coordinated environmental and water use monitoring, data collection and management as the basis for effective basin operations and management, including at the national levels of the riparian states.

- Summary of notes and other inputs from stakeholders

The key priorities highest ranked (extremely important) and pointed out by several stakeholders are:

- *Improve knowledge and monitoring of lake water balance and levels, water balance modelling system.* ICPAC highlights that water balance is known to some degree from ongoing work at ICPAC in setting operation water resources forecast models. In addition there is evidence of the gap on the outflows from the Lake into Congo River at Lukaga, as well impact of climate variability and change on the Lake Water balance. According to EEAS-Bujumbura this is one of the main priorities due to the flooding events occurring since 2020, which have seriously affected local population. In addition no data is currently available: a monitoring system will be developed in phase 2 of LATAWAMA project that will begin in early 2024. In addition it is reminded by EEAS that a monitoring and model system should be developed in phase 2 of LATAWAMA project that will begin in early 2024: in this context for LTA is extremely important the contribution of research centres and Universities, as no consistent data are available at this stage. A monitoring water quality system and open-access platform is going to be put in place (LATAWAMA Project).

Key priorities specifically highlighted by EEAS- Bujumbura are:

- *Improve knowledge and assessment of fishing sector, its monitoring and control, regulation* (Indeed riparian Lake Tanganyika Member States consider this one as one of the main priorities; a regional chart (closing of fishing between May 15th till August 15th of each year) has been developed and adopted by the 4 riparian countries, in the framework of LATAFIMA project. Sensitization and awareness campaigns to fishermen and local population have to be strengthened for the application of the chart. In addition the project LATAFIMA is addressing specifically monitoring and regulation issue, while fish stock assessment will be taken into account in the phase 2 of LATAWAMA project). Attention has also to be focused on ornamental fishes (above all in Tanzania)

- In the context of water quality and environment a specific focus is put on *improvement of waste (water and solid) management,* one of the main priorities for riparian Lake Tanganyika Member States and indeed it is already one of the priorities for the LATAWAMA project, to be further addressed in the phase 2 of the project.

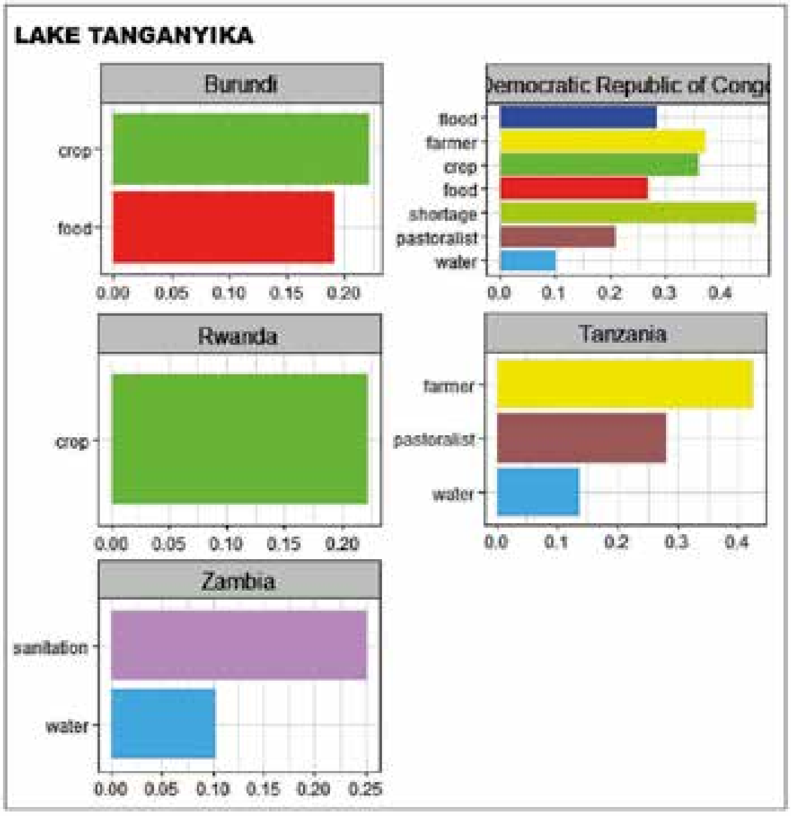
Other important priorities ranked as important or newly added to the proposed list:

- According to EEAS-Bujumbura *Implementation of risk reduction policies and development of early warning system* is an important priority to be considered. Indeed it is one of the main priorities for the National Disaster Risk Reduction (DRR) Platform in Burundi (Ministry of Interior). In this context a DRR cartography has been developed in Burundi (at national level), in the framework of an EU project implemented by IOM.

- Golden exploitation in Lac Kivu and Rusizi river basin should also be taken into possible consideration and analysed.

- Most recurrent water related keywords per country in the river basin:

Figure 85. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



RIVER BASIN 10

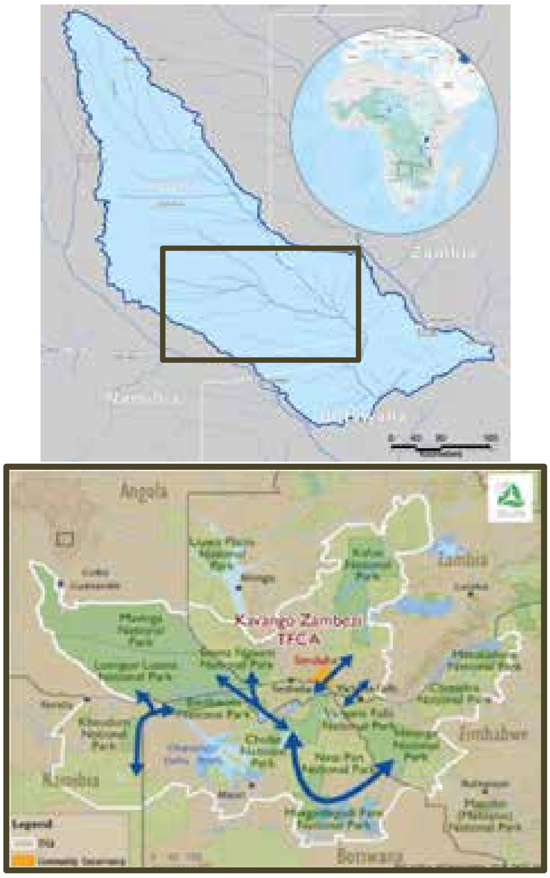
CHOBE-KWANDO (ZAMBEZI)

5.12 River basin 10: Chobe-Kwando (Zambezi)

5.12.1 Introduction

The Chobe River, also known as Kwando or Cuando River upstream Lake Liambezi, is a tributary of the Zambezi River shared by Angola (69.6% of the basin area), Botswana (10.5%), Namibia (10.4%) and Zambia (9.5%). Concretely, the river has its origin in the central plateau of Angola and drains about 22% of the Upper Zambezi region before joining the Zambezi River, upstream of the Victoria Falls. The Chobe River Basin (CRB) is a complex hydrologic system with an area of near 155,000 km², which occasionally connects the Zambezi River Basin (ZRB) with the Okavango Delta through the Selinda Spillway (where the Okavango flows into the Kwando/Linyanti Swamp, as it happened during the 2008/09 and 2009/10 floods; Turton et al., 2003; Kurugundla et al., 2010).

Figure 86. Chobe River basin and KAZA TFCA Map. Source https://www.kavangozambezi.org/.



Despite its large area, the basin has a very small influence on the Zambezi's average annual runoff (estimated contribution of 1%), as the Linyanti Swamp acts as an inland delta (which can expand up to 300 km² and experience floods in August). Concretely, the CRB is only linked to the Zambezi River through a narrow strip with another wetland area (the Chobe Swamps) (Schleiss and Matos, 2017), although it has important impacts on the hydrological regime of the Zambezi (World Bank, 2010): 1) through the above-mentioned occasional connection to the Okavango River Basin; 2) depending on water levels, the Zambezi can flow into the Chobe instead of the other way round (estimated yearly average contribution from the Zambezi to the Chobe in the range of 0 to 40 m³/s; Schleiss and Matos, 2017) and; 3) sometimes the river flows through an ephemeral channel (Bukalo Channel) into Lake Liambezi (an ephemeral lake where water evaporates).

Together with the Okavango Delta, the CRB is part of the the Kavango-Zambezi Transfrontier Conservation Area (KAZA TFCA, established in 2013), the world's largest transfrontier conservation area (520,000 km²) and which hosts the largest elephant population on earth. Besides, the CRB includes Mamili and Zambezi wetlands, the Chobe and Linyanti channels and floodplains and the Lake Liambezi (Burke et al., 2016). The CRB also includes two managed forest reserves (Chobe and Kasane Forest Reserves), three national parks (Chobe National Park in Botswana, and Mudumu and Mamili National Parks in Namibia), and a rapidly-urbanising area, the town of Kasane in Botswana, which is also an important regional tourism attraction. Mean annual precipitation in the basin is near 800 mm/year and most of it falls from October to March, being the CRB the driest sub-basin of the ZRB (Burke et al., 2016; World Bank, 2010).

The CRB floodplain is a seasonal marshland located on the border between Namibia and Botswana, providing a large wetland area and increasing the evapotranspiration of the river. The flooding season can be quite long (typically extending from February to July) and the inundated areas can change significantly over this time (Braget et al., 2018). Seasonal flooding is critical to the health and productivity of this area and, in recent years, has increased causing the re-emergence of perennial lakes and wetlands which had dried up considerably since the 1980–1990 dry period (Long et al., 2014). Landcover is dominated by mixed forest and grassland systems (65% and 30%); indeed about 43% of all the grassland/shrubland present in the ZRB belongs to the CRB. This land is primarily used to support subsistence activities and utilised for livestock grazing or agricultural lands; another dominant land use is forest, and several managed forest reserves are present in both countries. Significant vegetation changes have been reported in the last thirty years as caused by a complex interplay between significant increases in wildlife populations, decreases and variability in rainfall and river inundation extents, and increasing human population and rangeland utilisation by cattle (Mosugelo et al., 2002; Pricope et al., 2015).

For decades, the CRB has been largely underdeveloped due to political and civil unrest (estimated population of 288,000 inhabitants in 2005/06; World Bank, 2010). However, in recent years the basin is experiencing a pressure increase due to a combination of stressors, such as shifts in political leadership, climate change and further development plans. In this regard, and given the increasing number of regional, national and provincial development program for the KAZA region (as well as unplanned ones), the World Wildlife Fund (WWF), the KAZA TFCA Secretariat and the Zambezi Watercourse Commission (ZAMCOM) have just opened a call (February 2022) to submit proposals for a Strategic Environmental Assessment (SEA) of the CRB.

Besides, water transfers involving the CRB have been considered since the 1980s. The first one was the Chobe-Vaal water project, negotiated by South Africa and Botswana to supply the agriculture of the former. However, at the end South Africa's water shortage was addressed through the Lesotho Highlands Water Project instead of further progressing with the Chobe-Vaal one (Okidi, 2015). Currently, the development of the Chobe/Zambezi Water Transfer Scheme is a national priority for Botswana, and ZAMCOM has approved the use of 495 million m^3/year for it (150 million m^3 for the south of the country and 345 million m^3 for irrigation in Pandamatenga). Concretely, the project has two elements: 1) water transfer from the Zambezi to Pandamatenga (part of the Zambezi Integrated Agro-Commercial Development (ZIACD) Project) and; 2) transfer from Pandamatenga to the existing North-South Carrier 1 pipeline (to support water supply in Gaborone and the south of the country) (ZAMCOM, 2019). According to its Environmental and Social Impact Assessment (ESIA, published in 2009), the ZIADC project is the largest commercial agricultural development in Botswana (expected to double the national agricultural output) and also contemplates a large aquaculture component (re-using water from aquaculture to irrigation to save up to 28.8% of total gross water consumption). The ESIA considered that the project would use more than the current total water national requirements (including the mining sector), with the second phase roughly doubling water usage. However, the aquaculture component was generally deemed as over-ambitious (primarily due to market constraints, according to the 2011 Aquaculture Development Strategy for Botswana) and it was not explicitly mentioned in the feasibility study of the ZIADC (completed in 2015). Regarding irrigation, the feasibility study estimated the expected annual requirement at 270 million m^3 (about a half for fruit trees (mangoes) in the drip irrigation area and the rest for cereals, oilseeds, pulses and fodder crops under pivot irrigation). According to the African Development Bank (AfDB), another feasibility study for the Chobe-Zambezi Water Transfer Scheme was carried out in 2017. The project is at an advanced stage of preparation and the government of Botswana is currently exploring models for its funding. According to the dedicated project webpage of the AfDB, 2021 was the target year for the full feasibility report and consolidated ESIA.

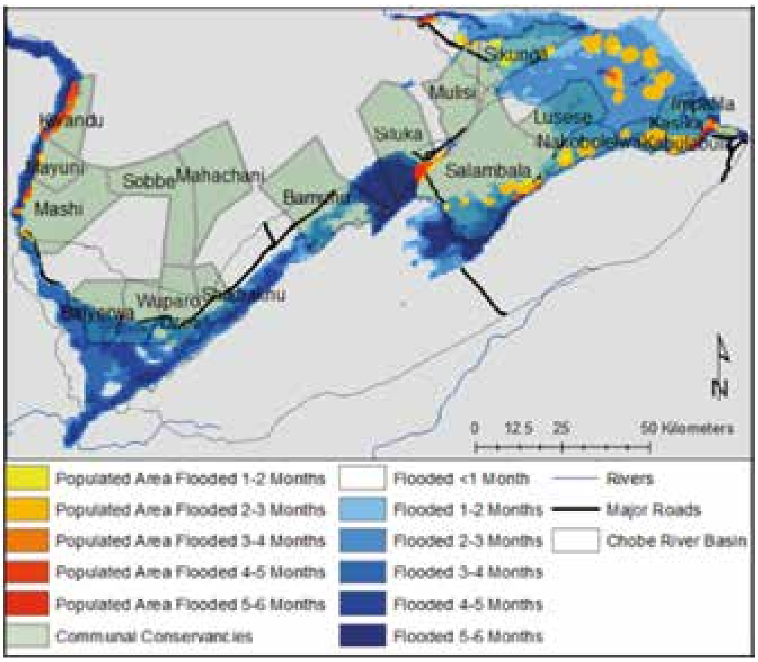
5.12.2 Key challenges

5.12.2.1 Hydrology

The CRB is predominately a dryland system, with the Chobe River providing the only permanent surface water. River flow is driven by the regional and local precipitation. The Kwando/Chobe sub catchment area, which feeds the Chobe floodplain and the Upper Zambezi, only receives about 800 mm/year of rainfall (whereas the headwaters of the Zambezi receive about 1330 mm/year on average; Beilfuss, 2012). Under a normal flow regime, the Chobe River acts as a tributary for the Zambezi. However, during flood events, the Chobe River reverses direction and flows back into the floodplain, inundating up to 1700 km^2 (Beilfuss, 2012).

The hydrology of the CRB is characterized by flood pulses dynamics and important contributions from the Zambezi and the Linyanti rivers. Specifically, for the Chobe Wetland and floodplain area, the most important source in terms of the amount of water is the Zambezi River itself, which pushes various amounts of water back into the Chobe (depending on its discharge and, to a smaller degree, on regional precipitation). Despite being one major subbasin of the ZRB (it covers about 11% of the total area), its contribution isr less than 1% of the total water runoff, as most of the water is going to feed the wetland and floodplain system and hence lost to evapotranspiration before it reaches the Zambezi River. Even in years of low flow, surface water remains in depressions for up to four months (semi-permanent water bodies) along the main channel of the Chobe and regions of the Zambezi and Mamili wetlands. Long-term water bodies can be found in Lake Liambezi, parts of the north-eastern Zambezi Wetlands and along the ridge of the Chobe River (Burke, 2016).

Figure 87. Population centres located within flood zones in years of high-magnitude flooding. Source: Burke (2016).



Flood pulses dynamics characterise the most important livelihood system in the basin. A flood pulse occurs when there is a substantial amount of water going into a river system, thus water rises above the banks and vegetation is inundated for periods of times ranging from a few weeks to months. Flood pulses deliver valuable nutrients and water, which are vital to plant development and a principal driving force for the productivity and types of biota in the river-floodplain region. These floods happen during the rainy season, between November and April. The peak occurs at the end of the rainy season and beginning of the dry season (April), when the peak discharge of the Zambezi River reaches the CRB. The CRB can experience a second flood pulse in the months of June and July, when the Kwando River on the western side of the CRB has its peak discharge (outside of the traditional rainy season). If the flood pulse is high enough, water can move from the Kwando River into the Linyanti Channel, then through Lake Liambezi, and finally into the ZRB. However, this is not a frequent event, and Lake Liambezi often remains dry (Long et al., 2014). These annual flood dynamics are highly variable in the CRB and can change dramatically in flow volume, duration, frequency, and timing (Braget et al., 2018). These floods have also important influences on both water quality and diarrheal disease in children under five.

Flow monitoring in the CRB is conducted through five operational stations in Botswana and two more in Namibia. Mean daily discharge (m^3/s) from these stations shall be shared between the Member States of ZAMCOM on a quarterly basis (ZAMCOM, 2016). In the case of Angola, it is necessary to consider that most weather stations were destroyed during the war, which limits the availability of historical climate data (USAID, 2018).

Population in the CRB is clustered around major town centres (such as Kasane), roadways and villages across the floodplains. Even in years of low flood events, 22,000 people are estimated to be exposed to flooding during a month in the Namibian floodplains of the CRB (Burke, 2016).

Besides, changes in mean annual runoff (MAR) are expected to lead to channel disruptions, which could trigger potential border disputes. The Linyanti-Chobe section of the Cuando River acts as an International River Boundary (IRB) between Namibia and Botswana. Biophysical risk factors include the extreme dynamism of the channel morphology, while among the socio-political ones there is a history of conflict over islands along the channel (Kasikili/Sedudu Island, judgment of the International Court of Justice, 1999), and over the Namibia-Zambia-Botswana tripoint downstream at the confluence (Grainger and Conway, 2014). In the case of Sedudu Island, declines in water levels have already pushed Namibian fishermen into the Botswana's side of the island (leading to shootings and arrests; Adaawen et al., 2019).

Groundwater

The hydrogeological system of the CRB develops in the thick and high transmissivity sedimentary Kalahari deposits, delimited to the East by a major regional tectonic discontinuity, and resulting in the outcropping of the crystalline basement formations (Mengistu, 2018).
Aquifer transmissivity and productivity is sensibly higher than in the crystalline basement (MacDonald et al., 2012), the uplift of the latter acting as a hydrogeological barrier and leading to the development of the large humid areas upstream and testified by the rivers meandering.

Groundwater flow modelling in the ZRB (Banda, 2020) confirmed the high transmissivity in its Western part. The SADC-GMI hydrogeological database and map (SADC-GMI, 2022) provides a rich dataset on groundwater quantity, accessibility and quality in most of Southern Africa, including detailed information on wells (e.g., water depth, productivity, quality) in the specific region of interest. The seasonal dynamic of flooding plains reasonably reflects in fluctuations in the groundwater table elevation, still the lack of level time series in the database does not permit to conduct any quantitative assessment; the same holds true for longer term (aquifers' depletion or repressurisation) trends. Problems of groundwater salinisation are reported and confirmed by existing data (SADC-GMI, 2022), due to upcoming phenomena resulting from local overexploitation and displacement of deep salinised water.

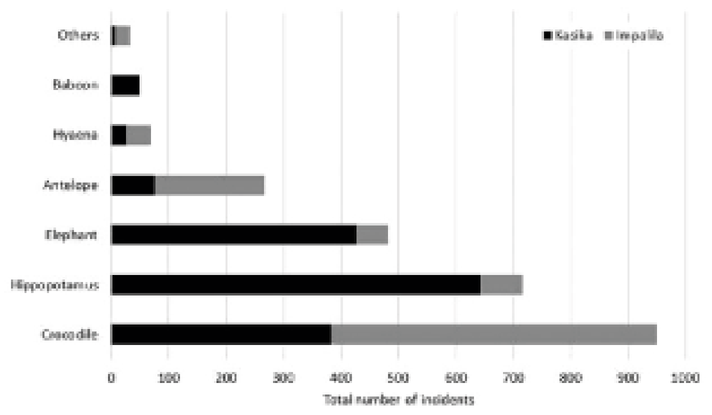
Currently, the KAZA-GROW project (2021-2022) aims to support the sustainable development and management of groundwater resources in the KAZA TFCA (concretely, in the Kwando Wildlife Dispersal Area, which includes the lower reaches of the Kwando/Chobe River in Angola, most of the Caprivi strip, parts of south western Zimbabwe and northern Botswana). Main expected outputs of the project are the development of a Transboundary Diagnostic Analysis and a Transboundary Groundwater Management Framework. The project is developed through a partnership between USAID (Resilient Waters Program), the International Water Management Institute (IWMI), the KAZA TFCA Secretariat and the Peace Parks Foundation.

Hydrology – issues and challenges

- Dependence on the Zambezi River: for the Chobe wetland and floodplain area, the most important source in terms of water amount is the Zambezi River, which pushes water back into the Chobe.
- Flood pulse dynamics characterise the most important livelihood system in the basin: high variability in space (extension) and time (start, length, recurrence, etc.). The 2009 Chobe flood was compared with the less intense 2008 flood, showing an increase of the flooded area of about 542 km2.The Linyanti-Chobe section of the Cuando River (the southern edge of the Caprivi Strip) acts as an International River Boundary (IRB) between Namibia and Botswana. It has been identified as a potential hotspot due to the extreme dynamism of the channel morphology and a history of conflict over islands along the channel.
- Population in the CRB is clustered around major town centres (such as Kasane), roadways and villages across the floodplains and, even in years of low flood events, 22,000 people are estimated to be exposed to flooding in the Namibian floodplains.
- The SADC-GMI hydrogeological database provides a rich dataset on groundwater quantity, accessibility and quality, including detailed information on wells (e.g., water depth, productivity, quality, etc.): problems of groundwater salinisation are reported and confirmed by existing data, resulting from local overexploitation and displacement of deep salinised water and leading to invasions by relatively deeper-rooted woody vegetation.

5.12.2.2 Agriculture and food security

Figure 88. Human-wildlife incidents in two locations on left bank of the Chobe river. Source: Gaillard et al. (2019).



As most of the CRB is included within the KAZA TFCA (more than 75%), the socioeconomic baseline survey conducted for this protected area could be taken as a proxy to describe the situation in the basin (Glatz-Jorde et al., 2014). According to this study, half of the households in Namibia and Botswana depend on markets for their food, while most of the households in Angola and Zambia rely on their own production. The diet is mainly based on vegetables and fish, being meat rarely consumed. However, levels of food security differ across the countries: most of households in Angola only have one meal per day, whereas households in Namibia and Botswana usually can afford three meals per day. Main crops include maize (near 75% of the households), sorghum, millet, ground nuts and vegetables (cassava was only reported in Zambia). A small share of this production in Namibia, Botswana and Zambia is sold (while in Angola is mainly for own consumption). Crop losses due to wildlife conflicts are a main issue in the area (average losses estimated at more than a third) and hippo was portrayed as having the highest impact on agriculture in the four countries (elephant was also mentioned in Angola and buffalo and leopard were perceived as a lesser threat; Glatz-Jorde et al., 2014). Figure 88 shows main human-wildlife incidents by species in two locations along the Chobe Rver (Gaillard et al., 2019). Despite these conflicts, the Chobe District is the only region in Botswana which is suitable for rainfed agriculture (Kaduyu et al., 2021). For example, Kasane in the Chobe District is considered as suitable for the growth of medium maturing cereals because it has a length of the rainy season of more than 100 days (Byakatonda, 2018). Regarding livestock, less than a third of households in the pilot area owned livestock (usually less than 10 heads, with only a few households reporting more than 40 heads). Main threats to livestock rearing arise from animal health, drought and loss of livestock to wildlife. In north-eastern Namibia, it is estimated that 6,864 heads of cattle might be attacked by crocodiles every year (half of them along the Chobe River; Aust et al., 2009).

Besides, households within the KAZA TFCA are highly dependent on a variety of natural resources, such as water, firewood, sand and clay, construction poles, thatching grass, reeds, fish and edible plants (Glatz-Jorde et al., 2014). Concretely, in the Chobe District, the high unemployment rate coupled with deep poverty (20%) and other social shocks made young people to be heavily reliant on forest resources, although socioeconomic factors such as education could diminish this dependence (Garekae et al., 2017). According to the State of KAZA symposium (2016), fisheries in the Zambezi-Chobe system have undergone a major decline in fish stocks from 1997 to 2015, although the catch per unit effort (CPUE) in the core area of the Kwando Rver system was stable, (experiencing a modest decline in the Lake Liambezi system mainly due to monofilament nets). Climate change is expected to reduce the spawning habitats, food resources for fry and juvenile fish and, consequently, fish stocks in the Zambezi-Chobe wetlands (reduction of the estimated annual habitat of 22% in the worst-case scenario, due to the reduction of the maximum flow and inundated area of the seasonal depressions or *mulapos*) (Martínez-Capel et al., 2017). Besides, bushmeat consumption became prevalent through trophy hunting tourism in the Chobe Enclave Conservation Trust and now contributes to food security for a significant number of community members (Stone and Stone, 2020). Finally, high levels of children malnutrition were considered as a main concern in the CRB (Midgley et al., 2012).

Irrigation in the CRB is underdeveloped and crop yields are generally low. However, the Linyanti Floodplain has a good potential for recession irrigation. Concretely, the Caprivi-Chobe Lake Liambezi Floodplain has a recession area of 9,000 ha (4.1% of the total floodplain area). Current irrigation areas in the CRB are estimated at 765 ha (495 ha during the dry season, 145 ha during the wet season and 125 ha which are perennial), with a total water abstraction of 10.14 million m^3/year (World Bank, 2010c). However, the current total water abstraction could be slightly higher (10.8 million m^3/year); (Spalding-Fecher, 2018). Equipped area for irrigation covers 620 ha and main irrigated crops include winter rice and vegetables (dry season) and citrus (perennial). Additionally, the implementation of identified irrigation projects could expand the irrigation area in 450 ha, although under a "High-level irrigation" scenario (including potential projects identified by the riparian countries) the irrigated area could increase by 18,000 ha (requiring a supplementary regulation in the basin up to 200 million m^3; World Bank, 2010b). Under this scenario, most of the new equipped irrigation area would correspond to sugar-cane cultivation (12,000 ha) and the rest to vegetables (3,000 ha) (Spalding-Fecher, 2018). However, it was concluded that the "High-level irrigation scenario" induced a great drop of the hydropower production potential in the ZRB, hence the economic losses exceed the benefits of this irrigation scenario (World Bank, 2010b). Importing food crop requirements within the CRB vary from one country to another, and were estimated at 16,000 tons in Angola, 8,000 tons in Zambia and 1,000 tons in Namibia and Botswana (although recent agricultural developments in some countries must have affected these figures; World Bank, 2010c).

Agriculture and food security – issues and challenges

- Namibia and Botswana households depend mainly on markets for their food supply, while in Angola and Zambia rely on their own production, even if with very low levels of food security and access. Population is highly dependent on forest systems.
- In Angola and Zambia, crop productivity and stability is a key element for food security. High levels of children malnutrition are reported as a main concern in the CRB. Irrigation in the CRB is underdeveloped and crop yields are generally low. However, the Linyanti floodplain has a good potential for recession irrigation.
- Livestock is dominant even if most of households do not own animals and several issues need to be managed such as health, security (wild animals), and in general drought and competition with other sectors.
- Decline in fish stocks was reported between 1997 and 2015.
- Crop losses due to wildlife conflicts.
- High unemployment rates, coupled with deep poverty (20%) and other social shocks, made young people heavily reliant on forest resources, although socioeconomic factors such as education could diminish this dependence.
- Irrigation in the CRB is underdeveloped and crop yields are generally low: large expansion of irrigation is discouraged due to its detrimental effects on hydropower production. Thus, other solutions to increase the productivity of agriculture are needed.

5.12.2.3 Socioeconomic

The configuration of the current socio-ecological system along the Kwando River in Namibia has been heavily influenced by the decisions of the former colonial government. While pre-colonial lifestyle was mainly based on the seasonality of the wetland landscape and the interaction between humans and other wetland species, enforced and non-enforced relocations starting in the 1930s emptied the western banks of the Kwando River and its extensive wetlands of inhabitants, while filling the eastern banks. Early relocations were motivated by different reasons: isolation of cattle herds, control of the tsetse fly (responsible both for trypanosomiasis and sleeping sickness, affecting both humans and cattle), to bring people close to roads or to make population accessible for labour recruitment. Besides, the wetlands underwent intensive anti-tsetse fly campaigns starting in the 1940s, using substances (DDT, dieldrin, endosulphan) later prohibited due to their terrible ecological and health consequences,

Socioeconomic – issues and challenges

- Social tensions arose from the difficulties to harmonise the needs of wildlife conservation (ecosystem and tourism) and those of local farmers, as well as racial conflicts and insecurity due to the dominance of the tourism industry by expatriates. Big differences were found between the four countries: households in Angola and Zambia lack both physical assets and access to facilities, services and markets, while financial assets are also low; Botswana and Namibia show better conditions (e.g., more readily available access to road networks, electricity, clean water sources and health facilities.
- Tourism sector is expanding, although its contribution to GDP is still limited and ranged from 5.7% in Angola to 2.9% in Namibia.
- Access to electricity at basin scale: only households in Botswana have a significant connection to electricity (near 50%), while hardly any household in Namibia is connected and none in both Zambia and Angola. Firewood is primarily used for cooking.
- Access to clean water and sanitation: water sources are generally shared with wildlife and livestock, so often they do not have a good quality for human consumption. Except for Botswana, access to clean water is thus unreliable.
- More than half of the households in the area lack sanitation facilities.

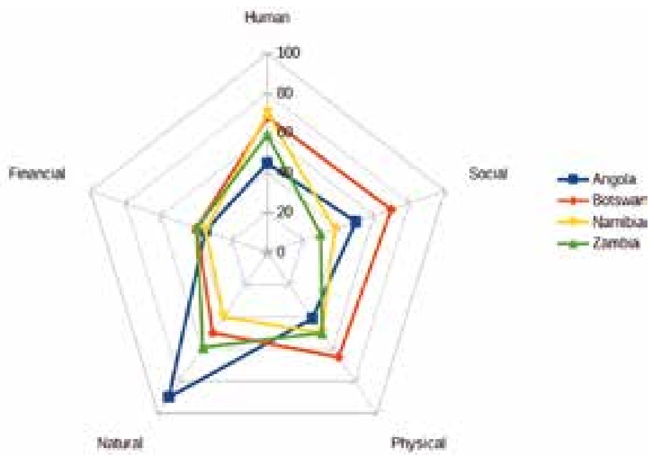
while biological methods were employed to eliminate the aquatic invader fern *Salvinia molesta* or Kariba weed (which appeared in the wetlands after the implementation of the Kariba dam and was effectively controlled in the mid-1980s). Therefore, the current environmental infrastructure has been configured during eight decades through the creation of an anthropogenic wilderness (wetlands emptied of both inhabitants and unwanted microbes and weeds), which was included within core conservation areas in the 2000s, transboundary migration areas in the 2010s and later in the KAZA TFCA (which encompasses more than three quarters of the CRB nowadays) (Bollig and Vehrs, 2021).

Similarly, in the wetlands of Chobe and Ngamiland in Botswana, state intervention fostered a successful cattle industry, eradicating disease (e.g., trypanosomiasis, foot-and-mouth disease) and subsidising farmers to improve their herds. However, the growth of the cattle industry divided the wetlands' society into wealthy cattle breeders and poor subsistence farmers, as well as increasing gender disparities (arable farming, the primary activity of women in the wetlands, did not receive state attention until 1982). By 1990s, an outbreak of lung sickness destroyed the wetlands herds and, following the return of peace to the Zambezi and Chobe basins (after the independence of Namibia and Zimbabwe), the government of Botswana encouraged the development of an international tourism industry. Tensions arose from the difficulties to harmonise the needs of wildlife conservation and those of local farmers, as well as racial conflicts and insecurity due to the dominance of the tourism industry by expatriates. Therefore, Botswana was prompted to move from inherited colonial ideas towards conservation to a more people-centred approach (Gumbo, 2010).

According to the KAZA TFCA socio-economic baseline survey, households in the partner countries obtain incomes from multiple sources, such as natural resources, diverse businesses, benefits from conservation, tourism, crop and fish farming, pensions, remittances and social grants. Less than half of the households get cash income under 500 USD per year (with a slightly lower percentage ranging from 500 to 2000 USD/year). However, big differences were found between the four countries (see Figure 89). Households in Angola and Zambia lack both physical assets and access to facilities, services and markets, while financial assets (income, household production and employment or business opportunities) are also low. However, households in Botswana and Namibia show better conditions, such as more readily available access to road networks, electricity, clean water sources and health facilities. However, this graph should be interpreted carefully, as Zambia's relatively low score of financial assets (crop farming) despite its importance for livelihoods only indicates low productivity. At country level, GDP per capita ranges from 6,405 current USD in Botswana to 985 current USD in Zambia (Angola's is 1,776 and Namibia's is 4,179 USD, respectively). Tourism contribution to GDP ranged from 5.7% in Angola to 2.9% in Namibia (Baipai et al., 2020). Regarding access to basic facilities:

- Access to electricity: only households in Botswana's part of the KAZA TFCA have a significant connection to electricity (near 50%), while hardly any household in Namibia is connected and none in both Zambia and Angola. Firewood is primarily used for cooking. Solar systems are the most popular electricity supply in Zambia (half of the surveyed villages), while only a small percentage of households use it in Namibia and none in Angola and Botswana. At country level, 45.6% of the population has access to electricity in Angola, 70.2% in Botswana, 55.2% in Namibia and 43% in Zambia.

Figure 89. Distribution of assets in the KAZA TFCA (excluding Zimbabwe).



Adapted from Glatz-Jorde et al. (2014). According to the State of KAZA symposium (2016), detected challenges in the area include the increase of the human population (largely rural and which heavily relies on natural resources for livelihoods), climate change, human-wildlife conflicts, threats to certain species, fisheries collapse, ecosystem fragmentation and low participation and leadership (particularly among the private sector and rural communities). The observed trend of increased but heterogeneous vegetation cover might be related both to higher spatial variability in surface water availability (precipitation and regional inundation patterns) and more frequent burning (Pricope et al., 2015). Besides, while ecotourism development in the area has led to accumulate natural capital in the form of wildlife, the reinvestment of its benefits in agriculture has increased the demand of land and, in parallel, the community-wildlife conflicts (Stone and Nyaupane, 2017). In the Chobe District in Botswana, existing land use conflicts are triggered by the increasing population and shrinking carnivore and herbivore habitats and feeding agriculture, government policies and increasing tourism potential. Other conflicts in the Chobe District arise between lodge and hotel owners and the nearby local community of the villages, due to hunting activities, waste generation and mining of construction materials (Kaduyu et al., 2021).

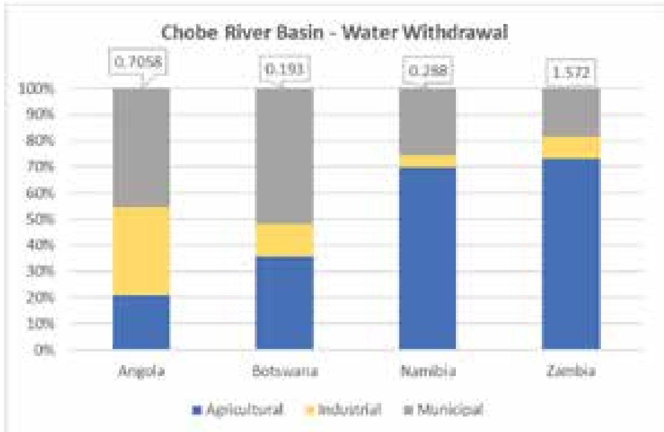
- Access to clean water and sanitation: water sources are generally shared with wildlife and livestock and often they do not have a good quality for human consumption. Except for Botswana, access to clean water is thus unreliable. Most communities in the KAZA region have access to water within 1 km from their villages. Water sources in Angola include shallow wells and swamps and, in Namibia and Zambia, water is collected from streams or boreholes. Regarding sanitation facilities, more than half of the households in the area lack them. At country scale, access to at least basic drinking water services reaches to 57% of the population in Angola, 92% in Botswana, 84% in Namibia and 65% in Zambia, while 51% of Angola's population has access to at least basic sanitation services, almost 80% in Botswana, 35% in Namibia and 31% in Zambia.

The KAZA TFCA currently has a Monitoring and Evaluation (M&E) system which takes 8 indicator groups into account (tourism, human-wildlife conflicts, land use, land cover, socio economic, species population, infrastructure and conservation/ecosystem integrity). However, reported gaps include: impacts on habitats due to the occurrence of fire; benefits accrued to households, income generation and operational costs; human-wildlife conflict data and; protected area management effectiveness.

5.12.2.4 Water use and demands

As reported by the Zambezi River Authority (SADC-WD and DANIDA-SIDA, 2007) reliable data on water use is not available in the Zambezi basin. To estimate water domestic uses, it has been assumed a consumption of 85 l/day/hab for urban uses and 20 l/day/hab for rural areas. Also, it is assumed that 90% of domestic water comes from surface water. A consumption of about 175 Mm^3 (urban) and 24 Mm^3 has been reported for ZRB in 2005. Based on current population density in the CRB, and assuming most of the population living in rural areas (only the town of Kasane is counted) a total of 1.5 Mm^3 can be estimated.

Figure 90. FAO reported water abstraction by sector: % of each sector and total absolute value (annual km^3).



Data for industrial water use is even scarcer: according to this report, a total of about 100,000 m^3/day water demand is needed for main urban areas in the ZRB; no data is currently available for the CRB.

Agriculture in the ZRB is mainly rainfed or flood dependent. About 5.2 M ha yearly is reported of which 85% is in Zimbabwe, Zambia and Malawi. Total irrigated area has been reported at 172,000 ha in 1995, of which only 1% is located in the Chobe, while the most part is in the Tete, Shire River, Kariba and Kafue basins. Total water use for irrigation is 1,500 Mm^3. Livestock is dominated by cattle and most is concentrated in the middle and lower basin (88%). To estimate water demand, a reference of 45 l/day/head has been proposed for non-dairy cattle and 90 for dairy, resulting in a total demand of about 140 Mm^3 in 2005.

Concerning environmental water requirements, very limited and heterogeneous data are available across the ZRB. Environmental flow is now recognised as a legitimate demand in the ZRB, but very limited regulation is currently in place. This is particularly important for river as it is impacted by water abstraction for irrigation, industrial and domestic uses, but also for flooded flats ecosystems and protected humid areas (Kafue Flats in Zambia, Chobe Wetland National Park, etc.). For example, for the Chobe and the Upper basin no data of regulation is available for Angola, Botswana, Namibia, while an indication for the water level in Lake Liambezi and some data are provided for water release (for example 400 m^3/s to 600 m^3/s by Itezhi-tezhi dam).

There is considerable potential and interest to improve navigability of the Zambezi River, including the lakes and impoundments. The initiatives require improved berthing infrastructure, flow level regulation, aquatic weed control and, in selected places, dredging. The resurgence of mining may prompt navigational improvement. Recently an agreement has been concluded between the Governments of Malawi and Mozambique to revitalise navigation on the Lower Shire.

Currently, the total water demand in the ZRB is reported at 20 Mm^3, corresponding to 20% of the basin water runoff, and the major consumption is associated with evaporation from reservoirs (85%) and agriculture (10%). For the future scenarios, main issues which could potentially impact water management in the CRB include: population growth and urbanisation, extension of irrigated land, importance of water flows and flood management, and expansion of the mining sector.

Looking at national data, it is interesting to note that, unlike most African countries, the share of the agricultural sector in Angola's total water withdrawals is much less than those of municipal or industrial usages (FAO, 2022). Municipal demand is the most important water demand, with a share of about 45%. This can be partially attributed to the neglection of the agricultural sector, arising from the civil war (1975-2002). In Botswana, we can observe a similar distribution (the highest percentage also corresponds to the municipal sector (43%) followed by agricultural and industrial sectors. In Zambia and Namibia, the distribution is very different: 70-73% of water withdrawals are for agriculture, while municipal (18-25%) and industrial (5-8%) have much limited impacts. In Zambia, there is now increasing attention directed towards the development of dams and irrigation, as the government advances efforts to enhance food security and adapt to the effects of climate change. The total value of water in the ZRB was estimated at 2,300 million USD in 1990 (irrigated and rainfed agriculture contributed by 30% each, followed by domestic water (22%), livestock (4%) and hydropower (3%)). Consumer surplus was much larger than producer surplus, and the economic value of water was not equally divided over the sub-basins (while Barotse and Cuando-Chobe basins provided relatively low economic benefits, they had the highest economic value due to their upstream location). Therefore, only one third of the total economic value of precipitation in the Upper Zambezi was due to the benefits of water in the basin itself (Hoekstra et al., 2003). Besides, use values of the Cuando and Linyanti-Chobe wetlands were estimated at 9 and 1 USD million/year, respectively, being fish production the main wetland service or product, followed by floodplain recession agriculture, natural products or medicine and livestock grazing (use values of ecotourism and biodiversity were significantly lower; Seyam et al., 2001). Under future scenarios of water demand and climate change projections, demand could exceed water availability in the CRB (even if moderate changes are considered; Beck and Bernauer, 2011). Water scarcity is already an issue

Water demand – issues and challenges

- Data availability: reliable data on water use is not available in the Zambezi basin. Although the Zambezi river authority provides estimations, they should be improved with regard to: source of water uses, industrial water abstraction, agricultural and livestock reported uses, environmental issues.
- Water demand at ZRB scale: currently, the total water demand in the ZRB is reported at 20 Mm^3, corresponding to 20% of the basin water runoff, and the major consumption is associated with evaporation from reservoirs (85%) and agriculture (10%).
- Main issues potentially impacting water management within the CRB: population growth and urbanisation, extension of irrigated land, importance of water flows and floods management, and expansion of the mining sector.
- Concerning environmental water requirements, very limited and heterogeneous data are available across the CRB and, in general, for the ZRB. Environmental flow is now recognised as a legitimate demand in the ZRB, but very limited regulation is currently in place. According to the analysis of future scenarios, demand could exceed water availability in the CRB. Water scarcity is already an issue in the Kwando Wildlife Dispersal area (KWDA) of the KAZA TFCA (which includes the lower reaches of the Kwando/Chobe river in Angola, most of the Caprivi Strip, parts of southwestern Zimbabwe and northern Botswana).
- Navigation: there is considerable potential and interest to improve the navigability of the Zambezi River, including the lakes and impoundments. The initiatives require improved berthing infrastructure, flow level regulation, aquatic weed control and, in selected places, dredging. An agreement has been concluded between the Governments of Malawi and Mozambique to revitalise navigation on the Lower Shire.
- National scale: in Namibia, infrastructure maintenance is the main concern, as existing boreholes are not sufficient to sustain large water demands. According to official sources, in Botswana no significant amounts of water are abstracted from the CRB, although the Chobe-Zambezi has been identified as the main source of surface water resources for future developments. Angola's agricultural water withdrawals as a proportion of total water withdrawals is much less than municipal or industrial usage. In Botswana, there is a similar distribution with the higher percentage corresponding to the municipal sector (43%), followed by the agricultural and industrial sectors. In Zambia and Namibia the distribution is very different: 70-73% of water withdrawal is for agriculture while municipal (18-25%) and industrial sectors (5-8%) have much limited impact.

in the Kwando Wildlife Dispersal area (KWDA) of the KAZA TFCA (which includes the lower reaches of the Kwando/Chobe river in Angola, most of the Caprivi strip, parts of southwestern Zimbabwe and northern Botswana). More than half of the KWDA (65%) is considered as having high to very high vulnerability to water scarcity and competition between wildlife and humans for the limited water and land resources is growing. Human-wildlife conflicts take place mainly during the dry season (when wildlife moves closer to water sources and animals are more prone to raid crops, kill livestock or break down fences or water tanks)

According to the Integrated Water Resources Management Plan (IWRMP) for Namibia (2010), in the Namibian part of the Zambezi-Kwando-Linyanti basin, future water supply was not considered a major challenge (even if the future water demand would be determined by irrigation developments and could rise from 10.3 million m^3/year in 2008 to 179.6 million m^3/year in 2030) but infrastructure maintenance was a main concern. According to the IWRMP, rural areas rely both on surface water (70%) and groundwater (30%) for their supply, and main consumptive uses include livestock and irrigation (although the city of Katima Mulilo (27,400 inhabitants) and surrounding settlements are also a significant consumer). Existing boreholes are not regarded as sufficient to sustain large water demands, and surface water is distributed through a pipeline network from the Zambezi and Kwando rivers (existing infrastructure capacity is 5.6 million m^3/year for groundwater and 4.75 million m^3/year for surface water, respectively). Water resources potential in the Zambezi-Kwando-Linyanti basin was estimated at 4,010 million m^3/year (4,000 million m^3/year of surface water, calculated as 10% of the mean annual average flow at Katima Mulilo, and 10 million m^3/year of groundwater).

The IWRM and Water Efficiency (IWRM/WE) Plan of Botswana (2013) stated that no significant amounts of water were abstracted from the Chobe River, due to the low population density and minimal irrigation demand in the area. However, it identified the Chobe-Zambezi as the main source of future surface water (550-1,700 Mm^3) for future developments. Regarding groundwater, the document pointed out the existence of good potential in western and northern Botswana to expand groundwater abstractions, for example around Maun and elsewhere in Ngamiland, Masama, Gweta, Botlhapatlou, Paje and Kang Phuduhudu. Water demand in the cluster of Kasane was estimated at 2,900 m^3/day and a potential transfer from Chobe and Congo was mentioned as a comment. According to this document, at the time of its release only a few environmental flow assessments had been undertaken in the country (the Chobe River was not mentioned among them) and the available environmental impact assessments (EIAs) raised concerns about downstream ecological requirements (monitoring of proposed mitigation measures was recommended).

Zambia's IWRM/WE Implementation Plan (2008) did not make any explicit reference to the CRB. The country's annual total renewable potential was estimated to be just over 100 km^3 (ranging from 68 km^3 to 130 km^3 depending on the year and with the Zambezi River, at the confluence of the Luangwa River, contributing to 60% of the runoff). The most developed basin in Zambia is the Kafue basin (in 2008 it supported near 40% of the country's population, hosting all the major industries and the largest hydropower station). Other basins undergoing increased pressure were Lunsenfwa, Kaleya and most catchments around Lusaka. Groundwater is well distributed across the country and its average renewable groundwater potential is estimated to be 49.6 km^3. Zambia's total water demand was estimated at 40 km^3/year, most of it for hydropower generation, a non-consumptive use (36 km^3/year). At the time of that assessment, agriculture used about 77% of the remaining water demand to irrigate 100,000 ha (although new significant developments were planned), industry accounted for 7% and the rest for domestic supply and other uses.

Neither the IWRM Survey nor Status Report of Angola (2009) mentioned the CRB. According to this document, the country has a complex hydrological network, with 47 main basins divided in 5 watersheds: Atlantic (41% of the surface area, the only international river is the Cunene River which forms the border with Namibia), Zaire (21.6%, feeds the Kassai River, one of the Zaire's tributaries), Etosha (3.8%, runs across the Etosha Plains in Namibia), Cubango (11.9%, feeds the Okavango region in Botswana) and the Indica (around 18.6%, water flows through Zambia and the Zambezi River discharges in the Indian Ocean in Mozambique). Total runoff was estimated between 120 and 150 km^3/year, and total consumption at the time at 2,330 million m^3/year, being agriculture the main water user (86%), followed by domestic supply (9%), livestock (3%) and the industrial sector (2%). Hydropower water use was estimated at about 5,000 million m^3. The main existing irrigation schemes took water from the Bengo River (Quiminha dam) and the Cunene River (Gove and Matala dams), while projected locations for new infrastructure included the Bengo, Catumbela, Kwanza, Cunje, Cunene, Dande and Luachimo rivers.

5.12.2.5 Water quality, health and environmental issues

As evidenced in the characterisation of the CRB in the previous chapter, the basin is one of the most pristine environments in Africa, with large areas uninhabited and reserved for wildlife, low population density (less than 5 per km^2), and urban land cover and cropland covering only 0.1 and 0.3% of the basin area, respectively. Intense agriculture is absent, while pasture and wildlife tourism are important sectors. Consequently, anthropogenic pollution from land use in the basin itself seems rather negligible.

A hydrological particularity needs consideration when looking into the water quality of the CRB: there are periodic inputs from the Zambezi River (becoming then a "tributary" of the Chobe River, inverting its flow in the wet season) and from the Okavango River Basin, which overflows occasionally into the Linyanti Swamps.

However, studies on physical-chemical water quality of the Okavango and Zambezi (with higher population densities in their basins) suggest an overall good physical-chemical status of those two rivers. Only occasionally, in some small tributaries draining from more densely populated areas, minor impacts from urban wastewaters were found, and close to some industrial agricultural plots fertiliser leaching was observed. However, these localised phenomena remain without any implication on the overall very good physical-chemical water quality of both rivers. In so far also any relevant cross-catchment anthropogenic pollution of the CRB can be excluded.

Water quality and health – issues and challenges

- Health statistics reveal that, besides the important issues of malnutrition, HIV, and indoor air quality problems, the biological quality of water remains a main human health issue, presumably also in the basin.
- Faecal bacteria and suspended particulate matter loads were much higher in the park areas than close to urban agglomerations (mainly driven by the alteration of the land-aquatic interface, through faecal loading and increased soil erosion from elephants and other wildlife).

Health statistics from the CRB countries reveal that, besides the important issues of malnutrition, HIV, and indoor air quality problems, the biological water quality remains a human health issue, presumably also in the basin. This is indicated by the prevalence of diarrheal disease and, partially, malaria and other vector borne diseases, although at a lower intensity than those typically observed in other African basins.

The CRB itself is at a negligible level of urbanisation and lacks almost any anthropogenic modification of the hydraulic system (dams, irrigation schemes, etc). In so far it can be expected that the observed biological threats to human health represent a sort of "natural baseline" of an ecosystem with its climatic and geographic particularities, which is not yet significantly impacted by anthropogenic pollution. Other than the typical situation of more densely populated Emerging Countries, where "traditional hazards" (such as the release of untreated urban waters) fire back on human health, it is here the pristine environment alone that threatens people.

Figure 91. Key (water quality related) challenges in the basin.

- Research and surveillance:
  - Permanent surveillance of bacteriological water quality for human consumption.
  - Monitoring and mapping of wildlife movements and its access to perennial sources of surface water.
- Mitigation:
  - Ensure domestic wastewater treatment, proper domestic waste management and access to safe drinking water.
  - Ensure water access for wildlife and refrain from its compression into smaller natural areas to avoid further of water quality declines and riverbank erosion.
  - Designate and maintain suitable wildlife corridors in a sustainable farmland-park balance to avoid human-wildlife conflict over available space.

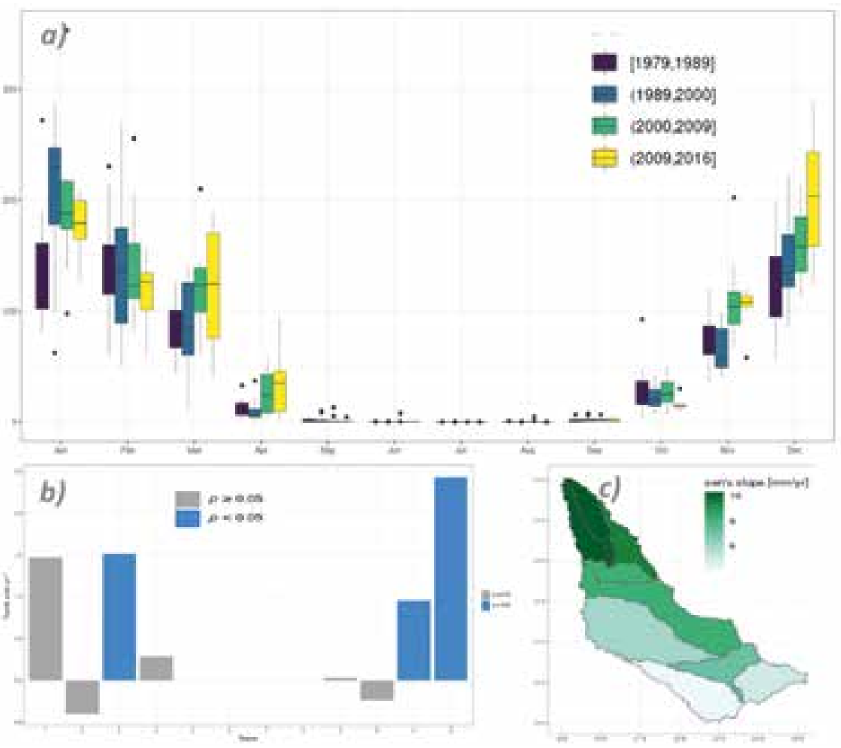
And indeed, field studies on microbial pollution of the surface waters support the particularity of this extraordinary river basin: faecal pathogens and suspended particulate matter (SPM) pollution (from river bank erosion) in the river are mainly driven by the alteration of the land-aquatic interface, through faecal loading and increased soil erosion from elephants and other wildlife.

This was observed in the Chobe River stretch close to the Zambezi confluence, where the faecal bacteria and SPM loads were much higher in the park areas than close to the urban agglomerations. Here, the highest *E. coli* and SPM concentrations occurred in the wet season (during January and February), before experiencing a decline in March.

5.12.2.6 Climate change and Climate Variability

Climatically, the CRB is located in the region of subtropical dry climates, characterised by alternating dry and wet seasons. The wet season occurs during the summer (October to April) and the annual average rainfall is approximately 650-700 mm/year. The mean maximum and mean minimum monthly temperatures during October (hottest month) reach 39 °C and 14 °C respectively, while the coldest month is July, with a mean maximum temperature of 30 °C and a mean minimum monthly temperature of 4 °C. Climate risks in the basin are related to high rainfall variability, which can cause seasonal flooding and occasional dry spells, The CRB was identified as a moderate vulnerability hotspot with regard to climate change, but it could face rising levels of vulnerability by 2050 (manifesting as localised problems for the communities, instead of significantly affecting the ZRB as a whole, due to its net zero contribution to the annual flow of the Zambezi River) (Midgley et al., 2012).

Figure 92. a) Average monthly rain for 4 periods in the CRB. b) Average monthly precipitation trend (significative when blue) and c) annual trend over the basin.



Decreased precipitation and increased dry years with warm phases of El Niño Southern Oscillation (ENSO) have been observed in the basin since the late 1970s, when a climate shift took place. Significantly few dry years were associated with La Niña and, since 2008, the basin has experienced higher than normal rainfall and floods. Therefore, decision making in the KAZA region should consider both the spatial and temporal patterns of rainfall (Gaughan and Waylen, 2012). In Botswana, ENSO was associated to moderate droughts during the summer season and influenced cereal yields (85% and 78% of yield variations in maize and sorghum, respectively; Byakatonda, 2018). Although ENSO is the main driver of southern African rainfall variability (e.g., influencing the number of tropical lows and their mean latitude, which are associated with 31% of rainfall across tropical southern Africa; Howard et al., 2019), it fails at explaining seasonal rainfall anomalies at times. In this regard, the main states of the Angola Low (AL, a low-pressure system located over the Bié plateau in Central Angola) have been found to significantly modulate daily southern Africa rainfall, as anomalously weak and southward AL states were more correlated to regional rainfall than ENSO (Crétat et al., 2019). Another prominent circulation system at mid-tropospheric levels over southern Africa is the Botswana High, which shows a stronger relationship with summer dry

Climate – issues and challenges

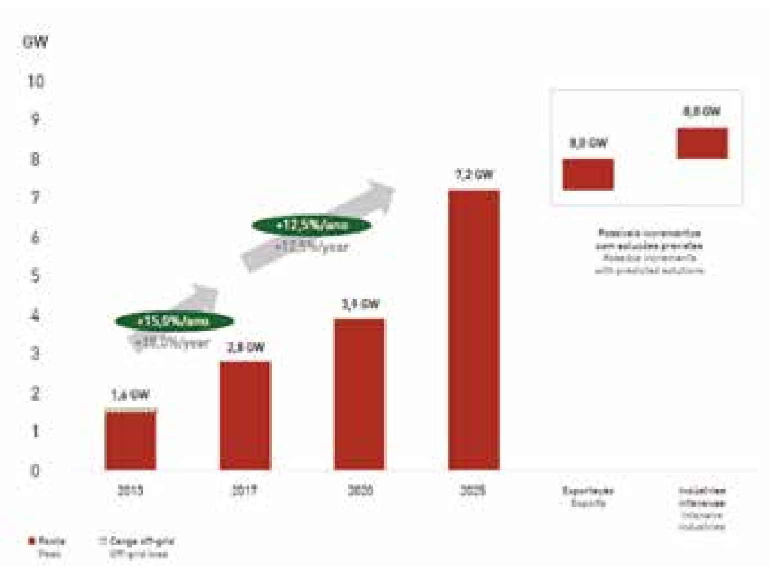
- The CRB is located in the region of subtropical dry climates characterized by alternating dry and wet seasons.
- Climate risks in the basin are related to high rainfall variability, seasonal flooding and occasional dry spells.
- Decreased precipitation and increased dry years have been observed in the basin since the late 1970s.
- In the recent years, annual rainfall trends are positive and lower in the lower part of the basin than in the upper part. Other authors report low negative trends of annual precipitation in the Chobe-Zambezi-Okawango area. Therefore, further analyses are suggested.
- A precipitation deficit of about 40% is likely to occur considering a return period of 5 years. Precipitation trends are generally low or insignificant although slowly increasing trends occur at the beginning and the end of the rainy season months (November, December and March).

spell frequency than ENSO in several important agricultural regions and whose variability also impacts on other important parameters for rainfed agriculture (e.g., maximum surface air temperature, daily surface air temperature range and days of maximum temperature extremes) (Driver and Reason, 2017). In addition, it has been suggested that atmospheric teleconnections in Southern Africa are more sensitive to Sea Surface Temperature (SST) forcing over the Atlantic Ocean during La Niña, while SST forcing over the Indian Ocean predominantly influences them during El Niño. This could affect the predictability of rainfall over the region, as the phase of the Subtropical Indian Ocean Dipole (SIOD) can disrupt or enhance its response to ENSO (Hoell et al., 2017). According to Cordano and Cattaneo (2021) a precipitation deficit of about 40% is likely to occur considering a return period of 5 years. Precipitation trends are generally low or insignificant although slowly increasing trends occur at the beginning and the end of the rainy season months (November, December and March). Besides, annual rainfall trends are positive and lower in the lower part of the basin than in the upper part (see figure in the Box). The results seem to slightly differ from the outcomes of Gaughan and Waylen (2012), showing low negative trends of annual precipitation in the Chobe-Zambezi-Okawango area. Therefore, further analyses are suggested.

5.12.2.7 Water and Energy

According to the Integrated Water Resources Management Strategy and Implementation Plan (ZAMSTRAT) of the ZRB, a total capacity of 4,684 MW (about 10% of the total potential) has been developed in the basin. Concretely, 75% of this capacity is located on the Zambezi River itself, producing an average of almost 33,000 GWh per year (SADC-WD and DANIDA-SIDA, 2007). A number of hydropower plants in the ZRB are run-of-river plants with only a small reservoir or intake dam, while other plants have a reservoir with a storage capacity to store water from the rainy through the dry season. Only three reservoirs have a regulating capacity of significance: Kariba, Cahora Bassa and Itezhi Tezhi and they can be associated to important water loss issues (about 17 km³ loss by evaporation has been reported). The evaporation loss is dominated by Kariba and Cahora Bassa.

Figure 93. Trend of the maximum annual energy load of the system until 2025. Source: Angola Energia 2025 (Angola Energy 2025 (gestoenergy.com).



According to the long-term vision of Angola's power sector (Angola 2025), energy consumption at national level could reach a load of 7.2 GW (more than four times the present). Grid extension and rural electrification are considered as priorities (grid expansion will enable the electrification of 5% of the population and 173 locations, 32 locations will be served by small-hydro, diesel or solar and 500 "solar villages" will be installed in off-grid main villages and other settlements). To ensure a safe power supply, the document estimates that Angola should have 9.9 GW of installed capacity, achieving more than 70% of installed renewable capacity (additional capacity of 800 MW of biomass, solar, wind and mini-hydro) and with a strong reliance in hydro and gas (which will correspond to 66% and 19% of installed power capacity, respectively). The total share of hydro regarding internal consumption could oscillate between 70% in favourable years and 48% in dry years. However, the provinces that intersect the CRB (Cuando Cubango and Moxico, located in the south-eastern part of the country) are not expected to either host large consumption clusters or generation facilities (see figure in the Box).

Botswana's Integrated Resource Plan for Electricity (2020) envisions three energy demand scenarios by 2040: 1) Business as Usual (BAU), an optimistic scenario characterised by rapid GDP growth and electricity consumption of around 8.5 TWh; 2) Alternative (ALT), assuming slower growth rates due to a reduction of diamond production and electricity consumption of 6 TWh and; 3) Energy Demand Management Measures (EDM), considering same economic growth than the BAU (Business As Usual) scenario but including technological progress and energy efficiency measures (electricity consumption of 7.7 TWh by 2040). The existing power generation system in Botswana is based on fossil fuels (two coal-fired power plants and two diesel generators). Identified new projects include a solar PV power plant (100 MW, expected to feed electricity to the system by 2021) and a Coal Bed Methane (CBM) generation initiative (10 MW, expected by 2025). Apart from coal-bed methane, there are no proven reserves of other fossil fuels in the country (such as oil or gas, petroleum products are imported). There is significant solar potential and wind (the latter in the south-west and eastern parts of Botswana). Other energy resources are biogas and fuel wood, but the country does not have hydropower potential.

According to Namibia's National Renewable Energy Policy (2017), the country has the world's second highest solar irradiation regime, high wind potential (especially in coastal areas), several hot springs (which could indicate potential for geothermal energy development, although limited data is available), an opportunity for biomass-based energy (through the conversion of the encroacher bush, an invasive species which covers 30% of the land, into bioenergy) and hydropower potential in the Kunene, Kavango and Orange rivers. However, when the document was released, the country's demand (600 MW) was higher than its installed generation capacity (500 MW, 65% corresponding to hydro, 24% to coal, 9% to fuel oil and 2% to solar PV) and made the gap through electricity imports (59% of Namibia's supply during the previous decade, with imports being a main concern due to the prospect of power shortages in the Southern African Power Pool, SAPP). Besides, the document stated that only one third of the population had access to electricity and more than half of the country still used traditional biomass for cooking. By 2030, Namibia aims to achieve 70% or more of electricity generated using renewable sources.

In Zambia, the National Energy Plan (2019) identifies an increasing energy demand due to demographic and socioeconomic factors (average increase of 150-200 MW/year, expected population increase from 17.9 million in 2019 to 26.9 million by 2035). Currently, the installed generation capacity in Zambia is 2,976.3 MW (80.8% of hydro, 10% of coal, 3.5% of heavy fuel oil, 2.7% of diesel and 3% of solar PV). The mining sector is the main consumer of electricity (estimated 51.1%), followed by the domestic sector (33.2%). Zambia's hydropower potential is estimated at more than 6,000 MW, out of which 2,354 MW has been developed (large hydropower projects under feasibility studies account for an additional capacity of 2,800 MW). Other renewable sources of energy include: solar (the country has a good potential both for photovoltaic and solar thermal applications, although the level of investment has been low due to high capital costs and inadequate regulatory frameworks); wind (suitable resources for electricity production, water pumping for household use and irrigation, but not currently developed); geothermal (it is believed to have potential for power generation and direct applications, although high exploration costs have prevented its proper exploitation); small hydropower (currently only amounts to 1.5% of the installed capacity due to barriers such as economies of scale and long distances to load centres, but it could play an important role in rural electrification (only 4.4% of rural households have access to electricity) and the off-grid space); biomass (70% of the primary energy supply, being wood fuel the main fuel for cooking) and; waste for energy production purposes. The country also has coal reserves over 30 million tonnes and large deposits of uranium (although their use has been restricted to research, education, industrial and medical applications). Petroleum products (contribution of 9.4% to the total national energy demand) are imported.

Water and Energy – issues and challenges

- According to the long-term vision of Angola's power sector (Angola 2025), energy consumption at national level could reach a load of 7.2 GW (more than four times the present one). Grid extension and rural electrification are considered as priorities. However, the provinces that intersect the CRB are not expected to either host large consumption clusters or generation facilities.
- Botswana: the existing power generation system is based on fossil fuels. Identified new projects include a solar PV power plant (100 MW, expected to feed electricity to the system by 2021) and a Coal Bed Methane (CBM) generation initiative (10 MW, expected by 2025). The country does not have hydropower potential. There is significant solar potential and wind.
- Namibia: the country has the world's second highest solar irradiation regime, high wind potential (especially in coastal areas), several hot springs (potential for geothermal energy development, although limited data is available), and an opportunity for biomass-based energy (encroacher bush bioenergy). Hydropower potential in the Kunene, Kavango and Orange rivers. Only one third of the population had access to electricity and more than half of the country still use traditional biomass for cooking.
- Zambia: the mining sector is the main consumer of electricity (estimated at 51.1%), followed by the domestic sector (33.2%). Zambia's hydropower potential is estimated at more than 6,000 MW, out of which 40% has been developed (large hydropower projects under feasibility studies account for an additional capacity of 2,800 MW).

5.12.3 Summary map and priorities

The priorities listed below have consistently emerged as ongoing ones requiring concerted attention:

- Management of protected areas in the context of a WEFE Nexus sustainable management
    - *Ensure park and Protected Areas transboundary management*. The basin hosts part of the KAZA TFCA conservation area, protected forest (2), natural parks (3), the largest elephant population on earth and several important wetlands.
    - *Improve assessment and monitoring of seasonal flooding*. Seasonal flooding process is critical to the health and productivity of such natural systems but has influences on crop productivity, land management and both water quality and human health (diarrheal disease); it is highly variable in time and space and dependent on climate variability and input from other sources (such as the return flow from Zambezi).
    - *Development of a strategic environmental assessment*. Importance of the area is growing fast: current call for a Strategic Environmental Assessment has been opened in early 2022 by ZAMCOM and WWF.
    - *Assessment of water transfers*. Pressure from development activities: e.g., i) water transfer systems have been proposed or are under discussion. Currently the Chobe/Zambezi Transfer Scheme has been identified as a development priority for Botswana and ZAMCOM, with the scope to improve irrigation development and water supply. ii) Livestock grazing is already impacting landcover by favouring a reduction of natural vegetation and soil fertility.
- Assessment of hydrological regime
    - *Improve assessment of precipitation trends*. An increasing trend of precipitation, specifically in the months of November, December and March-April. Further assessment required.
    - *Improve data and monitoring of water deficit*. Precipitation deficit (with short return period) is quite high in the basin, specifically in grassland and agricultural regions and nearby the natural wetland area. Data and knowledge for the quantification of the impact is required.
    - *Monitoring and assessment of flood pulses*. Flood pulses dynamics characterise the most important livelihood system in the basin: high variability in space (extension) and time (start, length, recurrence, etc.) need a continuous monitoring and assessment.
    - *Groundwater assessment*. Water-table lowering has been associated with localised desiccation and it is resulting in increased soil salinisation, leading to invasions by relatively deeper-rooted woody vegetation.
- Management of the increasing water demand
    - *Improve data collection and sharing*. Reliable data on water use is not available. Total water demand in the Zambezi is 20% of the basin water runoff, and the major consumption is associated with evaporation from reservoirs (85%) and agriculture (10%). Anyway, a specific assessment at Chobe level is required. According to future scenarios analysis, demand could exceed water availability in the CRB.
    - *Improve hydro-economic modelling capacity*. Main issues potentially impacting water management within the basin: population growth and urbanisation, extension of irrigated land, importance of water flows and flood management, and expansion of the mining sector. Modelling of such data in the basin is a key activity.
    - *Research and agreement about environmental flow requirement*. Very limited and uneven data for environmental flows. Even if environmental flow is now recognised as a legitimate demand in the whole ZRB, very limited regulation is currently in place.
    - *Improve knowledge on navigability water requirements*. New potential water demand from navigability requirements: the interest to improve navigability in the Zambezi River will require an impact assessment of flow control and management.

  - *Specific National issues:* Namibia identified water infrastructure maintenance as the main concern; Botswana pointed out the Chobe and Zambezi rivers as the main water resources for future development. Highest demanding sectors: agricultural sector (at national level) is dominant in Zambia and Namibia, while is lower in Botswana and Angola (where municipal and industrial uses are the dominant ones).

- Addressing water quality and water related health issues
  - *Improve monitoring and assessment of biological water quality*. Health statistics reveal that, besides the important issues of malnutrition, HIV, and indoor air quality problems, the biological water quality remains as a threat for human health, presumably also in the basin.
  - *Improve monitoring and assessment of faecal bacteria* and suspended particulate matter loads are much higher in the park areas than close to the urban agglomerations (mainly driven by the alteration of the land-aquatic interface through faecal loading and increased soil erosion from elephants and other wildlife).
  - *Ensure monitoring and mapping of bacteriological water quality*, *wildlife movements and its access to perennial sources of surface water (corridors for animals)*. Management of human and wildlife coexistence: ensure water access for wildlife and refrain from its confinement into smaller natural areas; designate and maintain suitable wildlife corridors in a sustainable farmland-park balance.
  - *Ensure domestic wastewater treatment*, proper domestic water and waste management and access to safe drinking water.

- Climate change and variability
  - *Improve knwoledge and research in CC and CV*. Climate risks in the basin are related to high rainfall variability, seasonal flooding and occasional dry spells. Decreased precipitation and increased dry years have been observed in the basin since the late 1970s. In the recent years, annual rainfall trends are positive and lower in the lower part of the basin than in the upper part. But other authors report low negative trends of annual precipitation in the Chobe-Zambezi-Okawango area. Therefore, further analyses are suggested.
  - *Assessment of precipitation deficit*. A precipitation deficit of about 40% is likely to occur considering a return period of 5 years. Precipitation trends are generally low or insignificant although slowly increasing trends occur at the beginning and the end of the rainy season months (November, December and March).
  - *Explore potential of floodplain for irrigation*. Explore potential of Linyanti floodplain for irrigation agricultural expansion (water demand, crop productivity, etc.).

- Address socioeconomic issues and social tension
  - *Improve synergies among wildlife conservation and development users*. Social tensions in the basin arose from the difficulties to harmonise the needs of wildlife conservation (ecosystem and tourism) and those of local farmers. Reducing population dependency on forest is an important strategy to limit the issue.
  - *Reduce uneven socioeconomic levels in the 4 countries:* households in Angola and Zambia lack both physical assets and access to facilities, services and markets. Botswana and Namibia show better conditions, such as more readily available access to road networks, electricity, clean water sources and health facilities. Access to electricity: only households in Botswana have a significant connection to electricity (near 50%), while hardly any household in Namibia is connected and none in both Zambia and Angola. Except for Botswana, access to clean water is unreliable. More than half of the households in the area lack sanitation facilities.
  - *Improve consideration of river dynamics impact on social tension*. The Linyanti-Chobe section of the Cuando River (the southern edge of the Caprivi Strip) acts as an International River

Boundary (IRB) between Namibia and Botswana. It has been identified as a potential hotspot due to the extreme dynamism of the channel morphology and a history of conflict over islands along the channel.

- *Improve knowledge of fishing sector.* Monitoring and assessment of fishing sector and issues. Assessment of tourism trend and development and impact on other sectors.

- Management of the development of energy sector
    - *Improve grid and rural electrification and access to energy.* Angola: grid extension and rural electrification are considered as priorities. However, the provinces that intersect the CRB are not expected to either host large consumption clusters or generation facilities. Namibia has the world's second highest solar irradiation regime, high wind potential (especially in coastal areas), several hot springs (potential for geothermal energy development, although limited data is available), and an opportunity for biomass-based energy (encroacher bush bioenergy). There is a recognised hydropower potential in the Kunene, Kavango and Orange rivers. Only one third of the population has access to electricity and more than half of the country still use traditional biomass for cooking.
    - *Improve development of renewable energy exploitation.* In Botswana, the existing power generation system is based on fossil fuels. Identified new projects include a solar PV power plant and a Coal Bed Methane (CBM) generation initiative. The country does not have hydropower potential, while there is significant solar and wind potential. Zambia the mining sector is the main consumer of electricity (estimated 51.1%), followed by the domestic sector (33.2%). Zambia's hydropower potential is estimated at more than 6,000 MW, out of which 40% has been developed. New large hydropower projects under feasibility studies account for an additional capacity of 2,800 MW.
    - *Reduce firewood demand.* Firewood is primarily used for cooking, causing also health issues.

- Coordinated basin water use monitoring, data collection and management as the basis for effective basin operations and management, including at riparian state national levels.
    - *Improve transboundary collaboration.* Dependence on the Zambezi River: for the Chobe wetland and floodplain area, the most important source in terms of the amount of water is the Zambezi River, which pushes various amounts of water back into the Chobe.

- Summary of stakeholder feedbacks.

In the case of Chobe River basin direct feedback has been provided through EEAS-Gabarone by GIZ.

Key priorities specifically highlighted by EEAS- Gabarone - GIZ are:

- *Assessment of proposed water transfer systems*, with the scope to improve development of irrigation and water supply. It is important to analyse and know the risks posed by poverty and degradation upstream of the basin to safeguard investments as well as understanding the risks of large-scale extraction to the ecosystems of the basin (upstream-downstream effects).
- *Data availability and sharing (Water demands, abstractions, etc.).* Data is regarded as a precondition for transboundary water management and should thus be a focus of the TEI TWM interventions.
- *Pay attention to specific National issues* (such as water infrastructure maintenance for Namibia, water demand and supply interest by Botswana, etc.). EEAS highlights that national priorities must be acknowledged to enable riparian states link the transboundary issues to their respective agendas.
- *Reduce uneven socioeconomic levels of the population living in the basin.* Some specific notes pointed out by GIZ: Considering the high poverty in rural Angola, which makes up 70% of the basins territory, a focus of interventions in this area would be expected. However, the analysis then requires more depth regarding the subsistence-based livelihoods in rural Angola, how these systems affect land and water use and how socio-economic interventions would impact on water security. Livelihoods interventions for food security and WASH interventions should be included. The upstream situation should be

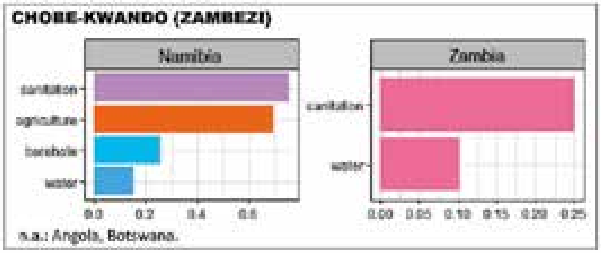
considered as part of risk-informed planning of large downstream projects, like the Pandamatenga irrigation scheme.

- *Improve Transboundary collaboration and agreement between Zambezi and Chobe management.*

Concerning the report GIZ highlight the lack of a political context in the development of assessment and also point out that the high disparities between the four riparian countries should be more taken into consideration, given the transboundary approach of the analysis.

- **Most recurrent water related keywords per country in the river basin:**

Figure 94. Water related events extracted from the ACLED database are representative of water management issues in specific areas in the African continent. The Armed Conflict Location & Event Data Project (ACLED) (Raleigh et al., 2010) offers a collection of political violence and protest events across the developing world. The original dataset, including more than 162 thousands episodes of violence (162,705), was subset in order to identify the episodes related to water resources management. The selection of keywords singled out has been used to highlight violence events potentially related to the water resources management.



5.13 Transboundary River Basin Issues and Relevant STI areas

5.13.1 Food security

In all Sub-Saharan Africa River basins a high level of food insecurity is still a major issue affecting almost 30% of the population. Food insecurity is still a key issue also in the more developed basins, especially in rural and remote areas where poor households can face food insecurity issues even in countries considered as "food secure" (e.g., in case of commodity price shock, specifically when there is high dependency on market access for basic food supply; some examples are in the Chobe-Kwando sub basin in the Zambezi and most of the countries (except SAF) in the Orange). Food issue is associated with*: i)* Low agriculture productivity level, scarce soil fertility management and volatile and unstable production due to its vulnerability to Climate Change (CC) and Climate Variability (CV) arising from its mostly rainfed nature; ii) Fish stocking management: overfishing, not regulated (and illegal) catch, missing monitoring and control data, conflict among countries, alien species, etc.; iii) Livestock management, pasture and transhumant movements: identified issues are linked with limitation to mobility (due to expansion of agricultural land, wildlife interactions and conflicts with farmers), degradation of rangelands, pasture productivity, access to water.

- Actions and STI areas for development in African river basins: i) Strategies for improving soil fertility management to increase the resilience of traditional and rainfed systems to CC and CV and improve farmers' awareness regarding proper soil fertility management (studies and capacity building on regenerative agricultural approaches (moisture retention techniques, drought resistant crops, agroforestry, etc.) ii) Ensure the identification of sustainable intensification practices in order to improve productivity but ensure limited expansion of cropland; iii) Assessment of irrigation cropping systems for the identification of causes of limited production below expectation and identified potential (existing infrastructures have not achieved the irrigation potential identified in the preliminary studies); iv) enhance data collection and assessment of the nexus between pastoralism and agriculture; v) assessment and data to ensure forage production and protect local species (see for example *Kuri* cow in the Lake Chad).
- Specific STI areas:
  1. **Lake Victoria**: i) Adoption of strategies for the valorisation of mixed agricultural production systems (cropping, livestock, pastoral system protection, wetland); ii) Improve knowledge and monitoring of fishing stock in the lakes and assess the impacts from increasing pressures (loss of biodiversity, water cycle and levels, water quality, overfishing); iii) Explore solution to positively conditioning fishing practices sustainability as European market is one of the main importers.
  2. **Niger**: i) Identify strategies to reinforce the coexistence of traditional fadama farming (lowland or inland valleys), recession flood farming, agroforestry, irrigated rice farming ii) Assessment of expansion plan for big irrigation scheme (improvement of plan ensuring long term maintenance of irrigation systems); irrigation efficiency and water productivity and cost benefit analysis of irrigation systems iii) Unlock markets for farmers (e.g., identification of opportunities for the development of the transportation network). Improve knowledge and monitoring of livestock movements access to water and pasture demands.
  3. **Zambezi**: i) Improve data for assessment of fishing sector; Reduce inequality: e.g., unequal land distribution in Malawi; unequal distribution of wealth and income in Namibia; ii) Enhance food security assessment in southern Mozambique and Zimbabwe; iii) Explore the role of existing small water storages to support irrigation.
  4. **Lake Chad**: i) Enhance monitoring of fishing stock and assessment of impacts and trends. ii) Improve adoption of strategies to reduce pasture's diseases and to favour the permanence of local Kuri cow. iii) Malnutrition issue. iv) Monitoring of cropping land suitability reduction as impacted by shrinkage of growing period (explore drought resistant cropping systems).
  5. **Orange**: i) Enhance food self-sufficiency potential specifically in Lesotho, Namibia and Botswana areas of the RB; ii) Reduce heterogeneity of distribution of economic importance and of level of development in the river basin between the riparian countries; iii) Improve the consideration of affordability and cost-benefits ratio of irrigated agriculture expansion in food unsecure regions.

6. **Okavango**: i) Improve the assessment of tourism development and its impacts on other sectors; ii) Improve subsistence and support to fishing industry. ii) Enhance the assessment of flood pulses impacts on subsistence agriculture.
7. **Senegal**: i) Identify strategies to protect traditional food production systems in the basin (based on flood recession agriculture and floodplain fisheries), threatened by navigation/hydropower developments; ii) Identify the main barriers which hinder the productivity of current irrigation schemes in the Senegal River valley and potential options to tackle them; iii) Identify strategies to promote local animal husbandry, threatened by multiple challenges (e.g., pressure of the agricultural sector, CV and CC, etc.) and which could contribute to reduce Senegal's dependence on dairy product imports (which demand is on the rise due to urbanisation and its related consumption models).
8. **Limpopo**: i) Need for better information on the distribution and management of water for agriculture in the basin, as well as its implications on economic hardships; ii) Diffusion of alternative practices and capacity building (e.g., generative agricultural approaches).
9. **Tanganyika**; i) Better characterisation of fishing stocks and adoption of strategies to address their decline (e.g., preventing the use of active abnormal fish nets and the capture of juveniles); ii) Increase the resilience of the agricultural sector to climate shocks and assess the implications of the large number of refugees (fleeing from DRC, Burundi) in regional food security; iii) Improve the transportation network to enhance the security of food supply and the humanitarian response to emergency situations (e.g., rehabilitation of Bujumbura port will reduce maize transport costs from Zambia to Burundi).
10. **Chobe**: i) Identification of potential measures to avoid crop/livestock losses due to human-wildlife interactions; ii) Assess the effects of climate change on the reduction of fish stocks in the Zambezi-Chobe wetlands (e.g., reduction of seasonal depressions or mulapos).

5.13.2 Management of flow regime, floods, droughts and CC

An important element arising out of these analyses is the existence of a knowledge gap, and above all the existence of a controversial discussion among the main causes of land degradation and water balance at river basin scales. Groundwater (GW) and aquifer system monitoring and knowledge is often reported as a priority, but missing data and information are evidenced in most of the River Basins: indeed, GW exploitation is sometimes reported as low and other times as very high, but regularly pointing out very poor knowledge (e.g., reported evidence of depletion, but with high uncertainty as limited data and modelling capacity available). Impact of CC always identified as a key issue, even if the specific impact on different sectors is still controversial and requires documented regional assessment (to take into consideration regional specific elements, downscaling of CC scenarios and specific impact of local CV impacts on the short term). Impact of dam management on river flow is also a general issue for most of the basins. In this regards support multi-purpose infrastructure and cost benefit analysis should be ensured for past and future dam development and management.

- Actions and STI areas for development in African river basins: i) A key action identified and shared by all the stakeholders is the need for the development of agreed and shared data, knowledge and human capacity development (HCD) across the riparian countries; ii) Development and enhancement of scientific, objective and open data, models and monitoring that contribute to further understand the phenomena and the potential mitigation and adaptation solutions; iii) Optimal water level and release quantification and management in the reservoirs and lakes; agreed identification of dominant causes impacting floods (specifically in the Niger), assessment and resolution of competition between sectors (tourism, hydropower, agriculture, environment, etc.); iv) Definition and agreement (among countries and users) for river environmental flow (spec. in the Orange); improve scarce monitoring and knowledge of water balance data (see the Okavango); clarify the ongoing debate on land-use changes and impact on soil water holding capacity in the Senegal; v) Improve knowledge of climate variability and change and their impacts on water availability over time and space, (e.g., rainfall changes are of utmost importance in Lake Victoria, as direct rainfall supplies most of water inputs to the lake).

- Specific STI areas:
    1. **Lake Victoria**: i) Assessment of the changes (trend on short and long term temporal scale) of lake levels and identification of main factors affecting water balance; ii) Development of robust hydro-economic and physically based modelling capacity and scientific knowledge; iii) Improvement of early warning system for the protection of fisherman from damage and death caused by storms on the lake.
    2. **Niger**: i) Identification and agreement between countries among identification of major drivers of floods (e.g in Mali, Cameroon and in the Delta); ii) Improve the accuracy of the Global Forecast System (GFS); iii) Improve assessment of local and short-term negative precipitation variability (dry spell); iv) Given the dimension of expected additional dams in this basin, the development of integrated hydro economic modelling (capacity and knowledge at local scale, HCD) is specifically key in this basin.
    3. **Zambezi**: Conduct assessment of the impact of dredging and canalisation plan in the river and delta; ii) Mozambique: Assessment and HCD for the identification of strategies to reduce impact of natural hazards (cyclones, floods, droughts). iii) Assessment of the impact pf water flow regulation on tourism (e.g, Victoia Falls, and Batoka dam).
    4. **Lake Chad**: i) Improve knowledge and agreement among water balance dynamics in Lake Chad (lake extent and trends still controversial); ii) Ensure assessment of pastoral livelihoods as in the Lake Chad basin could be more vulnerable to climate variability than farming and fishing ones.
    5. **Orange**: i) Environmental flow requirements need to be adequately addressed. Need for an agreed definition.
    6. **Okavango** i) Improve research actions to solve the issue of absence of sufficient information regarding the scale, significance and resilience of ecosystem responses within the Okavango river basin (and specifically in the Delta) to decreased inflows; ii) Further analysis on the impact of CC and CV: e.g., deforestation along the Okavango River leads to an augmentation of the inflow to the Delta, mitigating the local effects of climate change.
    7. **Senegal**: i) Design of an artificial flood regime to protect traditional food systems (highly vulnerable to hydroclimatic conditions and allocation changes) and ecosystems; ii) Detail assessment of the impacts of land degradation on the hydrological response of the Upper Senegal, as it is the major contributor to the Senegal river flow and has undergone significant land use changes in recent years; iii) Identification of measures to address the rapid progression of the breach in the Langue de Barbarie (which started after the rapid drainage of flood waters to preserve the city of Saint-Louis; iv) Risk assessment of sea level rise due to climate change in the coastal areas of the basin (considered as highly vulnerable due to its low, plain nature).
    8. **Limpopo**: i) Enhance the knowledge on the interaction between surface water and groundwater (increased due to dam construction); ii) Assess the reliability of existing water measures (rainfall, flows) and improve data collection and validation procedures; iii) Improve control of groundwater abstractions (as many boreholes are not registered).
    9. **Tanganyika**: i) Improve knowledge and monitoring of the water balance and level fluctuations of Lake Tanganyika; ii) Assessment and mitigation of wetland shrinkage issues (e.g., in Burundi); iii) Conduct specific groundwater assessments in the Lake Tanganyika Basin (as most of the existing studies in the region are focused in Tanzania or other basins); iv) Risk assessment of flood/landslide/mudslide prone areas (e.g., Burundi).
    10. **Chobe**: i) Improve data collection mainly in the Angolan part of the basin (as most weather stations were destroyed during the war) and regarding to groundwater (lack of water table level time series does not permit to conduct any quantitative assessment or detect trends); ii) Better characterisation of channel morphology dynamics in potential zones of conflict (e.g., among Namibia and Botswana in the case of Kasikili/Sedudu Island).

5.13.3 Management of increasing water demand

In general, a very high increase is expected for agriculture and hydropower sectors in most of the river basins. Specifically an increasing and stronger competition between hydropower, irrigation, navigation and natural flow is clearly expected: in the White Nile (Lake Victoria) this is particularly evident for navigation and because of pressure on wetland; in the Niger the figure is quite complex and irregular across the river basin (development of new dams upstream, impact on the Inner delta, navigability in the middle Niger, erosion issues in some regions, not efficient use of water release by irrigation systems, exploitation pressure already very high during dry seasons, relative small capacity for GW exploitation etc.); in the Zambezi large water transfer systems are under discussion and would need a more equitable water allocation among riparian countries. In the Lake Chad high GW exploitation level for drinking water is already identified. In the Orange water demand and resource sharing is specifically under discussion for Namibia and South Africa.

- <u>Actions and STI areas for development in African river basins</u>: i) Enhance Basin-Wide Water management plan and assessment specifically important to identify optimal and agreed water allocation among the countries. ii) Assessment of water demand variability across space and time (changes within the basin and in different periods of the year) and as impacted by planned and future new dams (high potential for hydropower and irrigation identified); iii) Even if the trade-offs between sectors users and water demand have been someway already identified and assessed (see Senegal RB), still uncertainty remain specifically for traditional food production systems that as water user are much more sensitive to hydro-climatic condition and external factors which should ensure traditional system water demand allocation; iv) Increase data and knowledge for the quantification of growing demand from all different sectors and the assessment of their cross-sectoral links. v) Raising awareness of the need of a new management approach: shift from looking into ways to increase water supply to looking into ways to improve management the water available. vi) Dissemination of strategies and best practises for: increase the use of recycled water, more efficient irrigation system (drip vs flood), improve water accounting systems, and improve cropping system water productivity. vii) Research and strategies for the identification of more equitable water allocation among users, regions and countries: importance of water accounting to indicate the relative contribution of different economic sectors to socio-economic development to identify proper water use allocations at appropriate geographical scales (local, regional, national and basin-wide).
- <u>Specific STI areas</u>:
  1. **Lake Victoria**: i) Trade off assessment for the identification of optimal management taking specifically into account navigation issue.
  2. **Niger**: i) Assessment of potential role of large groundwater resources in middle and lower NRB (e.g., Iullemeden and Taoudéni aquifers) supporting adaptation strategies and specifically rural poor areas drinking water supply. ii) Assessment of the seasonality of water demand (e.g. Markala dam, different timing between demand and supply).
  3. **Zambezi**: i) Impact assessment of potential water transfer projects and identification of equitable allocation strategies; ii) Sustainability assessment of groundwater exploitation.
  4. **Lake Chad**: i) Explore the potential and sustainability (high exploitation already observed in Niger and Nigeria) of Quaternary phreatic aquifer to sustain drinking water and livestock demand; ii) HCD to ensure the enforcement of wells protection regulations; iii) Enhance access to safe drinking water by replacing traditional supply methods.
  5. **Orange** i) Increase research and effectiveness assessment of MAR (Managed Aquifer Recharge), an emerging approach aimed at augmenting groundwater storage. ii) Disaggregate into basin-wide vs country-level issues and challenges, considering geographical and temporal scales: iii) Reduce use of flood irrigation system: knowledge and HCD for farmers; iv) Identification of optimal water conservation practices (e.g., re-use of water, desalination, rainwater harvesting, etc.).
  6. **Okavango**: i) Need to implement a comprehensive basin-wide water management plan; ii) Enhance modelling and scientific based determination of optimal objective, fair and reasonable water allocation to each of the riparian states; iii) Improve knowledge on groundwater recharge; iv) Assess the economic value of ecosystem services.
  7. **Senegal**: i) Assessment of the trade-offs of allocation policies between the two main coalition objectives identified in the basin (traditional food production versus hydropower-navigation); ii) Improve the knowledge about groundwater systems and promote the adoption of measures for

their legal protection and control (e.g., the Diass aquifer in Senegal is experiencing intensive water abstraction to supply the increasing demand of Dakar).

8. Limpopo: i) Need for better water management approaches (as demands are higher than current water availability) and identification of both supply (e.g., use of recycled water) and demand-side measures (e.g., change to drip irrigation) to decrease water scarcity; ii) Improve stakeholder involvement for effective policy implementation.

9. Tanganyika: according to the existing literature, neither current water diversions for irrigation nor hydroelectric production in the Rusizi tributary have significant impacts on Lake Tanganyika, but future scenarios on water demand should be explored for the basin.

10. Chobe: i) Need to collect further information on water uses (agricultural, domestic and industrial sectors) and improve the knowledge on environmental flow requirements; ii) Assess the potential impacts of the Chobe/Zambezi Water Transfer Scheme in the basin (especially in the main protected area, the KAZA TFCA).

5.13.4 Addressing water quality issues and health related diseases and degradation.

Biological water quality is a key issue in all river basins, whereas anthropogenic chemical pollution of the environment is not, given the degree of its development, a priority problem for human health and the environment. Indeed, in some cases, chemical pollution is identified as a key problem in several areas and programmes, but it should be noted that most of these problems are usually very local in nature and are well localised, e.g., near large cities, extensive industrial agriculture, mining, etc. They are also specifically related to occupational risks and hazards. In contrast to the European context, pesticides are not currently a generalised environmental risk in river basins, but rather a risk to workers' health, due to poor management of domestic and industrial processes and waste. Diarrheal, bacteria and water borne diseases (such as malaria, schistosomiasis, filariasis, dengue, yellow fever) are mostly associated with urbanisation and alteration of ecological systems. These diseases are a key issue for all river basins analysed. Other important issues captured in several case studies are: mercury issues gold mining areas (White Nile RB, Mali and Guinea in the Niger RB, Orange RB, Senegal RB) and other mining related contamination problems. Pollution from agrochemicals, eutrophication issues and industrial impacts on water quality are mainly due to untreated urban effluents, domestic, industrial and livestock waste. Pesticides are normally below law limits, but some local specific issues persist: for example, in the case of cocoa and cotton plantations. Micro and small macro plastic issues in water are also detected (specifically in the Lake Victoria RB (Nile) and in the Delta of Niger). Oil spills issues (specifically in the Niger RB). Land degradation with loss of biodiversity, deforestation, Land-use and land-cover changes, proliferation of invasive species, desertification and bush fires, soil salinisation and indoor air pollution.

- Actions and STI areas for development in African river basins: i) Assessing and mapping the risks related to biological water quality and water-borne diseases, identifying the most urgent ones and promoting their proper integration in the impact assessment of new dam and irrigation infrastructure projects (human health issues related to water quality are key specifically in Lake Victoria, Niger, Lake Chad, Senegal, Limpopo, Tanganyika and Chobe). Explore non-invasive solutions, such as those proposed in the Senegal RB; ii) Improved research and monitoring: Basin-wide monitoring and mapping of bacteriological water quality and waterborne diseases, specifically for all new dam/irrigation projects. iii) Specific environmental impact assessment and mapping of mining and oil projects; iv) Establishment of a groundwater monitoring network; v) Mitigation: Improving wastewater treatment and waste management, awareness raising and technology transfer are needed in the area of waste management and recycling; v) Evaluation of wetland restoration and erosion control programmes.

- Specific STI areas:

1. Lake Victoria: i) Identify and propose mitigation strategies to tackle wetland degradation, arising from multiple drivers (such as urbanisation expansion, extension of agricultural land and livestock and improve knowledge for the identification of strategies for wetland restoration.

2. Niger: i) Environmental damage and chemical pollution arise from gold mining in Mali and Guinea: the focus should be on inventorying the artisanal mining sites and implementing existing mercury reduction/replacement technologies and waste management programs. ii) Assessment of oil

exploitation impact on local communities in the Delta region; iii) Assessment of plastic waste mismanagement issue in the Delta region.

3. **Zambezi**: i) Assessment of eutrophication and its causes (excessive use of fertilisers, untreated wastewater effluents, etc.), specifically assess hotspots in Zimbabwe, Harare area, Shire, etc.); ii) Identification of strategies to limit saltwater intrusion in the delta, specifically during the dry season, which affects fisheries and agriculture; monitoring of mining mainly for iron and steel and in the Copper-Belt; introduction of riparian protection zones strategies; iii) Monitoring of the impact of wetland exploitation for agriculture and fishing.
4. **Lake Chad**: i) Improve monitoring and scientific knowledge of floodplain shrinkage, wells protection, ii) Improve assessment of land degradation, specifically for land use and landcover changes, invasive plant species, alkalinity and eutrophication (linked with untreated sewage and animal faeces.
5. **Orange**: i) Improve monitoring of degradation of wetlands, loss of species and alien invasive vegetation (specifically in the river mouth); ii) Improve knowledge and monitoring of environmental issues (land degradation, erosion, etc.) specifically in the Lesotho highlands; iii) Implementing a basin-wide monitoring programme for radionuclides in ground and surface waters; basin-wide monitoring of POPs, heavy metals, and radio-nuclides in biota; basin-wide monitoring of chemicals of emerging concern, such as pharmaceuticals and microplastics; iv) Monitor water pollution and salinisation in areas of intense irrigated agriculture (CPIS) along the river banks.
6. **Okavango**: i) Assess impacts on the delta area (arising from upstream water exploitation and pollution) and identify mitigation measures; ii) Implement biomonitoring and ecosystem health monitoring at basin level.
7. **Senegal**: i) Improve the integration of the health component within the WEFE nexus framework, to control the negative impacts associated to dam development (e.g., expansion of schistosomiasis) in the context of new infrastructures; ii) Identification of strategies to cope with localised salinity issues (e.g., near the river mouth); improve water quality monitoring, especially in areas which host potentially pollutant activities (e.g., Falémé and Bafing rivers).
8. **Limpopo**: i) Need for an effective integration of water quality issues in water management, ensuring monitoring, compliance and enforcement (especially in pollution hotspots such as the Olifants River in South Africa).
9. **Tanganyika**: i) Assess the main drivers of land degradation and related impacts on water quality, identifying hotspots within the basin and proposing mitigation measures; ii) Monitoring of localised pollution issues in drinking water sources (e.g., arsenic and fluoride in Tanzania) and biological risks; iii) Measures to control the expansion of water hyacinth.
10. **Chobe**: i) Assess the impacts of wildlife on water quality.

5.13.5 Management of water-energy sector

In this assessment, the focus is on the analysis of issues related to hydropower, mainly highlighting the current hydropower production in the river basins and the expected potential for the coming years. Hydropower is dominant in Lake Victoria (White Nile) basin, but with evidence of water shortage issues (Burundi). In some river basins, it is reported that hydropower potential is not yet highly exploited (e.g., in the Niger RB where it is argued that only 1/3 of the potential is exploited). The need for a more complete assessment of potential conflicts and impacts on other sectors has been often identified as a priority (see competition with navigation services and natural flow requirements in the Lake Victoria, flooding impact evidenced in the Niger RB, Senegal, and Zambezi. In the Senegal RB, dams are currently satisfying about 18% of the energy demand but impact on other sectors (e.g., traditional food production) are already an argument of stress, conflicts and tension between different users. Inefficiencies inherent in large dams have been identified (evapotranspiration losses, impact on local ecosystems, maintenance problems, etc.). A frequent issue identified is the need to reduce fuel wood and charcoal demand that is still dominant in most of the basins. Limited connection to existing grid (low electrification rate) is often an issue for most of the rural areas: even RBs with high hydropower and energy production would need an improvement of the transmission network to ensure an equal and fair redistribution and allocation of energy. A way to compensate for this limitation would be the development of very local alternative systems using renewable energy (mix bioenergy-PV).

- <u>Actions and STI areas for development in African river basins</u>: i) Explore the potential of small hydropower plant to support rural electrification and the synergies with other sources (biogas, residues valorisation, PV, Floating-PV and Solar); ii) Support multi-purpose infrastructure and cost benefit analysis. iii) Solve transboundary water disagreement (see e.g., South Africa and Namibia in the Orange, upstream and downstream countries in the Nile) and move to equitable (energy and water) resource allocation; iv) Explore alternative solutions to mitigate reservoir management inefficiencies by implementing, for example, floating PV system limiting evaporation loss; v) Research for the identification of alternative energy production to reduce fuel wood and charcoal dependency (e.g., improved stoves); vi) Explore solutions using Renewable Energy: Bioenergy - PV – hydropower - Floating photovoltaic system; vii) Improve regional dialogue for better cooperation (coordination and collaboration) in power infrastructure development among countries to make a regional power market and cross-border exchanges feasible.
- <u>Specific STI areas</u>:
  1. Lake Victoria: i) Exploring the transferability at river basin scale of solutions being investigated in Uganda for the use of mini grid networks to supply energy to rural villages.
  2. Niger: i) Improve the consideration and assessment of dams impacts on the diffusion of malaria and other vector borne diseases.
  3. Zambezi: i) Improve impact assessment of dam management on wet season flow and sediment transportation (specifically identifying impacts on the Delta); ii) Identify and conduct rehabilitation projects for old dams (e.g., see the ongoing Kariba Dam Rehabilitation Project (KDRP).
  4. Lake Chad: i) Explore solutions for decentralised renewable energy technologies (such as solar and wind energies) to support economic growth in central and northern parts of the LCB.
  5. Orange: i) Improve assessment and identification of adaptation measures to reduce sedimentation and loss of storage capacity in reservoirs, specifically in Lesotho and downstream in South Africa; ii) Solve transboundary water disagreement (e.g., between South Africa and Namibia).
  6. Okavango: i) Ensure considering impacts assessment of any attempts to impound water or alter river flows in the catchment upstream of the Okavango Delta, to avoid alteration of the patterns of sediment (sand) transport, essential for Delta ecosystem; ii) Detailed feasibility assessment of new proposed potential hydropower projects (considering the uncertainty of future inflows).
  7. Senegal: i) Better characterisation and understanding of the implications of the Banda Gas-to-Power for the participation of Mauritania in the subregional hydropower sharing mechanism of the OMVS (as the country will be transformed from a net consumer into a net producer).
  8. Limpopo; i) Hydropower potential is quite limited in this basin (semi-arid nature), identification of alternative renewable energy sources.
  9. Tanganyika: i) Provide access to the African power grid in the case of sparsely populated regions in the eastern part of the basin; ii) Promote the use of indigenous renewable energy sources to increase electricity production (e.g., geothermal energy).
  10. Chobe: i) According to the national plans, no significant developments are expected in the basin but data at the basin level is not available (data collected in the context of the KAZA TFCA, the whole Zambezi River Basin and at country level had to be used as proxies).

5.13.6 Summary and remarks

The sharing of River Basins reports and list of identified key priorities with EU Delegation and the CoEs Nework developed in the framework of current and past research and collaboration with African Partners (ACEWATER Project, WEFE-Senegal, e-Nexus Western Africa, etc.) has given an important support for the validation of selection and, even if at a prelaminar stage, ensuring an agreement and synergies with current priorities more urgent for stakeholder. Clearly this is a continuous process that still to be further developed by more direct interactions with stakeholders by means of, for example, dedicated workshop, webinars, meeting where direct interaction can facilitate the exchange and the agreement of common identification.

Indeed still we should observe that not all invited experts and EU delegations provided a direct feedback, or sometimes they have limited to agree with the proposed reporting. This is anyway normal and expected and indeed, we have drafted the methodology by highlighting the need for a following phase with more direct interaction (as sharing of pdf reports and Excel survey files is not always the effective way for interaction). This was nevertheless the most practicable and effective way we have identified, given time constraints and issues for travelling (Covid).

It is also important to point out that also each feedback provided is characterized by a sort of *bias*, as influenced by specific expertise and area of interest of the experts/universities, or by specific current political interests or by missing knowledge of awareness among a priority. Indeed in some case may happen that scientific literature, data may point out a specific issue (such as for example for water borne disease) that indeed is not always perceived as a most urgent priority.

In this context it is so important to highlights that:

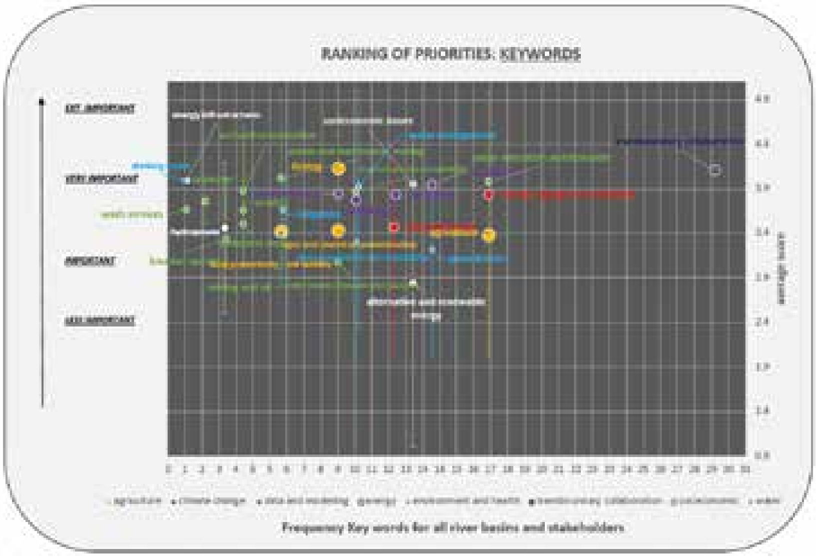
- For all the 10 river basin at least one reference EU Delegation have provided feedback or gave insight about the assessment (in some case the EU Delegations involved external actors in the feedback process such as for example for GIZ and River Basin Authorities and Commissions (OKAKOM, ORASECOM, OMVS, etc.).
- Some CoEs provided feedback for several river basins that is important above all for the intercomparison across different situation.
- Several CoEs expressed the interest for this kind of assessment and identification of priorities research areas, and also confirmed the intention to give a feedback, even if finally they were not yet able to provide it in the deadline proposed.
- The ranking is a supporting info, which should not replace the selection list that remain, according to our methodology, the result to be used to feed the dialogue and discussion. This means that even if some priorities have been ranked as less important by the stakeholder this does not imply that that priority should be disgarded or removed.

Even if this type of analysis would require ideally a higher number of feedback, and potentially is gonging to be refined and implemented in a next phase we have also assessed the relation among the frequency and the score of several priorities. Give the heterogeneity of priorities identified within each river basin, a keywords list has been used and linked with each priority. In this analysis a total of 31 keywords have been identified.

Table 3. Example list of keywords used for the analysis of Priorities ranking.

Keywords		
agriculture	groundwater	saltwater
agro and chemical contamination	hydropower	socioeconomic issues
alternative and renewable energy	invasive species	transboundary collaboration
climate change and variability	irrigation	wash services
dams management and sustainability	land productivity - soil fertility	waste and wastewater manag.
drinking water	mining and oil	water allocation and demands
energy infrastructures	modelling	water borne diseases and bacteria
environment and sustainability	monitoring	water management
erosion	open data	wetland conservation
extreme events	protected area	
fishing	R&D and HCD	

Figure 95. Ranking of key priorities: Keywords associated to the key issues identified in the river basin are mapped in relation with (average score of ranking, minimum and maximum values are reported as bars) and with their frequency.



It is interesting to note: i) Transboundary collaboration is the most frequent keywords and always ranked with very high score (between very important (4) and extremely important (5)). ii) Alternative and renewable energy issue is quite frequent, but generally considered less in the ranking (average is about 3, that correspond to important, but range is quite big from 1 (not important at all) to 4 (very important). It is also interesting to note that fishing, socioeconomic, monitoring and climate change are generally abundant and well positioned.

This graphics is meant actually just to illustrate a potential analysis to be refined and revised, once more feedback would be available.

As already introduced the main target of this assessment is to identify the priorities and to feed the dialogue and discussion process, with no need, at this stage, to give a priority as this is indeed a responsibility of stakeholder and managers.

5.14 Communication and dissemination

5.14.1 WebGIS

In the context of the assessment a Web mapping tool has been developed.

The tool is finalised to:

- Provide a **quick overview** of the main issues detected at basin level for each of the main thematic areas.
- Provide the user with **spatially explicit information** to identify potential hotspots within the basin.
- Develop a **dynamic, evolving consultation tool** which will be updated regularly to feature the current state of the art and to adapt to the user's needs.

The collection of Maps can be so divided: i) dedicated *basin maps* (one for each selected basin) and a general one on *governance*.

It will be available on the JRC Water Knowledge Management System AQUAKNOW (https://aquaknow.jrc.ec.europa.eu).

In addition a tutorial and Introduction Video about the WebGIS and its main functionalities is available on Aquaknow platform at the following link:

https://aquaknow.jrc.ec.europa.eu/WebgisTutorial.mp4

5.14.2 Introduction Video

An introduction video has been also prepared to introduce and give a quick outlook to the Project and activities developed and specifically about the objectives of the work.

The video is available in English and in French (subtitles).

It is accessible through Aquaknow.

5.15 Conclusions and way forward

Water and natural resource management is under increasing pressure, particularly in Africa, due to a number of factors including climate change, population and economic growth, political instability and increased competition for more and more limited resources. The analysis, assessment and management of water resources in the African continent is particularly challenging, as 90% of water resources are found in 63 transboundary river basins and their per capita distribution is highly unequal and variable. Various transboundary basins and a few aquifers are covered by bilateral or multilateral agreements (UN, 2018).

Identifying appropriate and timely adaptation measures to cope with the above mentioned changes is one of the greatest challenges for development and cooperation which would require an increased focus from both the political and scientific perspectives, integrating cultural and historic aspects at regional level to ensure effective collaboration among countries, institutions and populations.

To this scope, this report aims at carry out a first assessment for a selected subset of the most important transboundary river basins in Africa. The focus is on the water sector, not because of a predominance versus other components of the WEFE Nexus, but due to its nature as a cross-cutting resource and driver for development.

The preliminary analysis of key issues and priorities in diverse regions and contexts across the African continent highlighted some common points of interest. As expected, some key factors have a clear and cross-cutting impact on all river basins, regardless of their specificities or levels of development. Amongst these, an obvious example is related to climate change and climate variability issues, which have a direct impact on natural resources and people. The identified priorities should be taken into account in future cooperation and development plans, as they are essential in the identification and implementation of water management strategies.

Other common drivers, particularly challenging in the context of African river basins and which can have a clear impact on water resources are: i) water demand increase (driven by population and economic growth) and; ii) political instability arising from competition for limited resources and from resource distribution inequality.

The analysis focused on the identification of data and scientific evidence supporting the characterisation of key issues and priorities. Indeed, data and scientific evidence are key to facilitate the dialogue across policymakers from different sectors and countries: they can be the basis to adjust and adapt polices and regulations that may differ across countries and sectors. To this scope, it is essential to develop a common and agreed knowledge base, build on objective and open data in order to facilitate the agreement and the convergence of different polices. The analysis started by collecting the most updated and relevant scientific and open access literature. It was then compared and integrated (when relevant) with programming documentations and other sources (grey literature). The latter deserve further and more rigorous analysis. Indeed, a common issue identified in several river basins is the dominance of specific sectors in the number of publications and available research (probably subject to the availability of data and the specific expectations and interests).

The analysis of programming documentation (strategic documents from the river basin authorities, World Bank projects and reports, national reference documents) allows to identify a selection of key issues for each river basin in most of the cases. However, the methodology and the data adopted in those documents to identify the key issues are generally not clear or not easily accessible. This may introduce some uncertainties and difficulties for example, when there is an interest to analyse and compare two or more river basins, belonging to the same region. In this case, it is important to have a common base for data and methods, in order to limit unexpected differences and to ensure the acceptance of alternative outcomes by all end-users. In this regard, this report includes a collection of scientific papers, technical documentation and data supporting this ongoing and continuous process: it must be reported that, in some cases, such as for the Chobe, the Limpopo, or for some specific regions within the river basins, open data and scientific documents are not available and only experts' consultation, grey literature, and programmatic documents were used to support the assessment.

Key priorities and issues have been summarised at two levels: 1) thematic level and; 2) river basin level. At this stage, no score or ranking is applied to the priorities here identified. To this scope, a dialogue with local experts and decision makers is required, in order to finally have a ranking and a validation of the identified issues.

Issues

Here, a preliminary summary of key issues is reported. This list is not exhaustive, but is intended to highlight issues of particular relevance to the river basins analysed. The key issues are described and summarised, but it is important to point out that a more detailed and locally focused analysis would be needed to ensure the recognition of lessons learned and identification of key challenges across regions and countries.

- Food security. In all river basins in Sub-Saharan Africa, a high level of food insecurity is still a major issue, affecting almost 30% of the population. Food insecurity issues are a key priority in most of the basins, threatening also those more developed, especially in rural and remote areas. Food security issues are normally related with:

    - Low productivity level of the agricultural system, scarce soil fertility management and volatile and unstable production because of climate change and climate variability: this is the case for the White Nile region, all Niger RB, Lake Chad RB, most of the countries in the Orange RB (not South Africa), Delta region in the Okavango (flood pulses areas), Senegal River valley (loss of traditional system), Tanganyika region (frequent climatic shocks) and for the Chobe (specifically because of competition with wildlife and dependency on markets). Land management problems (e.g., Niger delta loss of croplands due to oil pollution in the Niger delta, salinity problems in the Senegal RB, and erosion issues in the Lake Victoria RB).

    - Fish stocking management: this is specifically evident for the Lake Victoria RB, the Zambezi RB, the Lake Chad, the Okavango RB and its Delta, the Senegal RB and its Delta (biodiversity, salinisation), the Lake Tanganyika and the Chobe RB.

    - Livestock management, pasture and transhumant movements: livestock is the most important source of protein in the White Nile and identified issues are linked to mobility, degradation of rangelands and pasture low productivity. This issue is also specifically pointed out in the Niger RB, in Lake Chad RB, in the Senegal RB, and in the Chobe. Traditional pastoral husbandry is challenged by the climate crisis, competition with the agriculture sector, extension of protected areas, drought, and incidence of diseases and loss of livestock to wildlife (e.g., Chobe).

  - Impacts related to conflicts/terrorist groups (e.g., in Lake Chad or Lake Victoria, where a feedback look has been suggested between conflicts and fisheries).

  - Actions and mitigation options: i) improve soil fertility management to increase the resilience of traditional and rainfed systems regarding climate variability and change; ii) assessment of irrigation cropping system for the identification of its actual potential and the causes of its low productivity; iii) enhance the assessment and data collection to analyse the link between pastoralism and agriculture; iv) ensure forage production and protection of local species (see for example *Kuri cow* in the Lake Chad).

- **Management of flow regime, floods, droughts and climate change impacts.** An important element arising out of the analysis of the documentation is the existence of a knowledge gap and above all, the permanence of a controversial discussion about the main causes of land degradation and water balance at river basin scale. This controversial debate highlights even more the need for the development of scientific research, open data, models and monitoring. Examples of issues requiring further analysis are: water level and release quantification in the Lake Victoria; ongoing discussion regarding the identification of dominant causes impacting floods in the Niger; competition between sectors (tourism, agriculture, hydroPV, etc.) in the Zambezi; controversy about Lake Chad natural extent, optimal water level and trend assessment; agreement for river environmental flow definition and estimation in the Orange; scarce monitoring and knowledge about water balance data in the Okavango; ongoing debate on land use changes and impact on soil water holding capacity in the Senegal.

  Some general key issues:

  - Impacts of climate change: always identified as a key issue, even if the specific impacts on different sectors are still controversial and may require a regional assessment: for example, increasing floods in the Niger RB are someway associated with climate change or with poor land/dam management. Also impacts of land use changes on the hydrological response of the basins are controversial. Clearly, this uncertainty in the definition of process, data and water dynamics adds complexity to an already arduous transboundary management approach. In this context, a key action identified is the development of agreed and shared data and knowledge across the riparian countries.

  - Dam management: balancing hydropower production and flood protection in multipurpose dams, ensuring a suitable environmental flow regime (e.g., artificial flood pulses to preserve ecosystems and/or flood recession agriculture).

  - Groundwater and aquifer system monitoring and knowledge: it is often reported as a priority and missing data and information are evidenced in most of the river basins. Groundwater exploitation is someway reported as low in the Niger but a very poor knowledge is also pointed out; a specific need for monitoring and assessment is identified in the Lake Chad (some evidence of groundwater depletion); a strong dependence on groundwater is evidenced in the Senegal and in the Orange (evidence of depletion but high uncertainty due to limited data availability and modelling capabilities).

- **Management of increasing water demand.** In general, a very high increase is expected for agriculture and hydropower sectors in most of the river basins. More specifically:

  - A higher competition between hydropower, irrigation, navigation and activities based on the natural flow regime (e.g., flood recession agriculture) is expected: in the White Nile (Lake Victoria) this is particularly evident for navigation, which puts pressure on wetlands; in the Niger, related issues are quite complex and irregular across the river basin (development of new dams upstream, impact on the Inner delta, navigability in the middle Niger, erosion issues in several regions, inefficient use of water by irrigation systems, with water exploitation already very high during the dry season, relative small capacity for groundwater exploitation, etc.); in the Zambezi large water transfer systems are under discussion and a more equitable water allocation among riparian countries would be needed. In the Lake Chad, a high groundwater exploitation level for drinking water is already reported. In the Orange, water demand and resources sharing is specifically under discussion for Namibia and South Africa. Lack of a basin-wide water management plan has been identified for the Okavango: assessments and agreements on water allocation among the countries are needed. The trade-offs between sectors and water demand have been already identified and preliminary assessed in the Senegal RB: uncertainty remains, particularly for the traditional food production system, which is a much more sensitive user of water to hydroclimatic conditions and external factors than others.

- Actions and mitigation options: i) in all the basins, a key issue is the quantification of growing demands from all different sectors, and the assessment of their trade-offs; ii) a common requirement is the definition of a new management approach: shift, from looking into ways to increase water supply to looking into ways to manage the available water; iii) development of strategies for: increase the use of recycled water, more efficient irrigation system (drip vs flood), improving water accounting systems, enhancing water productivity in cropping systems, identification of more equitable water allocation among users, region and countries and; iv) identification of a portfolio of both supply and demand side measures; development of hydroeconomic models.

- **Addressing water quality issues and health related diseases.** The biological water quality is a key issue in all the selected river basins, while anthropogenic chemical pollution of the environment is currently not a priority for human health and the environment. Indeed, even if chemical pollution is identified as a key problem in several areas and programmes, most of these topics occur locally (in some specific areas, for example nearby big cities, extensive industrial farming, like sugarcane and rice farming in the Senegal Delta,) and specifically because of occupational risks (for example, unlike the European context, pesticides are not currently a risk for environment at river basin level, but much more for the health of workers in a context of uncontrolled use).

The main water borne diseases, such as malaria, schistosomiasis, filariasis, dengue or yellow fever, are mostly associated with the alteration of ecological systems (induced, for example, by urbanisation or dam development, as evidenced in the SRB) and the lack of access to water, sanitation and hygiene (WASH) services. These diseases are a key issue for all river basins analysed and they are particularly relevant for Lake Victoria and White Nile region, Niger (specifically because of flow regime alteration induced by dams), Orange, Okavango, Senegal, Tanganyika and the Chobe. These type of risks should be pointed out with more urgency and their negative impacts must be considered in the development and assessment of new projects for dams and irrigation infrastructures.

Other crucial issues are:

- Mercury issues in areas where gold mining is practised (in the White Nile RB, in Mali and Guinea in the NRB, in the Orange RB, and in the Senegal RB) and other mining related contamination problems (several areas in the NRB, coal mining region in the ZRB, uranium mining in the Orange, and iron and steel mining in the *Copper-Belt* in the Zambezi). Arsenic contamination of drinking water is also reported (Tanganyika). Oil pollution exists in the Niger delta.
- Pollution with agrochemicals, eutrophication and industrial impact: eutrophication is mainly due to untreated urban effluents, domestic, industrial and livestock waste; it has been associated to agriculture only in the case of the Zambezi. Pesticides normally are below law limits, but some local specific issues persist: for example, related to cocoa plantations in the NRB; occupational health risks due to limited training and equipment (NRB); risks related to industrial chemicals because of unregulated release, missing control, and limited regulation (general).
- Recently attention is also paid to micro and small macro plastic in water: specifically, based on current analysis, this issue has been reported in the Lake Victoria (Nile) and in the Niger Delta. A more detailed assessment is required.

- Land degradation with loss of biodiversity (fishing species), declining of natural areas (wetlands in the Lake Victoria, in the Zambezi and Senegal), deforestation (due to cocoa plantation in the NRB), saltwater intrusion and salinisation (Zambezi), land use and landcover changes (Lake Chad), proliferation of invasive species (Typha in SRB, Lake Chad, Lake Victoria and Tanganyika); desertification and bush fires (NRB and Senegal).
- Indoor air pollution is also a key issue (specifically reported in Lake Chad and Senegal).
- Actions and mitigation options: i) research and surveillance improvement (basin-wide monitoring and mapping of bacteriological water quality and waterborne diseases, specifically for all new dam/irrigation projects; specific assessment of environmental impact of mining and oil exploitation projects; and setting up of groundwater monitoring networks; ii) mitigation (improving wastewater treatment and waste management, rising awareness and technology transfer are needed in the field of waste management and recycling); iii) Wetland restoration and erosion control; iv) improve access to WASH services and clean cooking fuels.

- Management of water energy sector

In this assessment the focus is on the analysis of issues related to hydropower sector, mainly highlighting the current hydropower production in the river basins, the expected potential for the coming years and the presence of specific issues linked to the environment.

- Hydropower is dominant in Lake Victoria (White Nile) basin, but with evidence of water shortage issues (Burundi). In the NRB, it is estimated that only 1/3 of the potential is exploited. In addition, the need for a more complete assessment of the potential conflicts and impact on other sectors has been often identified as a priority (see competition with navigation services and natural flow requirements in the Lake Victoria, flooding issues evidenced in the NRB, Senegal, and Zambezi). In the SRB, existing hydropower facilities are currently satisfying about 18% of the energy demand, but impact on other sectors are already an argument of stress and tension between different users.
- Inefficiencies inherent to large dams have been identified: high water losses found in biggest dams in the NRB, Orange and in the Zambezi. A key scientific research area should therefore be focused on the exploration of alternative solutions to mitigate this negative effect: for example, by implementing floating PV systems which can produce energy while limiting evaporation losses.
- A frequently identified issue is the need to reduce fuel wood and charcoal demands, still dominant in most of the river basins (particularly in the Niger RB, in the SRB and in the Orange RB).
- Limited connection to existing grids (low electrification rate) is often an issue for most of the rural areas: even RBs with high hydropower and energy production would need an improvement of the transmission network to ensure an equal and fair redistribution and allocation of energy (see for example, north Uganda, Sudan and South Sudan in the White Nile basin; Kenyan, Tanzanian and Burundi rural population of the Lakes region).
- Actions and mitigation options: i) explore the potential of small hydropower plants to support rural electrification and the synergies with other sources (biogas, residues valorisation, PV, Floating-PV and Solar) ii) support multi-purpose infrastructure and cost benefit analysis; iii) solve transboundary water disagreements (see e.g., South Africa and Namibia in the Orange) and move to equitable (energy and water) resource allocation.

Further steps and way forward

Some important steps and actions are needed to ensure the valorisation and acceptance of the assessment presented here:

- Identification of **cross-cutting issues** for river basins belonging to common regional areas, by involving more directly stakeholders.

- Specific **adaptation solutions** at basin scale must be assessed in light of their potential applicability to other basins, given the existing agreement on the cross-cutting nature of multiple key issues and priorities.

- Identification of **key data gaps** and urgent areas of intervention. For example, groundwater monitoring and assessment is recognised as an important priority in a context of decreasing water resources availability, but it has so far received little attention.

- **Mapping of key issues**: a preliminary mapping of key layers and data has been implemented in a ***webgis*** system to facilitate the interaction with local experts and stakeholders. The development of this interactive mapping tool aims to provide: i) a quick overview of the main thematic issues at basin level; ii) spatially explicit information to identify hotspots; iii) a dynamic source of information, which will be updated regularly to feature the current state of the art and to fulfill the users' needs.

- Identification of **capacity building needs at technical, scientific and management levels**. Given the heterogeneity of existing cross-cutting and specific issues in African transboundary basins, related human capacity gaps should be urgently addressed.

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Chapter 1 – 4

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Chapter 5

Lake Victoria river basin

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RIVER BASIN 1
NILE (SPECIAL FOCUS ON LAKE VICTORIA AND LAKE ALBERT)

RIVER BASIN 2
NIGER

RIVER BASIN 3
ZAMBEZI

RIVER BASIN 4
LAKE CHAD

RIVER BASIN 5
ORANGE

RIVER BASIN 6
OKAVANGO

RIVER BASIN 7
SENEGAL

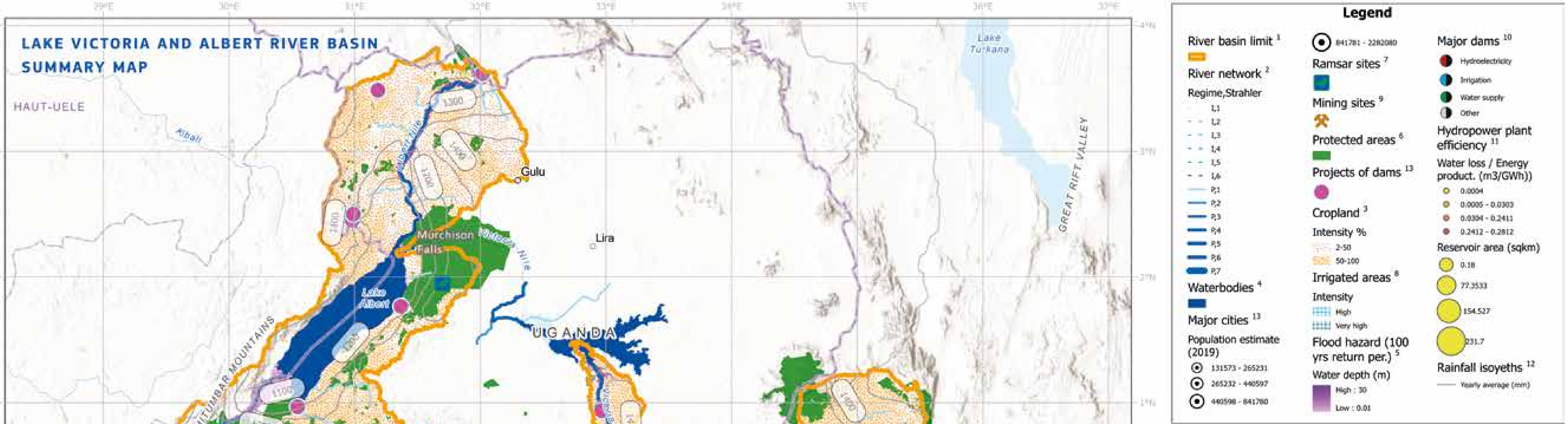
RIVER BASIN 8
LIMPOPO

RIVER BASIN 9
TANGANYIKA

RIVER BASIN 10
CHOBE-KWANDO (ZAMBEZI)

RIVER BASIN 1

NILE (SPECIAL FOCUS ON LAKE VICTORIA AND LAKE ALBERT)



Key challenges

Addressing changes to hydrological regime

- Lake levels: enhance assessment of process and impacts of external factors; Release curve of water from the lakes.
- Competition across sectors.
- Climate change and variability: assess impact on lake levels and on extreme events (floods, droughts, etc.)
- Hydrological Monitoring and modelling.

Management of the increasing water demand

- Wetland shrink.
- Monitoring and quantification of fluxes and stock of water.

Addressing challenges related to food security and agriculture

- Enhance land management: population depend on agriculture productivity for food security and poor natural resources management is impacting river basin economy and poverty.
- Enhance crop productivity: increase agriculture resilience increase productivity and limit crop production volatility.
- Ensure fishing sustainability

Addressing land degradation, water quality and health issues

- Invasive species (such as water hyacinth)
- Identification of wetland conservation strategies
- Assessment of cropland expansion, erosion, land degradation, impact of mining and oil exploitation
- Biological water quality: a key health issue in all countries; monitoring and mapping is required
- Water quality mitigation: improvement of wastewater treatment and waste management

Addressing socioeconomic issues

- Enhance awareness of socioeconomic value of the lakes and its ecosystem services.
- Fishing stock control and regulation to limit conflicts.
- Improve WASH services.

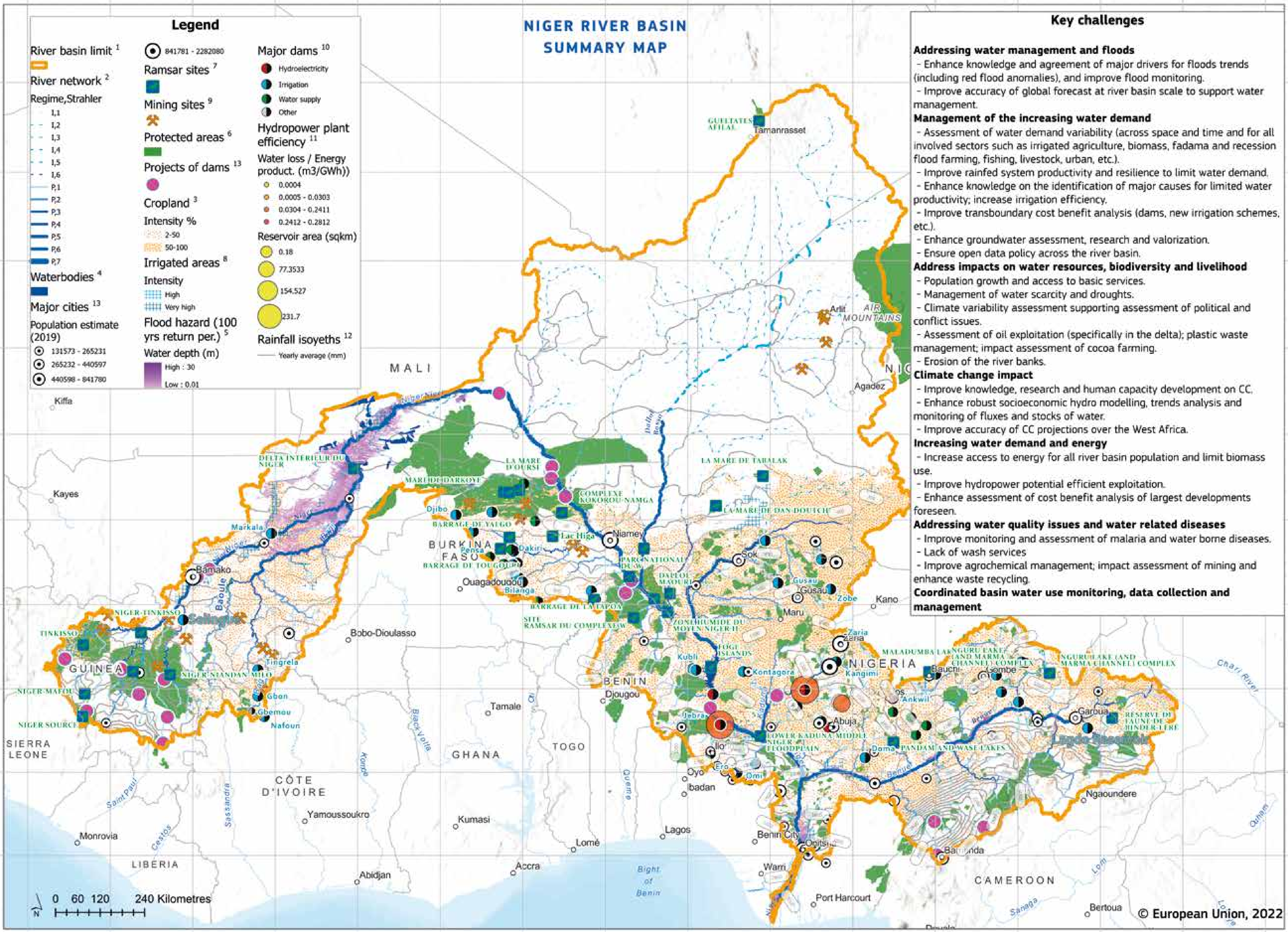
Management of increasing energy demand

- Enhance water sharing and cooperation
- Improve regional power market and cross border exchanges and high voltage network development
- Renewable energy expansion

Coordinated basin water use monitoring, data collection and management

RIVER BASIN 2

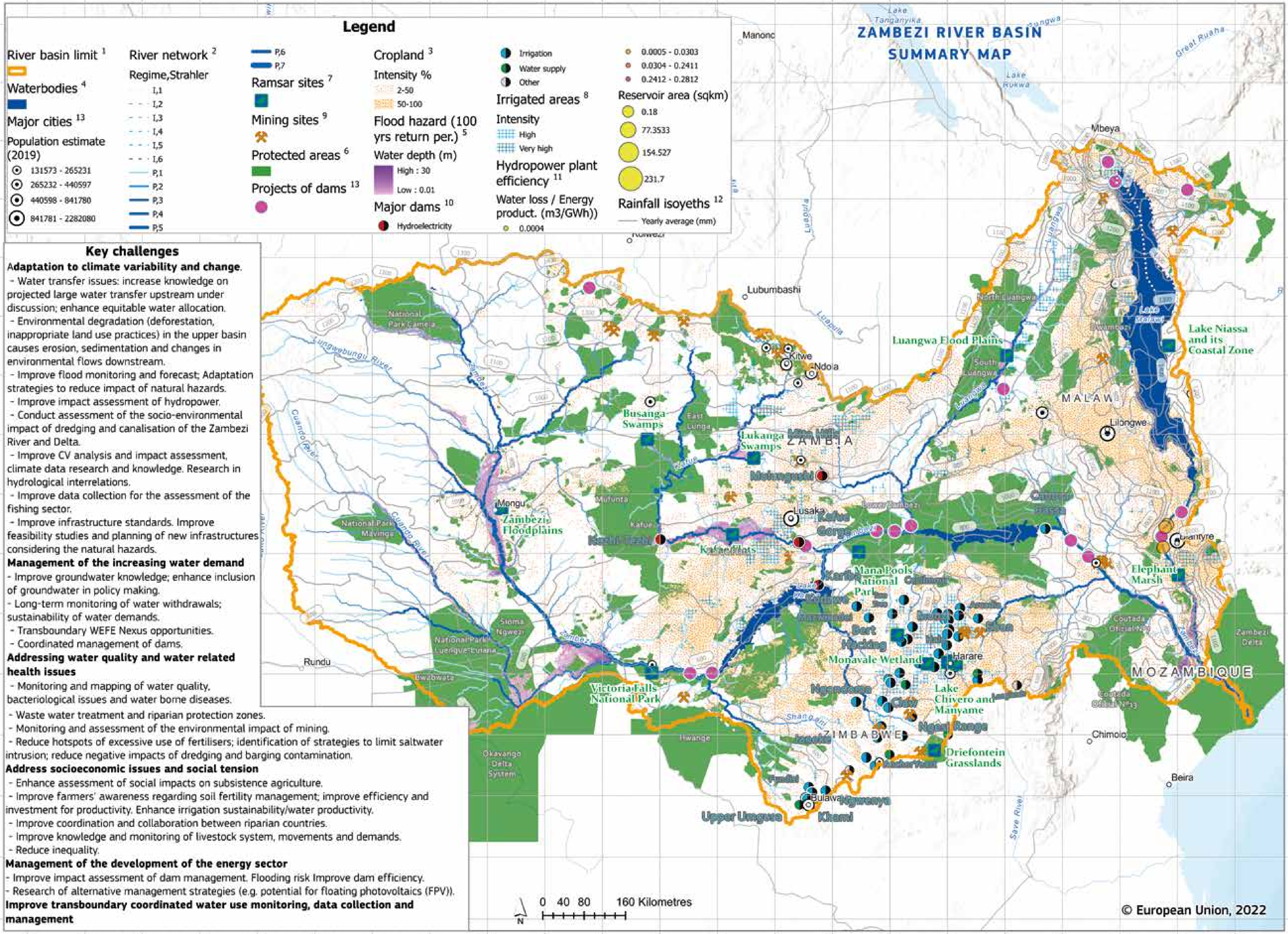
NIGER



NIGER RIVER BASIN SUMMARY MAP
Legend
River basin limit 1
River network 2
Regime,Strahler
1,1
1,2
1,3
1,4
1,5
1,6
P,1
P,2
P,3
P,4
P,5
P,6
P,7
Waterbodies 4
Major cities 13
Population estimate (2019)
131573 - 265231
265232 - 440597
440598 - 841780
841781 - 2282080
Ramsar sites 7
Mining sites 9
Protected areas 6
Projects of dams 13
Cropland 3
Intensity %
2-50
50-100
Irrigated areas 8
Intensity
High
Very high
Flood hazard (100 yrs return per.) 5
Water depth (m)
High : 30
Low : 0.01
Major dams 10
Hydroelectricity
Irrigation
Water supply
Other
Hydropower plant efficiency 11
Water loss / Energy product. (m3/GWh))
0.0004
0.0005 - 0.0303
0.0304 - 0.2411
0.2412 - 0.2812
Reservoir area (sqkm)
0.18
77.3533
154.527
231.7
Rainfall isoyeths 12
Yearly average (mm)
Key challenges
Addressing water management and floods
- Enhance knowledge and agreement of major drivers for floods trends (including red flood anomalies), and improve flood monitoring.
- Improve accuracy of global forecast at river basin scale to support water management.
Management of the increasing water demand
- Assessment of water demand variability (across space and time and for all involved sectors such as irrigated agriculture, biomass, fadama and recession flood farming, fishing, livestock, urban, etc.).
- Improve rainfed system productivity and resilience to limit water demand.
- Enhance knowledge on the identification of major causes for limited water productivity; increase irrigation efficiency.
- Improve transboundary cost benefit analysis (dams, new irrigation schemes, etc.).
- Enhance groundwater assessment, research and valorization.
- Ensure open data policy across the river basin.
Address impacts on water resources, biodiversity and livelihood
- Population growth and access to basic services.
- Management of water scarcity and droughts.
- Climate variability assessment supporting assessment of political and conflict issues.
- Assessment of oil exploitation (specifically in the delta); plastic waste management; impact assessment of cocoa farming.
- Erosion of the river banks.
Climate change impact
- Improve knowledge, research and human capacity development on CC.
- Enhance robust socioeconomic hydro modelling, trends analysis and monitoring of fluxes and stocks of water.
- Improve accuracy of CC projections over the West Africa.
Increasing water demand and energy
- Increase access to energy for all river basin population and limit biomass use.
- Improve hydropower potential efficient exploitation.
- Enhance assessment of cost benefit analysis of largest developments foreseen.
Addressing water quality issues and water related diseases
- Improve monitoring and assessment of malaria and water borne diseases.
- Lack of wash services
- Improve agrochemical management; impact assessment of mining and enhance waste recycling.
Coordinated basin water use monitoring, data collection and management
MALI
BURKINA FASO
GUINEA
SIERRA LEONE
LIBERIA
CÔTE D'IVOIRE
GHANA
TOGO
BENIN
NIGERIA
CAMEROON
Tamanrasset
Arlit
AIR MOUNTAINS
Agadez
Kiffa
Kayes
Markala
Bamako
Selingue
Bobo-Dioulasso
Ouagadougou
Niamey
Sokoto
Gusau
Kano
Zaria
Kaduna
Abuja
Kainji
Jebba
Ilorin
Oyo
Ibadan
Lagos
Benin City
Onitsha
Warri
Port Harcourt
Makurdi
Garoua
Lagdo Reservoir
Ngaoundere
Bertoua
Yamoussoukro
Abidjan
Monrovia
Kumasi
Tamale
Accra
Lomé
Djougou
Bight of Benin
DELTA INTERIEUR DU NIGER
LA MARE D'OURSI
MARE DE DARKOYE
COMPLEXE KOKOROU-NAMGA
BARRAGE DE YALGO
BARRAGE DE TOUGOU
BARRAGE DE LA TAPOA
PARC NATIONAL DU W
DALLOL MAOURI
LA MARE DE TABALAK
LA MARE DE DAN DOUTCHI
GUELTATES AFILAL
NIGER-TINKISSO
TINKISSO
NIGER-MAFOU
NIGER SOURCE
NIGER-NIANDAN-MILO
LOWER KADUNA-MIDDLE NIGER FLOODPLAIN
PANDAM AND WASE LAKES
MALADUMBA LAKE
NGURU LAKE (AND MARMA CHANNEL) COMPLEX
RESERVE DE FAUNE DE BINDER-LERE
0 60 120 240 Kilometres
© European Union, 2022

RIVER BASIN 3

ZAMBEZI



ZAMBEZI RIVER BASIN
SUMMARY MAP
Legend
River basin limit [1]
Waterbodies [4]
Major cities [13]
Population estimate (2019)
131573 - 265231
265232 - 440597
440598 - 841780
841781 - 2282080
River network [2]
Regime,Strahler
I,1
I,2
I,3
I,4
I,5
I,6
P,1
P,2
P,3
P,4
P,5
P,6
P,7
Ramsar sites [7]
Mining sites [9]
Protected areas [6]
Projects of dams [13]
Cropland [3]
Intensity %
2-50
50-100
Flood hazard (100 yrs return per.) [5]
Water depth (m)
High : 30
Low : 0.01
Major dams [10]
Hydroelectricity
Irrigation
Water supply
Other
Irrigated areas [8]
Intensity
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Hydropower plant efficiency [11]
Water loss / Energy product. (m3/GWh))
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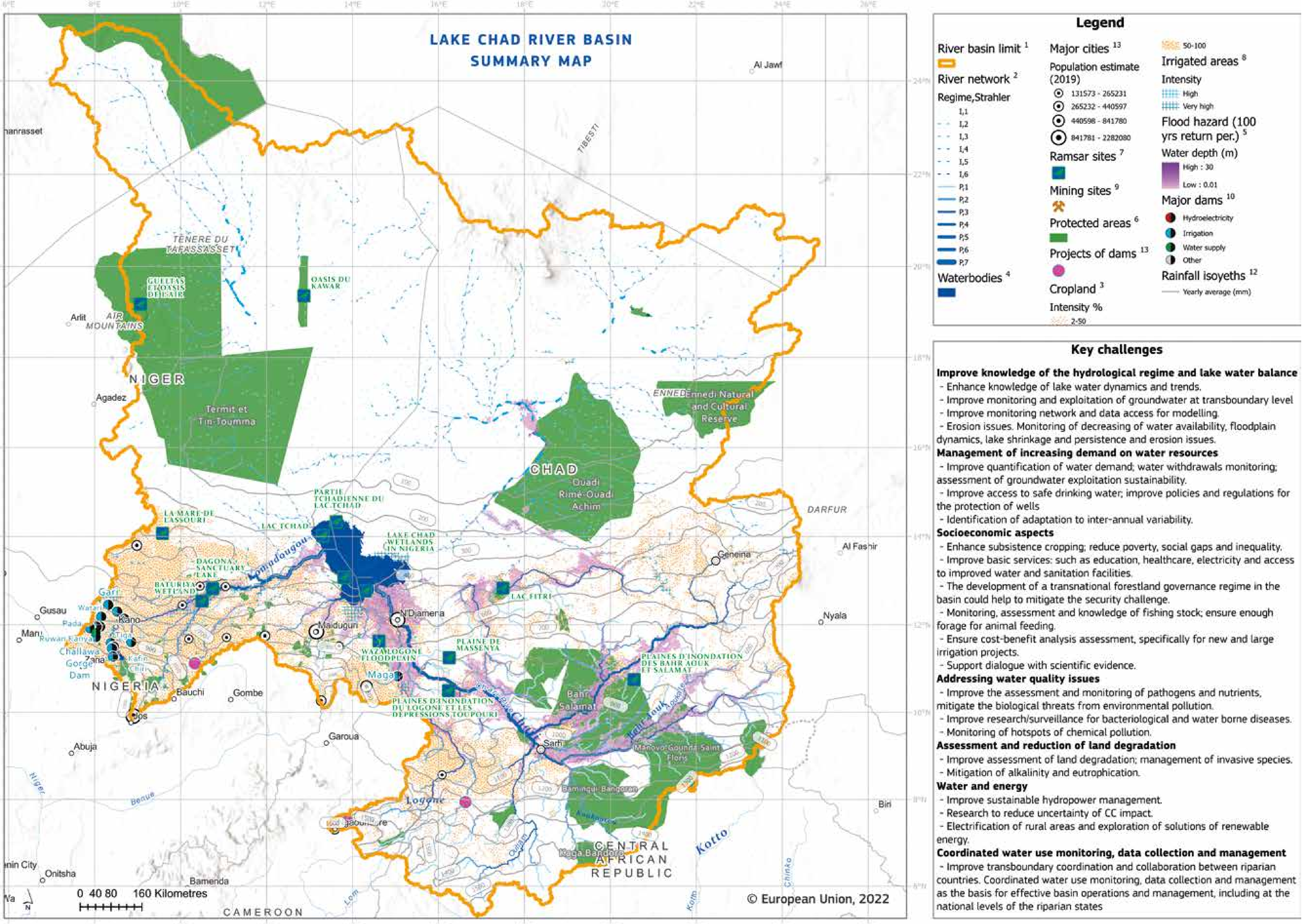
0.2412 - 0.2812
Reservoir area (sqkm)
0.18
77.3533
154.527
231.7
Rainfall isoyeths [12]
Yearly average (mm)
Key challenges
Adaptation to climate variability and change.
- Water transfer issues: increase knowledge on projected large water transfer upstream under discussion; enhance equitable water allocation.
- Environmental degradation (deforestation, inappropriate land use practices) in the upper basin causes erosion, sedimentation and changes in environmental flows downstream.
- Improve flood monitoring and forecast; Adaptation strategies to reduce impact of natural hazards.
- Improve impact assessment of hydropower.
- Conduct assessment of the socio-environmental impact of dredging and canalisation of the Zambezi River and Delta.
- Improve CV analysis and impact assessment, climate data research and knowledge. Research in hydrological interrelations.
- Improve data collection for the assessment of the fishing sector.
- Improve infrastructure standards. Improve feasibility studies and planning of new infrastructures considering the natural hazards.
Management of the increasing water demand
- Improve groundwater knowledge; enhance inclusion of groundwater in policy making.
- Long-term monitoring of water withdrawals; sustainability of water demands.
- Transboundary WEFE Nexus opportunities.
- Coordinated management of dams.
Addressing water quality and water related health issues
- Monitoring and mapping of water quality, bacteriological issues and water borne diseases.
- Waste water treatment and riparian protection zones.
- Monitoring and assessment of the environmental impact of mining.
- Reduce hotspots of excessive use of fertilisers; identification of strategies to limit saltwater intrusion; reduce negative impacts of dredging and barging contamination.
Address socioeconomic issues and social tension
- Enhance assessment of social impacts on subsistence agriculture.
- Improve farmers' awareness regarding soil fertility management; improve efficiency and investment for productivity. Enhance irrigation sustainability/water productivity.
- Improve coordination and collaboration between riparian countries.
- Improve knowledge and monitoring of livestock system, movements and demands.
- Reduce inequality.
Management of the development of the energy sector
- Improve impact assessment of dam management. Flooding risk Improve dam efficiency.
- Research of alternative management strategies (e.g. potential for floating photovoltaics (FPV)).
Improve transboundary coordinated water use monitoring, data collection and management
ZAMBIA
MALAWI
MOZAMBIQUE
ZIMBABWE
Lake Tanganyika
Lake Rukwa
Lake Malawi
Mbeya
Lubumbashi
Kitwe
Ndola
Lusaka
Lilongwe
Blantyre
Harare
Mongu
Rundu
Chimoio
Beira
Bulawayo
Luangwa Flood Plains
Lake Niassa and its Coastal Zone
Busanga Swamps
Lukanga Swamps
Zambezi Floodplains
Kafue Flats
Mana Pools National Park
Monavale Wetland
Victoria Falls National Park
Lake Chivero and Manyame
Driefontein Grasslands
Elephant Marsh
Zambezi Delta
Okavango Delta System
Hwange
0 40 80 160 Kilometres
© European Union, 2022

RIVER BASIN 4

LAKE CHAD



Key challenges

Improve knowledge of the hydrological regime and lake water balance

- Enhance knowledge of lake water dynamics and trends.
- Improve monitoring and exploitation of groundwater at transboundary level
- Improve monitoring network and data access for modelling.
- Erosion issues. Monitoring of decreasing of water availability, floodplain dynamics, lake shrinkage and persistence and erosion issues.

Management of increasing demand on water resources

- Improve quantification of water demand; water withdrawals monitoring; assessment of groundwater exploitation sustainability.
- Improve access to safe drinking water; improve policies and regulations for the protection of wells
- Identification of adaptation to inter-annual variability.

Socioeconomic aspects

- Enhance subsistence cropping; reduce poverty, social gaps and inequality.
- Improve basic services: such as education, healthcare, electricity and access to improved water and sanitation facilities.
- The development of a transnational forestland governance regime in the basin could help to mitigate the security challenge.
- Monitoring, assessment and knowledge of fishing stock; ensure enough forage for animal feeding.
- Ensure cost-benefit analysis assessment, specifically for new and large irrigation projects.
- Support dialogue with scientific evidence.

Addressing water quality issues

- Improve the assessment and monitoring of pathogens and nutrients, mitigate the biological threats from environmental pollution.
- Improve research/surveillance for bacteriological and water borne diseases.
- Monitoring of hotspots of chemical pollution.

Assessment and reduction of land degradation

- Improve assessment of land degradation; management of invasive species.
- Mitigation of alkalinity and eutrophication.

Water and energy

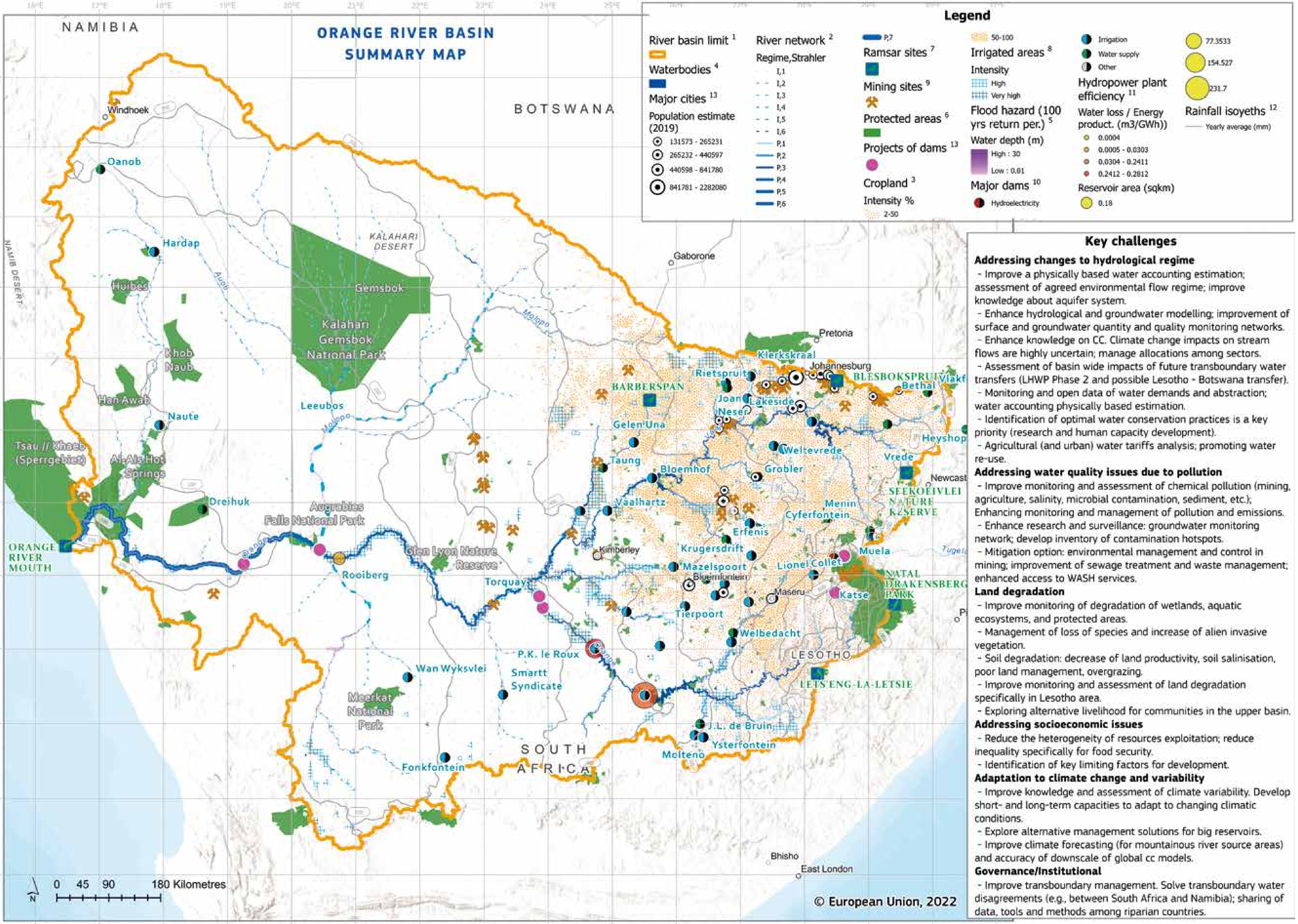
- Improve sustainable hydropower management.
- Research to reduce uncertainty of CC impact.
- Electrification of rural areas and exploration of solutions of renewable energy.

Coordinated water use monitoring, data collection and management

- Improve transboundary coordination and collaboration between riparian countries. Coordinated water use monitoring, data collection and management as the basis for effective basin operations and management, including at the national levels of the riparian states

RIVER BASIN 5

ORANGE



Key challenges

Addressing changes to hydrological regime

- Improve a physically based water accounting estimation; assessment of agreed environmental flow regime; improve knowledge about aquifer system.
- Enhance hydrological and groundwater modelling; improvement of surface and groundwater quantity and quality monitoring networks.
- Enhance knowledge on CC. Climate change impacts on stream flows are highly uncertain; manage allocations among sectors.
- Assessment of basin wide impacts of future transboundary water transfers (LHWP Phase 2 and possible Lesotho - Botswana transfer).
- Monitoring and open data of water demands and abstraction; water accounting physically based estimation.
- Identification of optimal water conservation practices is a key priority (research and human capacity development).
- Agricultural (and urban) water tariffs analysis; promoting water re-use.

Addressing water quality issues due to pollution

- Improve monitoring and assessment of chemical pollution (mining, agriculture, salinity, microbial contamination, sediment, etc.); Enhancing monitoring and management of pollution and emissions.
- Enhance research and surveillance: groundwater monitoring network; develop inventory of contamination hotspots.
- Mitigation option: environmental management and control in mining; improvement of sewage treatment and waste management; enhanced access to WASH services.

Land degradation

- Improve monitoring of degradation of wetlands, aquatic ecosystems, and protected areas.
- Management of loss of species and increase of alien invasive vegetation.
- Soil degradation: decrease of land productivity, soil salinisation, poor land management, overgrazing.
- Improve monitoring and assessment of land degradation specifically in Lesotho area.
- Exploring alternative livelihood for communities in the upper basin.

Addressing socioeconomic issues

- Reduce the heterogeneity of resources exploitation; reduce inequality specifically for food security.
- Identification of key limiting factors for development.

Adaptation to climate change and variability

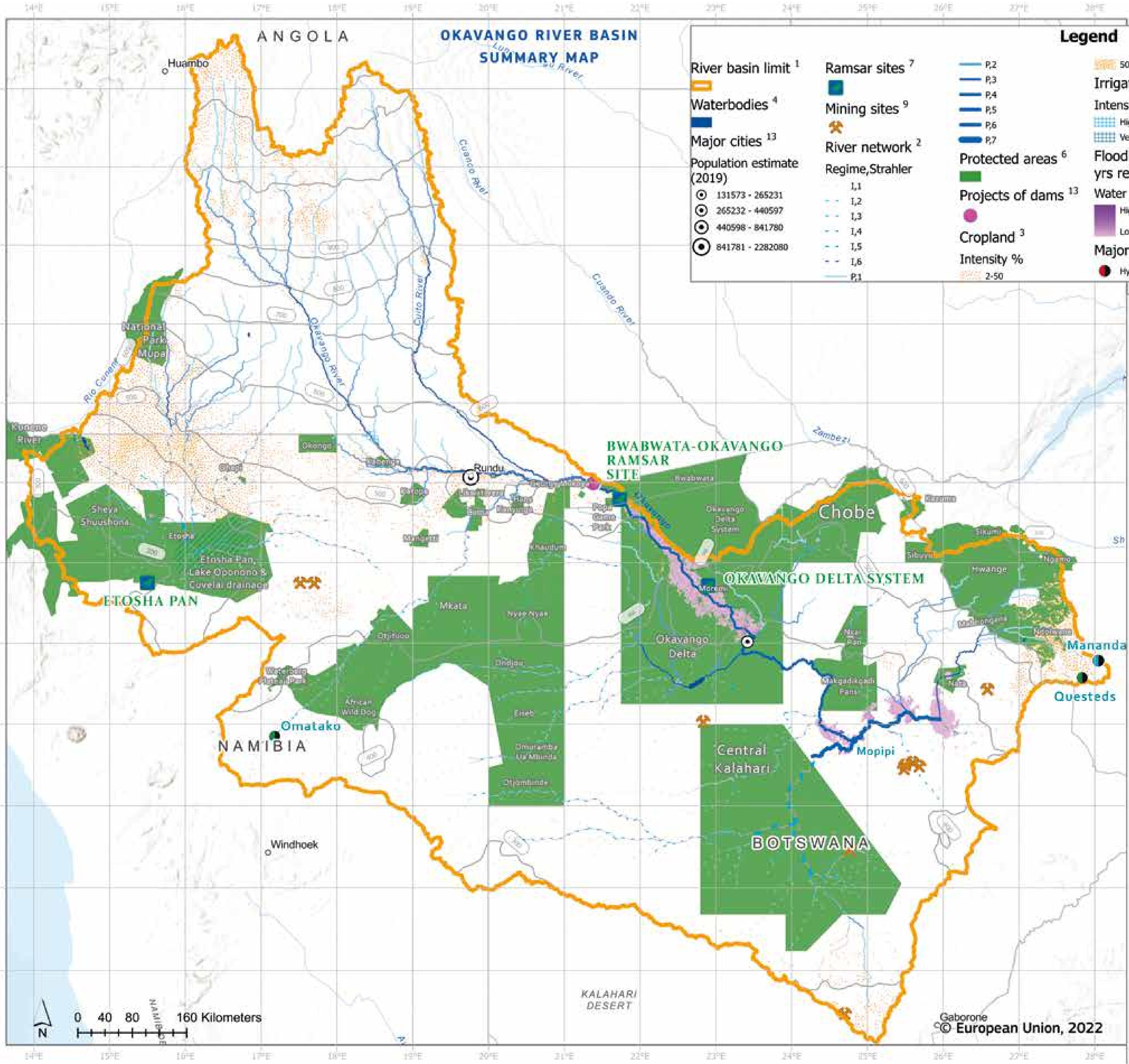
- Improve knowledge and assessment of climate variability. Develop short- and long-term capacities to adapt to changing climatic conditions.
- Explore alternative management solutions for big reservoirs.
- Improve climate forecasting (for mountainous river source areas) and accuracy of downscale of global cc models.

Governance/Institutional

- Improve transboundary management. Solve transboundary water disagreements (e.g., between South Africa and Namibia); sharing of data, tools and methods among riparian countries.

RIVER BASIN 6

OKAVANGO



Key challenges

Management of increasing water demand

- Improve the development of a water management strategy to ensure agreed and equitable water resources allocation.
- Monitoring and data on water demands and abstractions.
- Water quality management strategy is necessary to secure effective water and food security availability downstream; identify and agree on transboundary water resource and environmental trade-offs.

Adaptation to climate change and variability

- Develop a climate strategy at river basin level.
- Improve knowledge of climate variability and change which impact on the increasing unreliability of water availability and rainfall variability. Research to reduce uncertainty on predicted climate change impacts.
- Research on improving productivity (soil fertility, water productivity, flood pulses, mixed systems).
- Improve assessment and knowledge of impact on agricultural sector.

Addressing changes to hydrological regime (focus on the Delta)

- Improve the analysis of river management and impacts on the Delta (Data and modelling).
- Improve the assessment of impacts of river flow decrease. The natural flows in the Okavango River have experienced variation between -45% and +65% of the mean annual flow.
- Improve monitoring and assessment of loads of sediments as the Okavango Delta is dependent on inflowing loads of sediment
- Improve assessment of impacts of forest loss. Deforestation along the Okavango River leads to an augmentation of the inflow to the Delta, mitigating the local effects of climate change.

Addressing socioeconomic issues

- Assessment of tourism development.
- Improve knowledge and monitoring of fishing sector. Improve subsistence fishing industry.

Water and energy issues

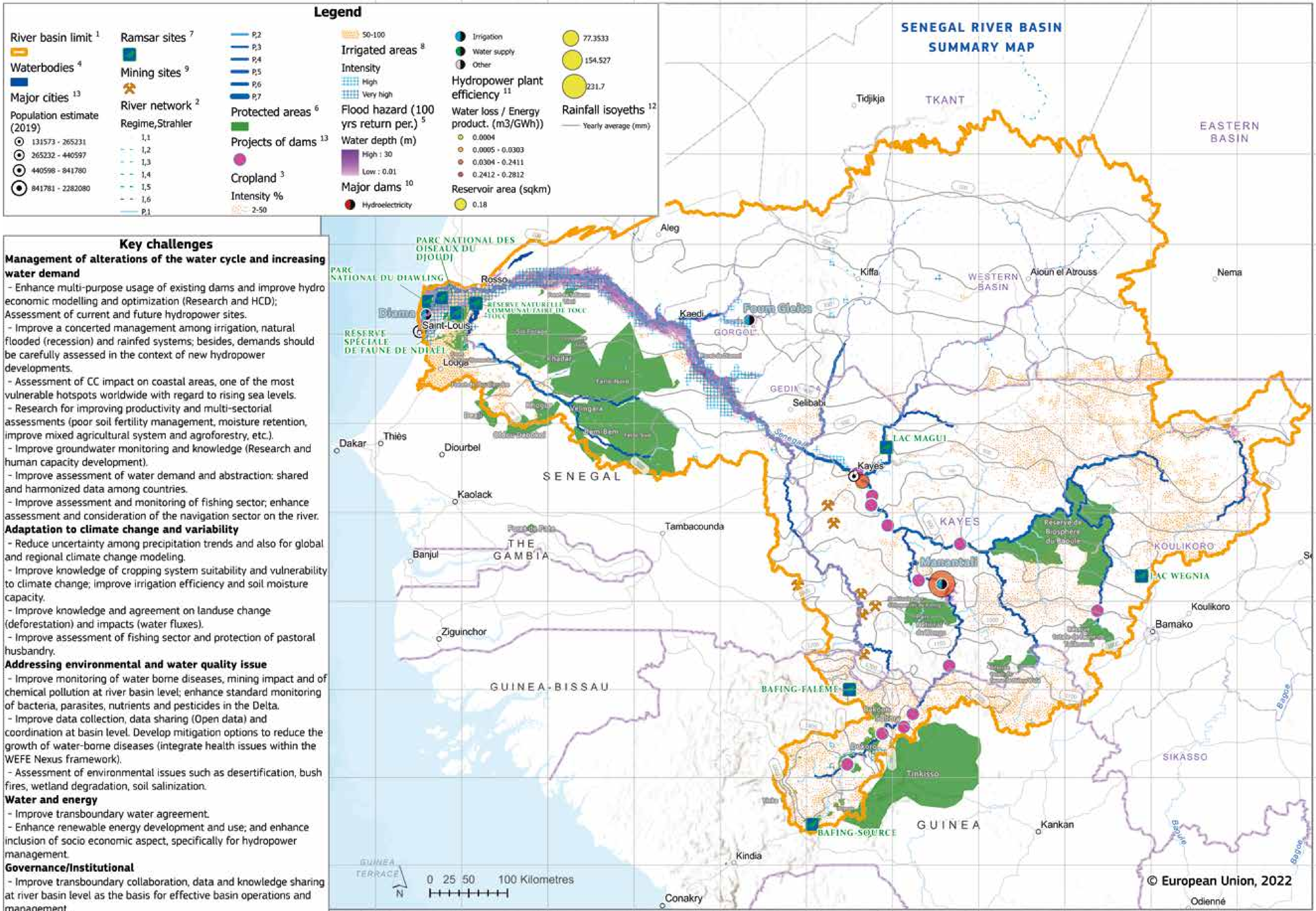
- Improve renewable energy contribution (Research and HCD): bioenergy, PV–hydropower, floating photovoltaic system.
- Enhance cost-benefit assessment for new hydropower plants.

Governance/Institutional

- Improve the development of a framework strategy at river basin level.
- Community engagement for socio-economic development and governance.
- Financing and resources (Financing mechanism & longer terms sustainability of strategic planning at RB level).
- Capacity & institutional assessment.

RIVER BASIN 7

SENEGAL



Key challenges

Management of alterations of the water cycle and increasing water demand

- Enhance multi-purpose usage of existing dams and improve hydro economic modelling and optimization (Research and HCD); Assessment of current and future hydropower sites.
- Improve a concerted management among irrigation, natural flooded (recession) and rainfed systems; besides, demands should be carefully assessed in the context of new hydropower developments.
- Assessment of CC impact on coastal areas, one of the most vulnerable hotspots worldwide with regard to rising sea levels.
- Research for improving productivity and multi-sectorial assessments (poor soil fertility management, moisture retention, improve mixed agricultural system and agroforestry, etc.).
- Improve groundwater monitoring and knowledge (Research and human capacity development).
- Improve assessment of water demand and abstraction: shared and harmonized data among countries.
- Improve assessment and monitoring of fishing sector; enhance assessment and consideration of the navigation sector on the river.

Adaptation to climate change and variability

- Reduce uncertainty among precipitation trends and also for global and regional climate change modeling.
- Improve knowledge of cropping system suitability and vulnerability to climate change; improve irrigation efficiency and soil moisture capacity.
- Improve knowledge and agreement on landuse change (deforestation) and impacts (water fluxes).
- Improve assessment of fishing sector and protection of pastoral husbandry.

Addressing environmental and water quality issue

- Improve monitoring of water borne diseases, mining impact and of chemical pollution at river basin level; enhance standard monitoring of bacteria, parasites, nutrients and pesticides in the Delta.
- Improve data collection, data sharing (Open data) and coordination at basin level. Develop mitigation options to reduce the growth of water-borne diseases (integrate health issues within the WEFE Nexus framework).
- Assessment of environmental issues such as desertification, bush fires, wetland degradation, soil salinization.

Water and energy

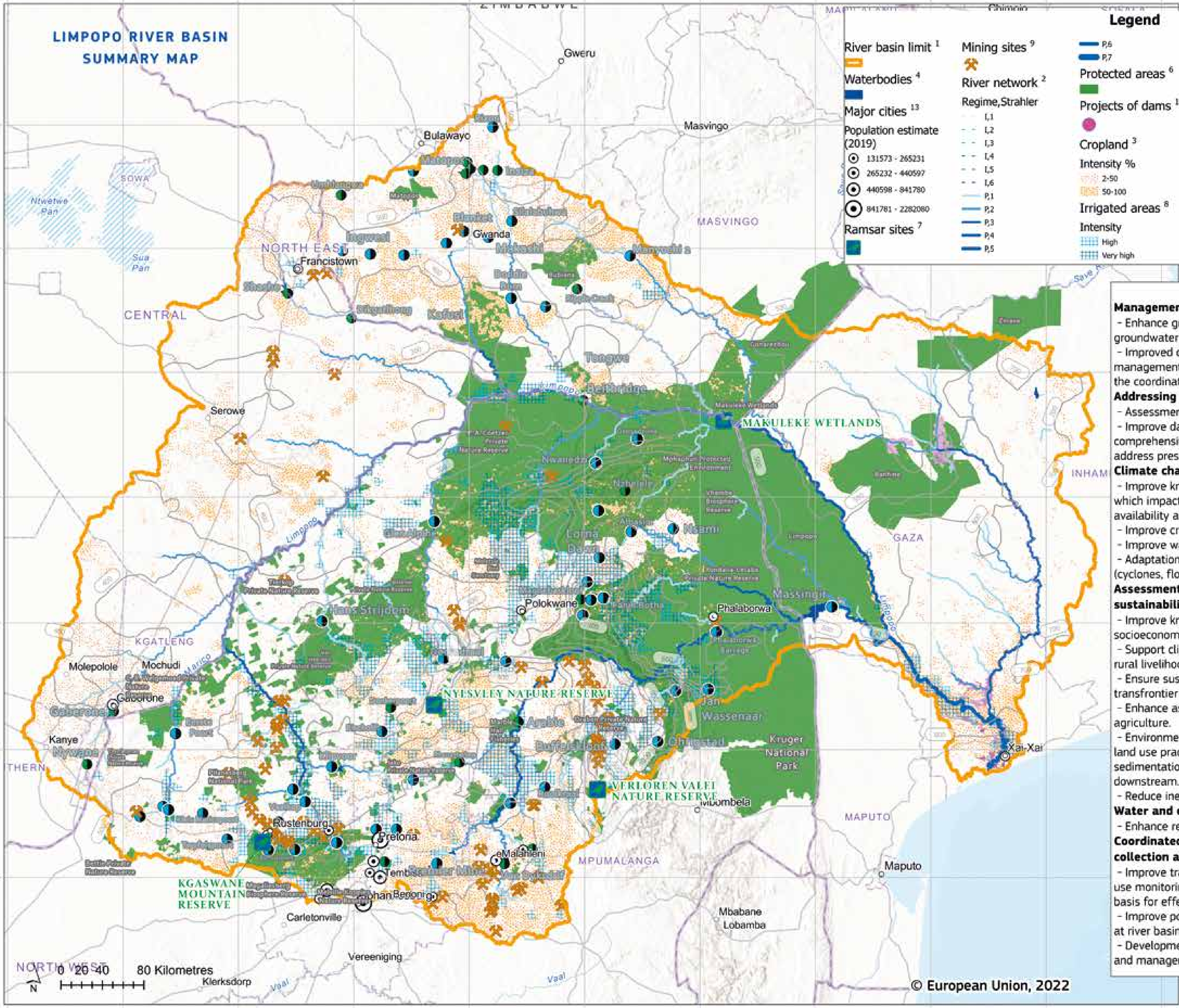
- Improve transboundary water agreement.
- Enhance renewable energy development and use; and enhance inclusion of socio economic aspect, specifically for hydropower management.

Governance/Institutional

- Improve transboundary collaboration, data and knowledge sharing at river basin level as the basis for effective basin operations and management.

RIVER BASIN 8

LIMPOPO



Key challenges

Management of the increasing water demand

- Enhance groundwater exploitation and improvement of groundwater infrastructure.
- Improved data collection and validation and overall management of water resources at river basin level and with the coordination and collaboration of all countries.

Addressing water quality issues.

- Assessment of groundwater quality and salinity issues.
- Improve data knowledge, collection and monitoring. Build a comprehensive water resources management strategy to address pressures on water supply that affect water quality.

Climate change impacts

- Improve knowledge of climate variability and change which impact on the increasing unreliability of water availability and rainfall variability.
- Improve crop productivity and sustainability.
- Improve water infrastructure resilience.
- Adaptation strategies to reduce impact of natural hazards (cyclones, floods, droughts).

Assessment of socioeconomic aspect and sustainability

- Improve knowledge and assessment capacity of socioeconomic and sustainability indicators.
- Support climate-smart agricultural practices to strengthen rural livelihoods and food security in the basin.
- Ensure sustainable management and support to transfrontier conservation areas.
- Enhance assessment of social impact of subsistence agriculture.
- Environmental degradation (deforestation, inappropriate land use practices) in the upper basin causes erosion, sedimentation and changes in environmental flows downstream.
- Reduce inequality across riparian countries.

Water and energy

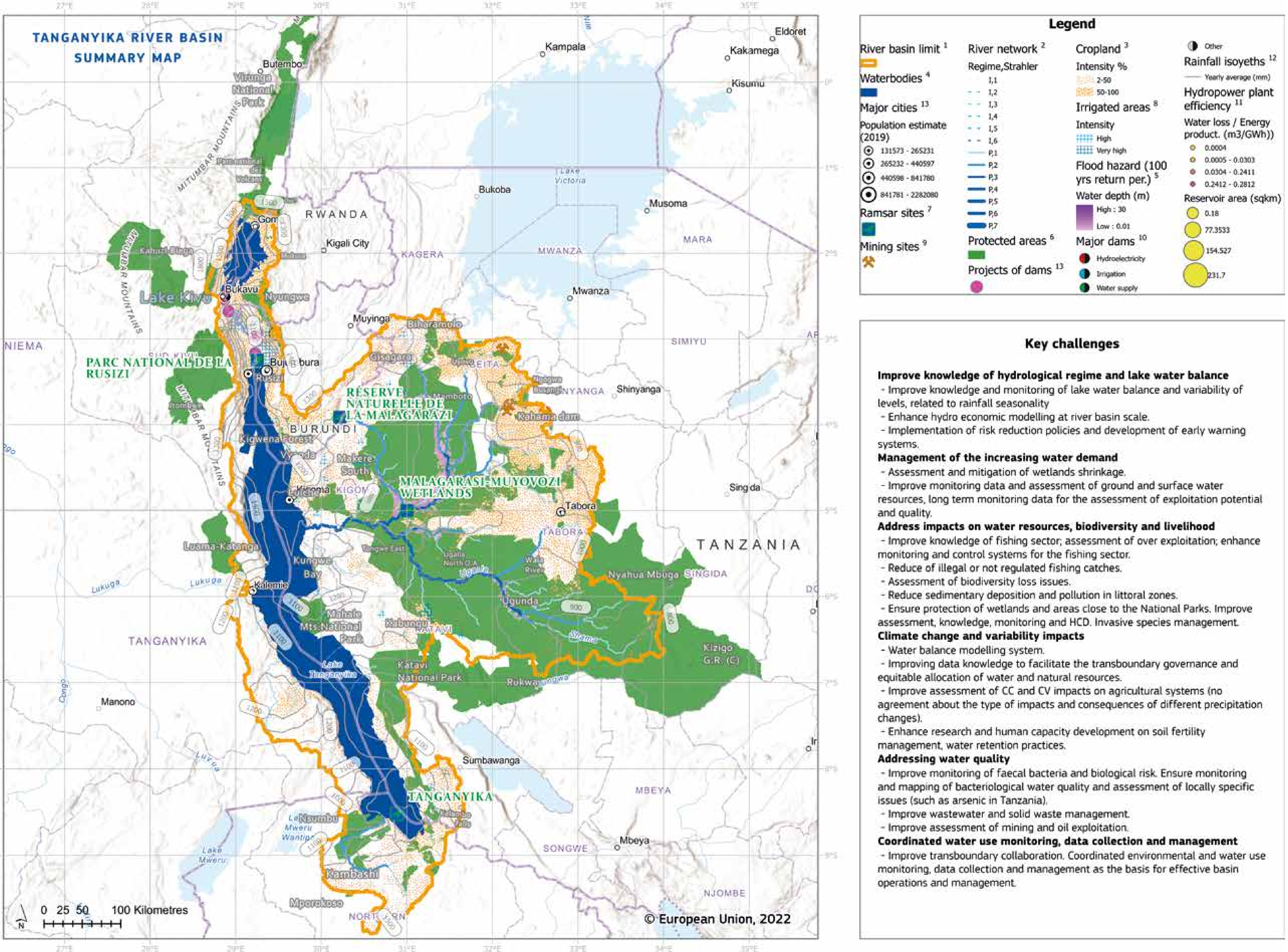
- Enhance renewable energy contribution.

Coordinated basin water use monitoring, data collection and management

- Improve transboundary collaboration. Coordinated water use monitoring, data collection and management as the basis for effective basin operations and management.
- Improve policy instruments to manage water governance at river basin level.
- Development of an effective basin-wide water allocations and management plan.

RIVER BASIN 9

TANGANYIKA



Key challenges

Improve knowledge of hydrological regime and lake water balance

- Improve knowledge and monitoring of lake water balance and variability of levels, related to rainfall seasonality
- Enhance hydro economic modelling at river basin scale.
- Implementation of risk reduction policies and development of early warning systems.

Management of the increasing water demand

- Assessment and mitigation of wetlands shrinkage.
- Improve monitoring data and assessment of ground and surface water resources, long term monitoring data for the assessment of exploitation potential and quality.

Address impacts on water resources, biodiversity and livelihood

- Improve knowledge of fishing sector; assessment of over exploitation; enhance monitoring and control systems for the fishing sector.
- Reduce of illegal or not regulated fishing catches.
- Assessment of biodiversity loss issues.
- Reduce sedimentary deposition and pollution in littoral zones.
- Ensure protection of wetlands and areas close to the National Parks. Improve assessment, knowledge, monitoring and HCD. Invasive species management.

Climate change and variability impacts

- Water balance modelling system.
- Improving data knowledge to facilitate the transboundary governance and equitable allocation of water and natural resources.
- Improve assessment of CC and CV impacts on agricultural systems (no agreement about the type of impacts and consequences of different precipitation changes).
- Enhance research and human capacity development on soil fertility management, water retention practices.

Addressing water quality

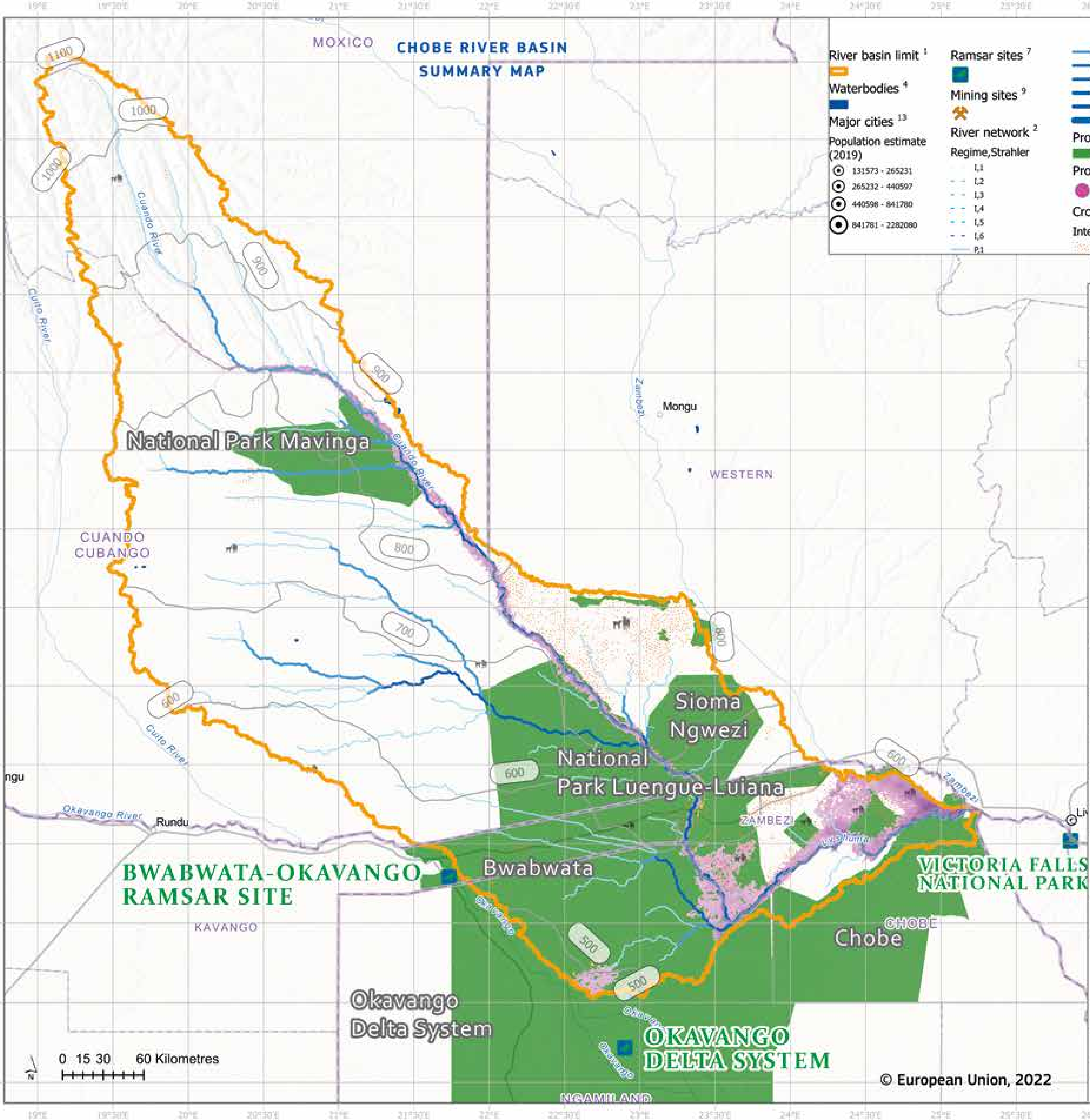
- Improve monitoring of faecal bacteria and biological risk. Ensure monitoring and mapping of bacteriological water quality and assessment of locally specific issues (such as arsenic in Tanzania).
- Improve wastewater and solid waste management.
- Improve assessment of mining and oil exploitation.

Coordinated water use monitoring, data collection and management

- Improve transboundary collaboration. Coordinated environmental and water use monitoring, data collection and management as the basis for effective basin operations and management.

RIVER BASIN 10

CHOBE-KWANDO (ZAMBEZI)



Key challenges

Management of protected areas in the context of a WEFE Nexus sustainable management

- Ensure Parks and Protected Areas transboundary management.
- Improve assessment and monitoring of seasonal flooding
- Development of a strategic environmental assessment (see current call for a Strategic Environmental Assessment opened in early 2022 by ZAMCOM and WWF).
- Assessment of water transfers.
- Assessment of livestock grazing impacts on natural vegetation and soil fertility.

Assessment of the hydrological regime

- Improve assessment of precipitation trends; improve data and monitoring of water deficit. Monitoring and assessment of food pulses and groundwater resources.

Management of the increasing water demand

- Improve data collection and sharing of reliable data on water use. According to future scenarios analysis, demand could exceed water availability in the basin.
- Improve hydro economic modelling capacity.
- Research and agreement about environmental flow requirement.
- Improve knowledge on navigability water requirements.

Addressing water quality and water related health issues

- Improve monitoring and assessment of biological water quality; improve monitoring and assessment of faecal bacteria and suspended matter loads.
- Ensure monitoring and mapping of bacteriological water quality, wildlife movements and its access to perennial sources of surface water (corridors for animals). Management of human and wildlife coexistence.
- Ensure domestic wastewater treatment, proper domestic waste management and access to safe drinking water.

Climate change and variability

- Improve knowledge and research in CC and CV; assessment of precipitation deficit.
- Explore potential of Linyanti floodplain for irrigation agricultural expansion.

Address socioeconomic issues and social tension

- Improve synergies among wildlife conservation and development to limit social tensions issues among several users.
- Reduce uneven socioeconomic levels in the four countries.
- Improve consideration of river dynamics impact on social tension. The Linyanti-Chobe section of the Cuando River (the southern edge of the Caprivi Strip) acts as an International River Boundary (IRB) between Namibia and Botswana.
- Improve knowledge, monitoring and assessment of fishing sector.

Management of the development of energy sector

- Improve grid and rural electrification and access to energy.
- Improve development of renewable energy exploitation.
- Reduce firewood demand. Firewood is primarily used for cooking, causing also health issues.

Coordinated basin water use monitoring, data collection and management

- Improve transboundary collaboration. Dependence on the Zambezi River: for the Chobe wetland and floodplain area, the most important source in terms of the amount of water is the Zambezi River.