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Towards an African Atlas of Water Energy Food Cooperation – Data collection

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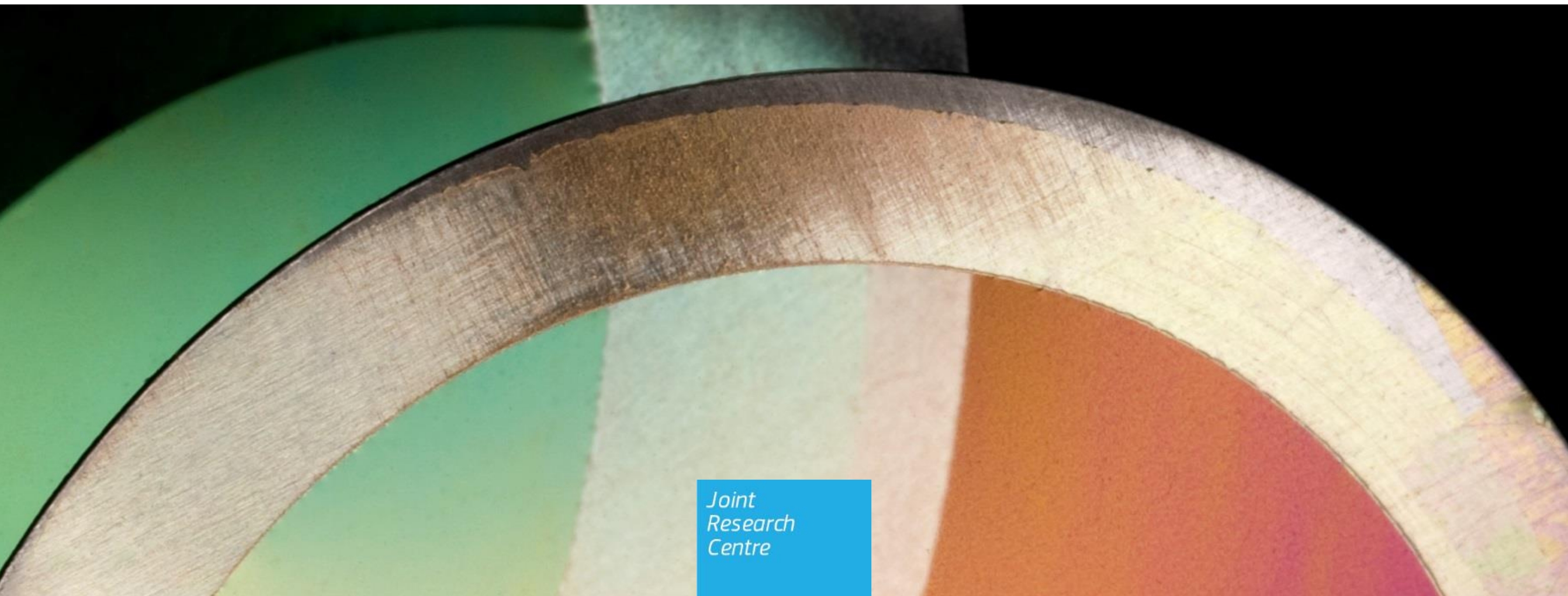

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Authors

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Abstract

The database described in this Report is one of the first steps in the construction of the African Atlas of Water Cooperation. Main scope of the project is "to create a dynamic tool addressed to policy-makers to stress hotspots and cues on the potential disequilibrium in the different Water-Energy-Food-Ecosystem components under different climate variability scenarios, natural resource supply, socio-economic and human demand at River Basin scales in Africa". By analyzing the interaction between water availability and uses at river basin scale, the tool is aimed at providing assistance to the efforts in the EC-Cooperation in Developing countries, and contributes to the development of the EU Migration Inclination Index.

The development of the tool is organized in a series of tasks. The first one, described in this report, attains to the collection of the main freely-available information regarding the most important transboundary basins in the African continent. This reports proposes a data collection, the organization of a database, a brief but at the same time detailed description of the River basins selected, and presents a digital tool created to visualize and manage the information collected.

The database hereby presented has to be intended as a living entity that will be integrated and further developed during the activities planned for the development of the African water cooperation atlas. The information presented in this report will be integrated with data collected at global, regional, basin, and local scale. This task will benefit from the collaboration with African partner institutions and International Organizations.

Digital contents

The data visualization tool could be found at the address:

http://d2-acewater-dev.jrc.it/Atlas/

Or scanning the following QR code:

1 Introduction

The analysis of the impacts of water resources inefficient use on energy and food security has been broadly identified as the ultimate frontier in the water management literature (among others: Giupponi and Gain, 2017; Namara and Giordano, 2017; SEI, 2011). Suboptimal allocation of water resources among the different consuming sectors could be responsible of large economic damages and, especially in the most vulnerable socio-economic systems, could cause food and energy insecurity and, in the most extreme cases, ignite social and political tensions (WEF, 2016). Competition over water is particularly intense in the transboundary water basins, where international agreements between the countries sharing the watershed are needed to ensure a cooperative and efficient use of the water resources (De Stefano et al., 2017, 2012, 2010; Dinar, 2004; Dinar et al., 2013, 2015; Wolf, 2009; Wolf et al., 2003). A first attempt to empirically identify the factors that are more likely to contribute to the geographical distribution of the hydro-political risk at global scale showed that the dynamics linked to the complex hydrological and socio-economic systems are determined by non-linear interactions and would be best assessed at basin scale (Farinosi et al., under review). The referred research article, as well as the associated technical report (Deliverable WEF-AFRIMED no 201602 – Technical Report no JRC105326), represented the first exploratory analysis aimed at highlighting the factors that are more relevant in determining the water cross-boundary issues, capturing also the non-linear relations between the main drivers. The conducted exploratory analysis produced an online tool designed to provide the policy maker with a flexible instrument able to capture historical and current trends of the factors relevant for hydro-political risk, but also the possibility to interactively construct future scenarios and eventually simulate different sets of policy options and strategies. This first attempt highlighted how a more detailed analysis of the hydro-political dynamics and competition over water at basin scale would be needed to understand the peculiar dynamics characterizing specific basins.

Building on the exploratory analysis conducted at global scale (Farinosi et al., under review), the Database for African Atlas of Water Energy Food Cooperation is designed to support the development of the regional African Atlas of Water Cooperation. The information collected was integrated into a Spatial Information System allowing the analysis of the dynamics of water-related extreme events, water availability, water quality, health, access to water, and energy and agricultural production. The final goal of the project is to develop a tool able to map water availability and uses at basin scale, analyzing the water system and assessing how suboptimal allocation of water resources could eventually be connected with the hydro-political risk at basin scale. The results of this study will support the work of the Commission in the contexts of Water Diplomacy, EU-Africa Cooperation, European Neighborhood Policy, and will contribute to the development of the EU Migration Index.

The database described in this Report is one of the first steps in the construction of the African Atlas of Water Cooperation. In this phase, we aimed at reviewing and classify all the information available that could be relevant for the analysis of the selection of Transboundary River Basins chosen for this work. A brief literature review about physical, climatic, hydrological, and socio-economic conditions of the main African transboundary river basin was conducted and presented in this report. These brief summary reports have the only purpose to present the main basins and to describe the results of the global analysis of hydro-political risk and need for water cooperation at the basin scale, highlighting the main critical aspects of each basin. Following the presentation of the basins, a review of the main data available is described. Final section of the report introduces the data visualization tool developed.

2 Data and Visualization

Data collected are taken from publicly available sources. Given the overall scope of the project, we aimed at collecting information covering all the aspects characterizing water availability and uses in the area: information that was derived by the analysis of the basins' dynamics in section 3. The main aspects covered by the database are:

- Climate
  - Precipitation and temperature profile;
  - Analysis of climate variability.
- Topography
  - Digital Elevation Model data of the basin;
  - Basin delineation, flow accumulation, and river network.
- Water
  - Hydrological data
    - Gauge station data;
    - Water resource mapping (remote sensing);
    - Groundwater resources;
    - Indicators about water availability.
  - Water Infrastructures
    - Dams and reservoirs location and basic characteristics;
    - Water sanitation and wastewater treatment.
- Land use
  - Agricultural areas;
  - Forested areas;
  - Human settlements.
- Agriculture (including livestock and fishery)
  - Crop production statistics;
  - Irrigation;
  - Livestock production statistics;
  - Freshwater fishery activities.
- Energy
  - Energy production in the basin;
  - Hydropower;
  - Biomass.
- Ecosystem
  - Protected areas;
  - Endangered species;
  - Water quality.
- Population dynamics

    - Population spatial distribution;
    - Demographic profile.
- Socio-economic data
    - Basin institutional management;
    - Governance;
    - Political power;
    - Population characteristics;
    - Ethnic groups;
    - Main social indicators.
- SDGs related data basing on the main indicators
- Violence and political stability
    - Data about civil conflicts;
    - Possible criticalities related with water management.

All the information resources are collected and presented in the format in which are made available by the original data source. No further changes respect to the original were made at this stage.

Visualization of the spatial information was made available through a graphical tool structured with the combination of a geoServer to maintain the geographic data, a PostGIS database to store geodata on the server side, and a client web-based tool designed to display and manipulate the stored information. In the client side, the tool proposed is a reusable component, programmed with Javascript and several geographic libraries that could be incorporated in any website that might need a geographic component.

The designed graphical tool is organized to interactively display: maps, map controls, operation widgets, layers panels, and charting tools. The instrument is designed to be extremely flexible and user friendly. The information is visualized at the river basin level or at raster level when available. Data about biophysical and socio-economic variables are displayed as either raster or vectorial layers. The result is a collection of data time series with the data sampled at a detailed spatial and temporal resolution. The tool provides the controls needed to display the evolution on the data over time.

3 African Main Transboundary Basins Description

The summary reports developed in this section have multiple goals: first, to provide a brief description of the main African transboundary basins, with their peculiarities and critical aspects; second, to describe the results of the global analysis conducted with the global analysis of the hydro-political risk (Farinosi et al., n.d.); and finally, to highlight those specific aspects that require further investigation basing on the raw data collected in the database presented in the next section.

The final African Atlas of Water Cooperation will not include all the basin presented in this Report, but only a selection of them.

Box 1. **Hydro-political risk and need for water cooperation**

In the description of the African transboundary basins, the spatial distribution of the hydro-political risk, also called need for water cooperation, was illustrated. This indicator was empirically calculated basing on historical episodes of water sharing issues. The analysis of the past transboundary water issues (conflict and cooperation over water resources) in international river basins and their determinants was conducted through the application of the Random Forest algorithm. Our aim was twofold: on the one hand, we aimed at highlighting the factors that are more relevant in determining the water cross-boundary issues, capturing also the non-linear relations between the main drivers. On the other hand, we aimed at producing a spatially explicit data driven indicator able to map and monitor the evolution of the hydro-political risk over space and time, under changing socio-economic and bio-physical scenarios. Historical (1997-2007) international water cross-border issues, both classified as conflict or cooperation, were put in relation with information about river basin freshwater availability; climate stress; human pressure on water; socio-economic conditions, including institutional development and power imbalance; and topographic characteristics. The application of the Random Forest approach outperformed alternative methodologies, such as linear models and statistical learning algorithms (RMSE = 0.218, R2 = 0.68). The analysis allowed to identify the most important factors determining water issues, such as water availability, population density, power imbalance, and climatic stressors, estimating their non-linear marginal impact on the hydro-political risk. The model fitted on historical observations was used to estimate a baseline condition of the spatial distribution of the hydro-political risk around the globe at high spatial resolution.

Further information in Farinosi et al (Under Review) – PUBSY Ref: JRC107644

3.1 Western Africa

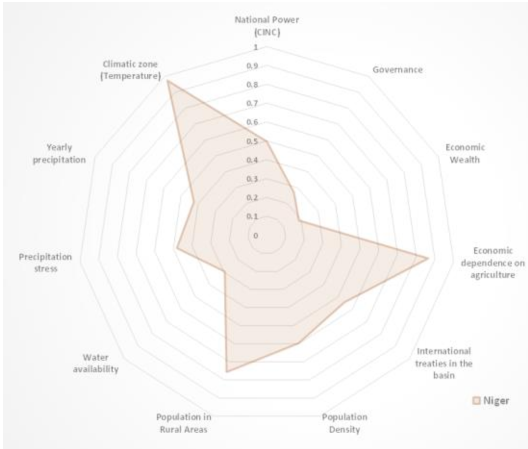
Main basins in Western Africa are:

- Niger;
- Senegal;
- Lake Chad;
- Volta.

3.1.1 Niger River Basin

The Niger River is the third longest river in the African continent. It drains an area of about 2.2 million squared kilometers crossing the borders of 12 countries in Western Africa. Majority of the basin area is characterized by very arid conditions.

Figure 1. Niger River Basin (left). Average normalized values of the main factors determining the Basin's hydro-political risk (right)



Need for water cooperation in the basin (average value for the basin): 0.447 (range 0-1)

Table 1. Summary of the Niger River basin main statistics.

Length	~ 4,200 km
Catchment area (hydrologically active)	2,273,946 (1,500,000) km^2
Average yearly precipitation (min - max)	~ 700 (~ 0 – 3,000) mm
Average discharge (min - max)	5,800 (500 – 28,500) $m^3 sec^{-1}$
Countries in the basin (* hydrologically active)	12 (9*) – Algeria, Benin*, Burkina Faso*, Cameroon*, Chad*, Côte D'Ivoire*, Guinea*, Mali*, Mauritania, Niger*, Nigeria*, Sierra Leone
Hydrologically active area % distribution ([+] water producer; [-] water consumer; [º] neutral)	Benin (2.5% [+]); Burkina Faso (3.9% [º]); Cameroon (4.4% [+]); Chad (1.0% [º]); Côte D'Ivoire (1.2% [º]); Guinea (4.6% [+]); Mali (30.3% [-]); Niger (23.8% [-]); Nigeria (28.3% [+] and [-]).
Population in the basin	~100,000,000
Main agricultural production	Rice, Peanuts, Corn, Millet, Sugar Cane, Cotton
Farming activities	Camel, Cattle, Sheep, Goat, Freshwater Pisciculture
River Basin Organization	Niger Basin Authority[1], founded in 1980 (replacing the Niger River Commission founded in 1964)

Data source: The Niger River Basin[2] (Andersen et al., 2005), and (Ogilvie et al., 2010)

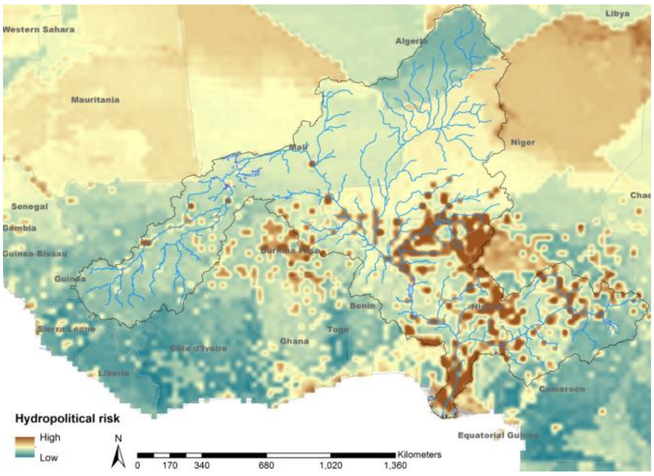
3.1.1.1 Hydro-political Risk and Need for Water Cooperation

The likelihood of hydro-political interactions, and that for the need for water cooperation was found to be higher along the main course of the river. The portion of the basin in the sub-tropical climatic zone of Guinea is characterized by a relatively lower likelihood of hydro-political interactions. The likelihood generally increases in the Malian, Burkinabe, and Nigerien portions of the basin, with the exception of the most arid and deserted areas, with hotspots in the most populated areas. The need for water cooperation is highest in

[1] http://www.abn.ne/
[2] https://openknowledge.worldbank.org/handle/10986/7397

the downstream portion of the basin, especially in the most populated and agriculturally more intensive areas of Benin and Nigeria.

Figure 2. Hydro-political Risk and Need for Water Cooperation in the Niger River Basin (Farinosi et al., n.d.)



3.1.1.2 Physical and climatic aspects

The river springs from the Fouta Djallon highlands in Guinea, a tropical region characterized by abundant precipitations, and flows following a northeast direction entering in the semi-arid and arid climatic zones in Mali. Here the river forms a large area of lakes and wetlands known as the Inland Delta. About 44% of the water entering the delta evaporates (Andersen et al., 2005), the remaining flow exits the wetland system with a delay of about three months and turns in the southeast direction toward the semi-arid regions of Niger and the tropical and equatorial climatic zones of Nigeria, finally flowing into the Atlantic Ocean in the Gulf of Guinea. The wet season varies between the climatic zones, on average, however, is concentrated in the summer period. That for, the river minimum peak flow is recorded during the period April-June, while the maximum peak is reached between September and December. In the middle Niger a double peak flow is usually recorded: in September due to the precipitations, and in December due to the delay caused by the Inland delta to the upstream flow. The Inland Delta acts as a huge reservoir that buffers and protracts the downstream wet season flow temporal distribution.

3.1.1.3 Socio-economic aspects

The Niger River basin countries are among the poorest ones in the world. Their classification in both the most widely known development indexes, the World Bank – World Development Index, and the UNDP - Human Development Index, is among the bottom 20 countries (over the 188 countries ranked, the classification of 2016 was: Burkina Faso 185; Benin 167; Cameroon 153; Chad 186; Côte d'Ivoire 171; Guinea 183; Mali 175; Niger 187; Nigeria 152)[3]. The main economic activities are represented by agricultural practices (25-35% of the GDP), strongly affected by climate variability, livestock production (10-15%), and fishery (1-4%) (Andersen et al., 2005; Ogilvie et al., 2010). Mining activities constitute the second major source of income in the area.

The basin accounts for more than 2.5 million ha of arable land, only a minor portion of which are actually cultivated. Infrastructural development is limited: only about 20% of the potential irrigation and hydropower development has been already exploited. About

[3] UNDP HDI official statistics (http://hdr.undp.org/en/composite/HDI)

265,000 ha are fully irrigated, mainly in Mali (~45%), Nigeria (~30%), and Niger (~ 17%) (FAO, 1997). As result, the vast majority of the agricultural production is rainfed. The main crops are represented by (dry-north to wet-south): seasonal pasture, sorghum, millet, banana, plantain, yam, cassava, and rice. Similarly, the livestock production varies with the climatic zones: camel, goat, sheep, poultry, zebu, and cow. The production is divided in two systems: nomadic and sedentary. Fishery occupies about 100,000 workers, with a total harvest of about 250,000 t/year(Ogilvie et al., 2010).

Hydropower production is very limited in the area: of the theoretical potential 30,000 GWh producible per year, the actual production is around 6,000. New installations are planned, as for instance the Fomi Dam (102 MW) in Ghana and the Toussa Dam (25 MW) in Mali, or under construction, as for the Kandadji dam (565 MW) in Niger. Due to the high flow variability and the lack of river infrastructures, the navigability is ensured only in minor portions of the river and in specific periods of the year (Andersen et al., 2005).

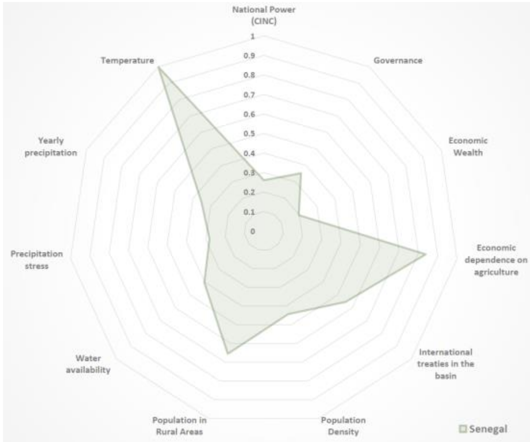
3.1.1.4 Main ethnic groups

Bambara (Mali, Niger); Bozo (Mali); Fulani (Niger); Hausa (Niger, Nigeria); Ijo (Nigeria); Jukun (Nigeria); Kanuri (Cameroon, Chad, Niger, Nigeria); Kakanda (Niger); Kede (Niger); Malinke (Mali); Somono (Mali); Songhai (Niger); Sorko (Niger); Tuareg (Algeria, Mali, Niger); Wurbo (Nigeria); Zarma (Niger).

3.1.2 Senegal River Basin

Senegal is the second largest river in West Africa after the Niger. The basin drains an area of about 290 thousands squared kilometers crossing the borders of 4 countries. The basin area is mostly characterized by arid and semi-arid climate characteristics, especially in the North, and tropical wet in the South.

Figure 3. Senegal River Basin (left). Average normalized values of the main factors determining the Basin's hydro-political risk (right)



Need for water cooperation in the basin (average value for the basin): 0.372 (range 0-1)

Table 2. Summary of the Senegal River basin main statistics.

Length	~ 1,800 km
Catchment area	290,000 km^2
Max Elevation (Country)	Bafing 800 m, Bahkoye 706 m (Guinea)
Average yearly precipitation (min - max) Average discharge (min - max)	~550 (~ 200 – 1,400) mm ~676 (9 – 3,300) m^3 sec-1
Countries in the basin (* hydrologically active)	4 (4*) – Guinea*, Mali*, Mauritania*, Senegal*
Hydrologically active area % distribution ([+] water producer; [-] water consumer; [º] neutral)	Guinea (11% [+]); Mali (53% [+]); Mauritania (26% [+]); Senegal (10% [+]).
Population in the basin	~ 5,600,000
Main agricultural production	Millet, corn, sorghum, watermelon, eggplant, pumpkin, tomatoes, hibiscus, rice, sugarcane.
Farming activities	Cattle, Sheep, Goat, Camel, Fisheries
River Basin Organization	Organisation pour la Mise en Valeur du fleuve Sénégal[4] (Organization for the development of the Senegal River - OMVS), established in 1972 by Mali, Mauritania and Senegal (Guinea joined in 2005).

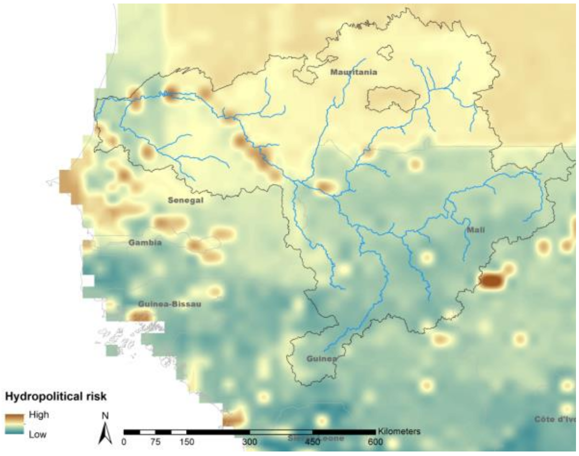
Data source: Organisation pour la Mise en Valeur du fleuve Sénégal: Physical Characteristics, Socio-economic Aspects; Senegal River Basin 2012 State of the Water Report (AbuZeid et al., 2012) FAO - Irrigation Potential in Africa: A basin approach[5].

3.1.2.1 Hydro-political Risk and Need for Water Cooperation

[4] http://www.portail-omvs.org/
[5] http://www.fao.org/docrep/W4347E/w4347e0h.htm

Hydro-political risk was found generally low in the Senegal River basin. Historical cooperation between the countries insisting on this watershed, sharing similar culture, language, and religion has contributed to limit the number of past water issues. Need for water cooperation was found to be higher in the Lower Senegal, in particular within the Mauritanian borders and in the agricultural areas along the Middle Senegal and Delta areas. Abundant precipitation, scarce population density and low agricultural productivity characterized the low hydro-political risk in the Guinean portion of the basin. The Malian territory was found to be generally characterized by a low risk, with hotspots around the main human settlements. Hydro-political risk in Mauritania and Senegal was found generally higher. In the first case, this is mainly due to the very dry climatic conditions of the country, while, in the second case, the human pressure over the scarce water resource was identified as the main factor of risk.

Figure 4. Hydro-political Risk and Need for Water Cooperation in the Senegal River Basin (Farinosi et al., n.d.)



3.1.2.2 Physical and climatic aspects[6]

Senegal River is originated close to the city of Bafoulabé (Mali) by the confluence of two main streams flowing northward from the Fouta Djallon Mountains in Guinea: namely, the Bafing (760 km) and Bakoy (or Bakoye – 560 km) rivers. Its flow in this upper portion is incremented by another tributary coming from Guinea, the Faleme River (430 km constituting the border between Mali and Senegal). From this point, the river flows following a north-western direction, moving from the subtropical biome of Guinea, to the semi-arid and deserted Malian and Mauritanian territories, before flowing into the Atlantic Ocean. Along its course divides the territories of Mauritania and Senegal, and receiving the flow of the Karakoro and Gorgol rivers. The average precipitation in the basin is around 500 mm yr^{-1}, ranging between 270 in Mauritania and 1,475 in Guinea. River flow is determined by the abundant precipitation in Guinea and the other tropical and sub-tropical portions of the basin. These areas are characterized by one rainy season spanning the period between May and October and almost no precipitation for the rest of the year. Consequently, the river flow seasonality is extremely high. Originally, the river's discharge was fluctuating between 3,320 $m^3 s^{-1}$ in September, to 9 $m^3 s^{-1}$ in May. After a prolonged drought in the early 1970s, however, it was decided the installation of flow regulating infrastructures in the upper part of the basin, in particular the Manantali dam (finalized in 1988) on the Bafing River, in Mali. An additional dam, Diama (1986), was constructed few kilometers from the coast. This was done to prevent seawater from entering the delta and going up the river, in some cases as far as 200 km, compromising all the efforts towards the increasing agricultural productivity of the valley.

[6] Organisation pour la Mise en Valeur du fleuve Sénégal: Physical Characteristics (http://www.portail-omvs.org/)

3.1.2.3 Socio-economic aspects

Most important economic activities in the Senegal basin are represented by agriculture, livestock production, and fisheries. Residual importance have the mining and other industrial sectors. Agriculture is the main occupation for the local population. In the upper Senegal basin, rainfed subsistence agriculture represents the main source of income for the local population. Main products include corn, millet sorghum, and watermelons. In the Middle and Lower portions of the basin, low precipitation does not allow rainfed agriculture, however, in the past, flood recession agriculture was extremely important for local population. This practice was interrupted with the installation of the Mantanali dam: recently the dam's operating rules were modified to re-establish this practice and ensure a controlled inundation of the floodplains in the middle and lower basin at the end of the rainy season (August-September). Main products of the flood recession agriculture, quantified in about 50,000 ha in Senegal and similar amount in Mauritania, include: corn, tomatoes, eggplants, pumpkins, hibiscus, rice, and watermelons. The decision to install the Mantanali and Diama dams was motivated mainly by flow regulation and the possibility to enhance agricultural productivity through irrigation. FAO[7] estimates quantify the irrigation potential in the basin in about 420,000 ha: only about one fourth of this is currently developed. Topography represent a considerable constraint for the development of irrigation in Guinea (potential for irrigation = 5,000 ha) and Mali (10,000 ha), while Senegal and Mauritania have the largest potential (240,000 and 165,000 ha respectively) (FAO, 1997).

Flow regulation and enhanced pasture boosted the livestock production in the basin, extremely important for Senegal, Mali, and Mauritania. Current livestock concentration is estimated in about 2.7 million cattle and 4.8 million sheep and goat heads. Although biodiversity and fish migration was estimated to be seriously impacted by dams' installation, reservoirs increased also the fish production, with yields estimated in about 25 to 45 thousand tons per year (OMVS; AbuZeid et al., 2012).

Mining activities are not developed in the Senegal Basin. Small gold production by local population is recorded in the upper portion of the basin. This activity is conducted in an artisanal way and is considered extremely impacting for local environment and human health. Huge iron reserves (1,100 million tons) were found in Mali (~ 500 million tons) and Senegal (~ 600 million tons), and phosphate (4 million tons) in Mauritania. Lack of infrastructural development, in term of fluvial transport, is identified as main limiting factor for the development of the mining industry: this is further worsened by political instability in the case of Mali. No other industrial activities are reported in the basin, except for the Senegalese Sugar Company processing the production of the 8,000 ha sugar cane fields and a minor fraction of tomatoes (OMVS; AbuZeid et al., 2012).

Hydropower production is extremely limited in the basin. Diama and Manantali dams were originally designed for irrigation and navigation purposes. Only in the early 2000s Manantali was equipped with a 200 MW hydropower plant and, with its 740 GWh yearly production, it is currently the main electricity source in the basin. Additional hydropower projects have been designed or are currently under construction. These include the Felou (70 MW - recently completed) and the Gouina (140 MW - under construction) run-of-the-river hydropower facilities in Mali. Additional 1,000 MW hydropower potential, three-quarter of which unexploited, was estimated for the Guinean portion of the basin (OMVS).

3.1.2.4 Main ethnic groups

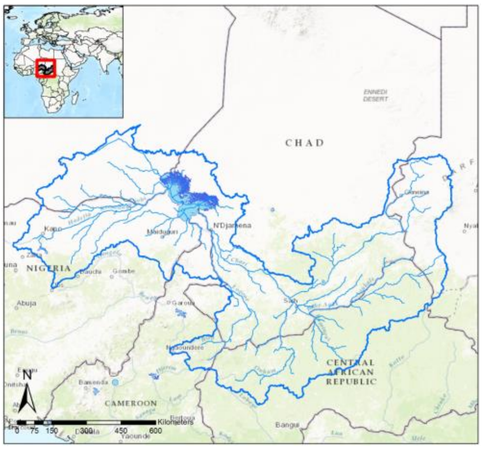
Bambaras, Fulani, Malinkes, Mauri/ Moor, Peuls, Soninke, Tukulor/Toucouleurs, Wolof.

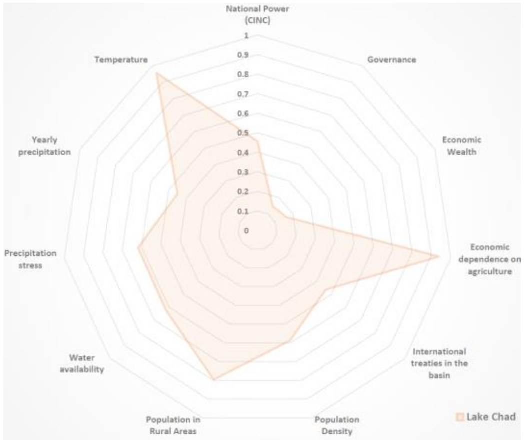
[7] http://www.fao.org/docrep/W4347E/w4347e0h.htm

3.1.3 Lake Chad Basin

Lake Chad basin, spanning an area of more than 1 million squared kilometers, is the largest endorheic basin in Africa. The basin area is mostly characterized by arid and semi-arid climate characteristics, especially in the North, and sub-tropical in the South. Lake Chad's surface has been considerably declining since the Holocene mainly due to changing climatic conditions.

Figure 5. Lake Chad Basin (left). Average normalized values of the main factors determining the Basin's hydro-political risk (right)





Need for water cooperation in the basin (average value for the basin): 0.308 (range 0-1)

Table 3. Summary of the Lake Chad basin main statistics.

Lake area	~ 4,516 km² (in 2012, ~25,000 km² in 1960, ~2,500 km² in 2008)
Catchment area	2,434,000 km² (hydrologically active ~ 1,000,000 km²) – Main tributaries: Chari-Logone basin (690,000 km²) and Komadugu-Yobe basin (148,000 km²)
Max Elevation (Country)	Chari-Logone: Chari 1,100-1,900 m (Bongos mountains - Central African Republic) – Lagone 1,200 m (Adamawa - Cameroon), Komadugu-Yobe 500 – 1,000 m (Nigeria)
Average yearly precipitation (min - max)	~320 (~ 100 – 1,500) mm
Average discharge (min - max)	Chari-Logone ~ 600 (250 – 1,800) m3 sec-1 - Komadugu-Yobe ~ 150 (0 – 700) m3 sec-1
Countries in the basin (* hydrologically active)	8 (6*) – Algeria, Cameroon*, Central African Republic*, Chad*, Libya, Niger*, Nigeria*, and Sudan*
Hydrologically active area % distribution ([+] water producer; [-] water consumer; [º] neutral)	Cameroon (4.8 % [+]); Chad (33.2 % [-]); Central African Republic (21.5 % [+]); Niger (12.3% [-]); Nigeria (18.5% [+]); Sudan (9.7% [+]).
Population in the basin	~ 45,000,000
Main agricultural production	Millet, sorghum, wheat, cocoyam, taro, maize, cassava, sweet potato, yam, onion, bell pepper, okra, cotton, rice, and dates.
Farming activities	Cattle, Sheep, Goat, Camel, Fisheries
River Basin Organization	Lake Chad Basin Commission[8] (LCBC), (Commission du Bassin du lac Tchad), established in 1964 by Cameroon, Niger, Nigeria, and Chad. Central African Republic joined in 1996, Libya in 2008. Sudan is observer since 2000.

Data source: Lake Chad Basin Commission; Report on the State of the Lake Chad Basin Ecosystem[9] (GIZ and LCBC, 2016)

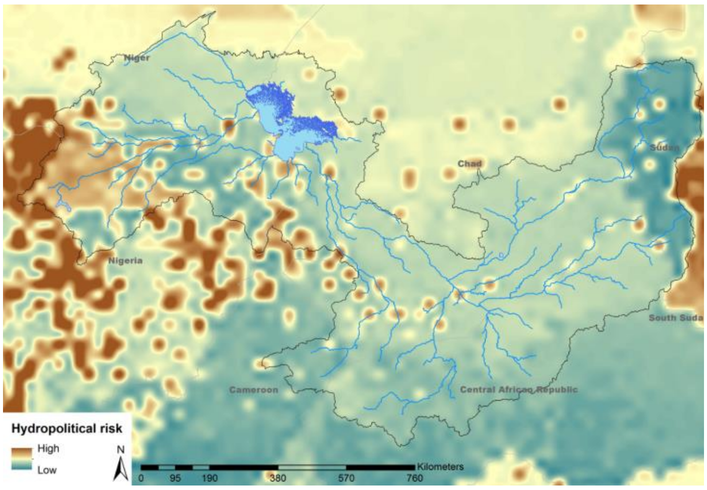
[8] http://www.cblt.org/en

[9] http://www.cblt.org/sites/default/files/download_documents/report_on_the_state_of_the_lake_chad_basin_ecosystem.pdf

3.1.3.1 Hydro-political Risk and Need for Water Cooperation

Lake Chad basin area is currently experiencing a major security issue due to the civil, military, and terroristic turmoil, however, it is not found to be a particular hotspot of hydro-political risk. The likelihood of having water related issues was found relatively higher in the areas where human pressure is highest, as for instance in the Nigerian, Nigerien, and Cameroonian portions of the basin. The hotspots include the agricultural areas within the Komadugu-Yobe basin in Nigeria and in the lower Chari-Logone basin in the south and southeastern Chad. Low population density and negligible agricultural activities characterize the low hydro-political risk in the north of the basin, mainly covered by the Sahara desert. The relatively high water availability respect to the very low human pressure in the Sudanese portion of the basin, determine the low hydro-political risk. This, however, does not imply that the area is peaceful, and not at risk in general: this portion of the basin in fact is impacted by the Darfur war, ongoing since 2003.

Figure 6. Hydro-political Risk and Need for Water Cooperation in the Lake Chad Basin (Farinosi et al., n.d.)



3.1.3.2 Physical and climatic aspects

Lake Chad reached its maximum extension, estimated in 2 million squared kilometers, at the end of Pleistocene (Ice Age). The lake is located at the border of the biggest desert on earth, the Sahara, where high temperature and lack of vegetation determine high evaporation rates; the flat topography of the area limits the lake depth to few meters (currently ranging between 1.5 and 4); moreover, the geology of its bed allows a certain degree of deep percolation: these factors made the lake extremely vulnerable to meteorological and climatic variability throughout its history. Chad Lake size shrank to almost disappearance in at least two occasions in the past 20,000 years. In more recent times, the lake reached its maximum extension (~26,000 km^2) during the 1960s: afterwards, precipitation declined considerably in the area and the water of the tributaries was more and more withdrawn for agricultural uses. Consequently, the size of the water surface shrank again, reaching its minimum in the late 1980s and slightly recovering afterwards till reaching the current state. As shown by historical changes, its peculiar biophysical characteristics make this hydrological system particularly vulnerable to climate change and anthropogenic pressure. The basin area is conventionally extended to include two other minor endorheic basins (Fitri and Dembe' lakes), and the hydrologically inactive areas of the north Chad, south Libya, and southeastern Algeria deserts (totaling ~ 2.4

million squared km). Although these areas could be very important in terms of potential competition over the scarce water resources in the basin, in this work it was considered only the hydrologically active area of the Lake Chad system (~ 1 million squared km). The two main rivers alimenting the Lake are the Chari-Logone from south-east, and the Komadugu-Yobe from west. The Cahri-Lagone basin drains about 690,000 km² of the wet areas in northern Cameroon and Central African Republic and, to a minor extent in terms of discharge, the southeastern Sudanese territories. The Chari River springs in the Central African Republic highlands and flows northwestwards for about 1,200 km; the Longone springs in Cameroon and flows northwards for about 1,000 km. The two rivers, jointly contributing for about 95% of the Lake Chad waters, merge at the border between Chad and Cameroon, nearby the Chadian capital N'Djamena. This river system is characterized by a high seasonal variability: it is almost dry in its lower part during the dry season and is subject to high flows and flooding during the wet period, between August and September. The Komadugu and Yobe rivers are semi-perennial water streams flowing northeastwards form the north east of Nigeria and merge at the border with Niger, nearby the Diffa settlement. It flows into the Lake Chad only during the rainy season, and contributes to only about 1.5% of its waters. This river basin is the most populous of the entire Chad basin, and the human pressure on the scarce water resources, especially in terms of agriculture is particularly high. Precipitation in the Lake Chad basin is unevenly distributed over space and time. In the northern portion of the basin, the rain amount is almost negligible, especially between November and March, very little for the rest of the year averaging below 300 mm in the Nigerien portion of the basin. In northern Nigeria precipitation is concentrated in the period June-September, averaging about 800 mm per year. The southern portion of the basin is the wettest, recording about 1,000 to 1,400 mm per year, more than half of which falls during the wet season between July and September. Intra- and inter-annual variability is extremely high, and long dry periods were recorded in the recent decades, as for the years 1973, 1984, and 2008 (GIZ and LCBC, 2016).

3.1.3.3 Socio-economic aspects

Majority of the 45 million people living in the Lake Chad basin, is distributed in the Nigerian territory (26 million), and in the main settlements in the south of Chad (10.6 million), Cameroon (3 million), and Niger (3.2 million). The share of population living in poor and very poor conditions is extremely large in the basin. Access to basic services, such as improved water supply, sanitation, electricity, education, and health care is extremely limited especially in the rural areas. Malaria and HIV/AIDS are widespread. Main economic activities in the basin are represented by crop farming, herding, and fishing, especially in the portions of the basin within the territories of Chad, Niger, and Central African Republic. The development of food processing industry and regional trade has been obstructed by military/social instability and natural disasters, mainly represented by prolonged droughts, as in the cases of 1973, 1984, and 2008. These factors have been also cause of massive internal migration, often associated with episodes of violence between newcomers, mainly represented by herders and fishermen from the lake's north shore, and indigenous populations living on the southern part of the lake. Additional massive migration episodes were caused by the recent political tensions especially in Darfur, Central African Republic, and in the Nigerian and Nigerien portions of the basin. Personal security, in terms of violence and sexual abuse, is also an issue for the local populations. Lower importance of the agricultural production for the overall national economy is recorded in the cases of Cameroon and Nigeria: however, agriculture, animal farming, and fishery yet represent the main sources of income and employment opportunity for the local communities. Rainfed agriculture is mainly concentrated in the portion of the basin within the Central African Republic territory, and at the border between Chad and Cameroon. Flood recession farming is common in the lower Chari-Logone basin. Moving northwards, irrigation is more and more common in both the Chari-Logone and Komadugu-Yobe river basins. Main irrigation practices are represented by groundwater extraction, polders, and small reservoirs along the main water bodies, in particular in the upper Komadugu-Yobe basin.

Relatively larger dams are also present in the area, as for the Maga dam on the Lagone River in Cameroon, designed for intensive rice cultivation. Food crops are mainly represented by millet, sorghum, wheat, cocoyam, legumes, corn, cassava, sweet potato, yam, onion, bell pepper, and okra; while cash crops include: cotton, rice, sugarcane, fruit, and date. Gum Arabic production is also common in Chad and Darfur. The northern part of the basin is almost completely unsuitable for agriculture. Animal farming is mainly represented by large and small livestock, as for camel, cattle, horse, sheep, goat, and poultry. Transhumant pastoralism is frequent in the basin. Fishery is an important activity in Lake Chad, producing about 100 thousand tons of fish every year, and in its main tributaries. Potential hydropower development was also analyzed and estimated for the Chari-Logone river system. However the adverse effects, in terms of evaporation and flow regimes, of the eventual installation of medium to large hydropower in the river basin for the fragile Lake Chad socio-environmental system have prevented hydropower development in the area. Water transfer from the neighboring Congo basin has also been hypothesized in the recent past. However, the adverse effects on the Congo basin navigation and hydropower sector, especially concerning the planned Grand Inga installation, have so far represented the main limitations of the project (GIZ and LCBC, 2016).

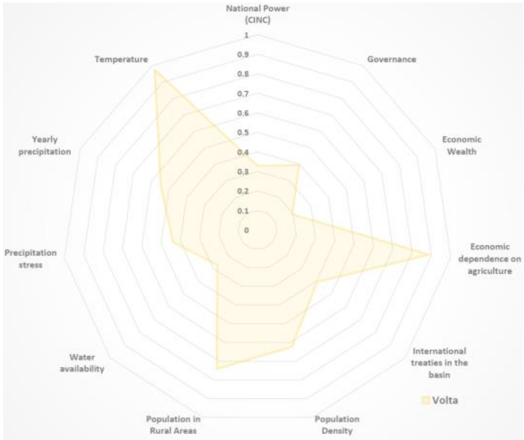
3.1.3.4 Main ethnic groups

More than 70 ethnic groups live in the basin, these include: Kanuri, Maba, Buduma, Hausa, Kanembu, Kotoko, Bagger, Haddad, Kuri, Fulani, and Manga.

3.1.4 Volta River Basin

Volta is the third largest river in West Africa after the Niger and Senegal. The basin drains an area of about 400 thousands squared kilometers crossing the borders of 6 countries. The area is mostly characterized by arid and semi-arid climate in the North, semi-tropical and tropical wet in its middle and lower portions in the South.

Figure 7. Volta River Basin (left). Average normalized values of the main factors determining the Basin's hydro-political risk (right)



Need for water cooperation in the basin (average value for the basin): 0.369 (range 0-1)

Table 4. Summary of the Volta River basin main statistics.

Length	~ 1,350 km
Catchment area	398,390 km^2
Max Elevation (Country)	920 m (Togo)
Average yearly precipitation (min - max) Average discharge (min - max)	~ 900 (~ 360 – 1,600) mm ~ 1,200 (260 – 3,800) m^3 sec^{-1}
Countries in the basin (* hydrologically active)	6 (5*) – Benin*, Burkina Faso*, Ivory Coast*, Ghana*, Mali, Togo*
Hydrologically active area % distribution ([+] water producer; [-] water consumer; [º] neutral)	Benin (3.4% [+]); Burkina Faso (43% [+]); Ivory Coast (2.5% [+]); Ghana (41.6% [+]); Mali (3.1% [º]); Togo (6.4% [+]).
Population in the basin	~ 24,000,000
Main agricultural production	Millet, corn, sorghum, rice, legumes, fruits, vegetables, cassava, cocoa, coffee, nuts, groundnuts.
Farming activities	Cattle, Sheep, Goat, Poultry, Pig, Fishery
River Basin Organization	Volta Basin Authority[10] established in 2009 (agreement signed in 2007).

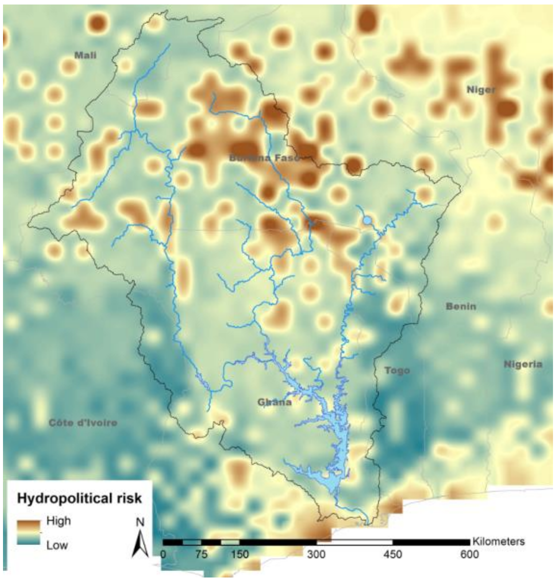
Data source: Volta Basin Authority; FAO - Irrigation Potential in Africa: A basin approach[11]; Barry et al. (2005), Opoku-Ankomah et al. (2006) UNEP-GEF Volta Project (2013), and Mul et al.(2015).

3.1.4.1 Hydro-political Risk and Need for Water Cooperation

[10] http://www.abv-volta.org/
[11] http://www.fao.org/docrep/W4347E/w4347e0u.htm

Hydro-political risk was found generally low in the Volta River. The upper portion of the basin, poor of water resources and heavily dependent on agriculture, is generally more subject to hydro-political risk than the southern and downstream portion. The main agricultural areas in Burkina Faso heavily rely on the surface water sources of the Volta and its upstream tributaries. The fast urbanization process characterizing the expansion of the main Burkinabe cities in the past few decades, substantially increased the anthropogenic pressure on the water resources in this area. White Volta was identified as a possible hydro-political hotspot due to the competition over the resource stored in three multi-purpose impoundments: Lake Bam, Lomita dam, and Bagre dam. Competition over water resources is fueled also by the extensive mining activities in the area. In the lower portion of the basin, the relative abundance of water resources determines the lower hydro-political risk. Competition among different water users, in particular energy and agricultural sectors, is however present in the Ghanaian and to some extent in the Togolese territories. Other issues include: change in water quantity and seasonal flow, land degradation, sedimentation of the reservoirs, water quality.

Figure 8. Hydro-political Risk and Need for Water Cooperation in the Volta River Basin (Farinosi et al., n.d.)



3.1.4.2 Physical and climatic aspects

The Volta Basin hosts a complex system of rivers flowing southwards from the northern portions of Burkina Faso and Benin and discharging their flow to one of the biggest manmade lakes in the world, the 8,500 km^2 Lake Volta-Akasombo reservoir, in central Ghana. Three are the main tributaries of the Volta: Black Volta, White Volta, and Oti river. The Black Volta (Mouhoun) springs from the Kong Mountains in the southwest Burkina Faso, close to the border with Ivory Coast and Mali, flows northeastwards for more than 200 km, and then turns south through the Burkinabe territories. Along its course, it determines the border between Burkina Faso and Ghana and then between Ivory Coast and Ghana. It finally turns eastwards and, after passing through the Bui dam, discharges its flow (ranging between 35 during the dry season and 375 m^3 s^{-1} in the wet) to the Lake Volta with a total course of about 1,300 km. White Volta originates in north Burkina Faso and flows towards Ghana following a southeastward direction. It receives the discharge of the Red Volta near Ouagadougou, and enters to Ghana till discharging its flow to Lake Volta. Its total length is about 1,100 km and its mean annual flow is about 300 m^3 s^{-1}. The Oti River springs from the Atakora Mountains in Benin and flows southwestwards through Togo and Ghana for about 900 km before joining the Volta Lake. Its flow is highly dependent on the abundant precipitation of the area: during the dry season is basically dry, but could easily go above 500 $m^3 s^{-1}$ during the wet season. Downstream the Akasombo and Kpong dams the Volta flows through a floodplain and discharge its flow in the Gulf of Guinea in Ghana, near the town of Ada Foah. The Volta basin spans four climatic zones. The Sahelian zone in the north receives less than 500 mm rain per year. From this point following a southward direction, precipitation increases: 500-900 mm in Burkina Faso (majority of the Upper Volta); 900-1,100 in the Middle Volta (including northern parts of Benin, Ivory Coast, Togo, and Ghana); 1,100-1.300 in the Lower Volta. Precipitation is characterized by a high seasonality: the rainy season lasts about two months in the Upper Volta, where precipitation is nearly zero for the rest of the year, and six to seven in the Lower part. About 70% of the precipitation in the basin falls between July and September. Seasonal flooding is common in the whole system. As in the neighboring Niger basin, precipitation decreased significantly after the 1970s, causing discharge decrease of about 14% between 1936 and 1998.

3.1.4.3 Socio-economic aspects

Volta riparian countries are among the poorest and underdeveloped economies in the world, with an average GNP per capita of about $372 (ranging between 190 in Mali and 710 in the Ivory Coast). Life expectancy is generally very low: between 42 and 56 years. Main reason is the inadequate access to health care and other basic services; about 30% of children are malnourished in Burkina Faso, 40% in Togo. Education is also rather low, about 50% of the population is illiterate. This phenomenon stresses the deep gender imbalance: in the case of women, in fact, this percentage could rise up to 80%, especially in Mali and Burkina Faso. The 6 Volta riparian countries score low in the Human Development Index classification. About two thirds of the population lies below poverty line in Mali, Burkina Faso and Ghana. In these countries income inequality is extremely high. With the exception of Togo and Ivory Coast (< 20%), over 50% of the gross capital formation in the Volta riparian countries depends on foreign aid. Main economic activities are represented by crop and livestock production, fisheries, forestry, mining, electricity supply, construction, manufacturing, and tourism. While the service sector is dominant in urban areas, agriculture still represents the main economic activity in the rural context, representing about 35 to 40 % of GDP and >60% of the employment in all the 6 countries, with peaks of about 90% in Burkina Faso and Mali. While average precipitation, at least in the middle and lower part of the basin, is theoretically sufficient for sustaining the agricultural production, its uneven spatial and temporal distribution is more and more affecting rainfed agriculture, increasing the need for irrigation infrastructures. Irrigation potential in the basin was estimated in about 1.5 million hectares, in particular: Burkina Faso 140 thousands ha, Benin 30 thousands, Togo 90 thousands, Ivory Coast 25 thousands, and Ghana 1.2 million ha (FAO, 1997). Only a fraction of the potential has been already developed and agriculture remain rainfed and poorly mechanized in the whole basin. The potential irrigation yearly water requirement, estimated in about 28.5 cubic km, could be virtually met by the yearly discharge, historically averaging about 38 cubic km (about 1,200 $m^3 s^{-1}$). Agriculture is mainly small scale, and of a subsistence nature. Main production is focused on food crops, such as sorghum, millet, maize, cowpea, yam, cassava, and groundnuts. Some cash cops, as cotton, cocoa and coffee, are also produced, but with practices characterized by poor efficiency and sustainability. Due to the heavy seasonality in precipitation and the frequent drought events, migration is extremely common. The phenomenon is mainly internal, as for 70% of the Burkinabe migrants. Rural migration is usually characterized by movement that could be temporary during the rainy season or permanent seeking more productive or less populated areas. This historically caused problems of land degradation due to unsustainable agricultural practices, overgrazing, and forest clearing for the production of cash crops, like cotton. International rural migrants mainly head towards Ivory Coast and to a lesser extent to Ghana. Transboundary people and goods movement has been eased with the development of the ECOWAS (Economic Community of West African States). Livestock production has been historically spread all around the basin. Main animal farmed are represented by poultry, cattle, sheep, goats, pigs, horses, and donkeys. Transhumant practices are traditionally more frequent in the upper portion, especially in Mali and Burkina Faso. Seasonal livestock migration has created tensions between nomadic and sedentary cattle breeders. Both farming and livestock production are extremely vulnerable to climate variability: after the 70s and 80s droughts it has been observed a massive relocation of large part of the population from the northern regions to the central plateau. Between 1975 and 1985 population in the Burkinabe capital Ouagadougou increased by 156%, while in Bobo-Dioulasso by 101%. Per capita domestic water use is considerably low, averaging between 25 liters per day in Mali to 65 l day-1 in some areas of Togo and Ghana. Fishery is a rapidly growing sector in the Volta basin. In Benin fish production reached 42 thousand tons per year, 10.5 in Burkina Faso, and 87.5 in Ghana employing more than 100 thousand people. Mining industry is developed in the territories of Benin, Burkina Faso and Ivory Coast: main production is represented by gold, zinc, bauxite, and manganese. Transformation industry and manufacture are not particularly developed in the basin, with the exception of the coastal Ghana, where aluminium production is the main energy demanding sector. Hydropower is mainly concentrated in the lower part of the basin, where one of the largest manmade lakes in the world was formed after the construction of the Akosombo Dam. This is a large hydropower project with a 1,020 MW (912 until 2006) plant that has represented the main power source for the area since its installation in the mid-1960s. The project was complemented by a second installation, the Kpong (or Akuse) dam, a 160 MW hydropower plant installed in the mid-1980s 24 km downstream the larger one. An additional 400 MW hydropower project was recently (completed in 2013) installed in the upper Black Volta, at the Bui Gorge in Ghana. Small impoundments have been installed along the main course of the Volta's tributaries for irrigation, urban supply and livestock production, especially in the headwaters in the drier Upper portion of the basin, within the boundaries of Burkina Faso. No large hydropower facilities are present in this portion of the basin, but water withdrawal for agricultural use is extremely high in both the Black and White Volta sub catchments. The biggest hydropower unit in the Upper Volta is located in Burkina Faso: the Bagre Dam, a multipurpose infrastructure with a 16 MW hydropower unit on the White Volta. The scarce diversification of the electricity production sources, makes the energy system of the area highly vulnerable to climate variability. Several additional hydropower projects are planned for the basin: nine on the Black Volta, three on the White, and two on the Oti River.

3.1.4.4 Main ethnic groups

The Volta River was the main transportation route among the various tribes that flourished along its banks and the banks of its tributaries. Main ethnic groups along the Black Volta (Ghana, Ivory Coast, and Burkina Faso) include: Bobo, Bwa, Marka, Samo, Dagara, Gourounsi, Lobi, Birifor, Gourounsi/Lela, Dioula, and Sénoufo. Mossi people are dominant along the White Volta banks, other communities belong to the Gourmantche, Bissa, Gourounsi/Nuni, Gourounsi/Kassena, Yana, and Kurumba people, present also in Ghana and Ivory Coast. Another group spread all over the basin is the Peulh: historically involved in transhumant cattle farming.

3.2 Eastern and Central Africa

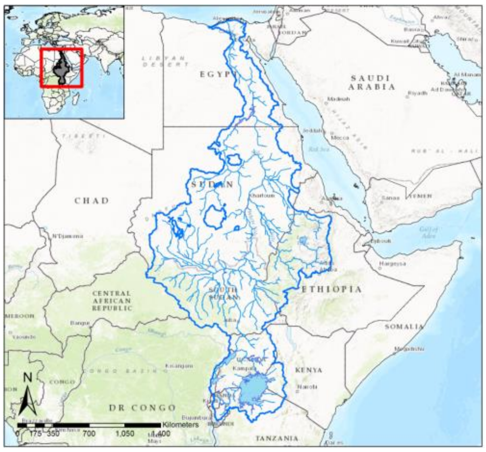
Eastern and Central Africa are almost completely covered by two of the biggest basins in the world:

- Nile
- Congo.

3.2.1 Nile River Basin

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 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 discharging its freshwater mass in the Mediterranean sea.

Figure 9. Nile River Basin (left). Average normalized values of the main factors determining the Basin's hydro-political risk (right)



Need for water cooperation in the basin (average value for the basin): 0.761 (range 0-1)

Table 5. Summary of the Nile River basin main statistics.

Length	~ 6,695 km
Catchment area	3,177,000 km^2
Max Elevation (Country)	White Nile 2,700 m (Uganda) – Blue Nile 1,788 (Lake Tana - Ethiopia)
Average yearly precipitation (min - max)	~ 615 (0 – 2,060) mm
Average discharge (min - max)	~ 2,283 (1,300 – 3,424) $m^3 sec^{-1}$
Countries in the basin (* hydrologically active)	11 (11*) – Burundi*, Rwanda*, Tanzania*, Kenya*, Congo (DRC)*, Uganda*, Ethiopia*, Eritrea*, Sudan*, South Sudan*, Egypt*
Hydrologically active area % distribution ([+] water producer; [-] water consumer; [º] neutral)	Burundi (0.4% [+]); Rwanda (0.7% [+]); Tanzania (3.7% [+]); Kenya (1.6% [+]); Congo (DRC) (0.7% [+]); Uganda (7.5% [+]); Ethiopia (11.5% [+]); Eritrea (0.8% [+]); South Sudan (19.5% [º]); Sudan (44% [-]); Egypt (9.6% [-]).
Population in the basin	~ 257,000,000
Main agricultural production	Wheat, corn, millet, sorghum, banana, plantain, tea, coffee, cassava, sweet potato, beans, rice, sugarcane.
Farming activities	Cattle, Chicken, Sheep, Goat, Camel, Fisheries
River Basin Organization	Nile Basin Initiative[12], established in 1999 as an intergovernmental partnership of 10 of the Nile basin countries (Eritrea participates as an observer).

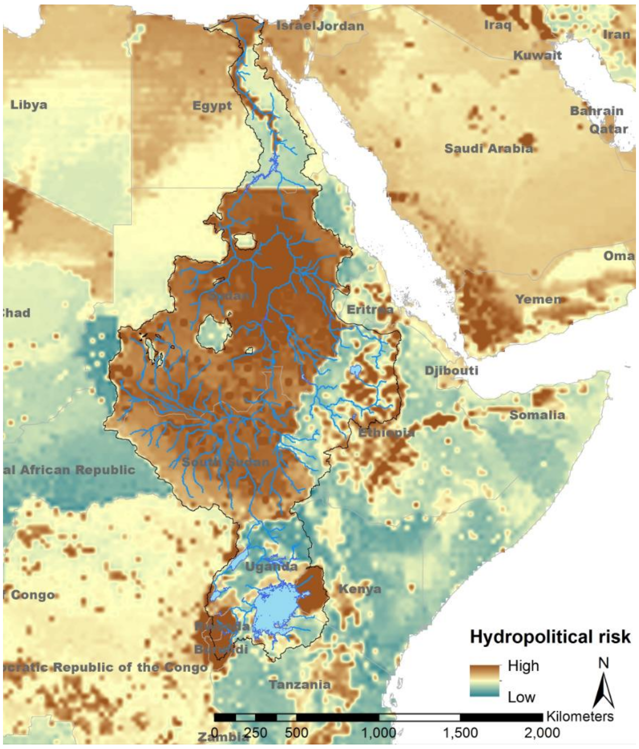
Data source: *The Nile Basin Water Resources Atlas*[13] (NBI, 2016); *FAO - Irrigation Potential in Africa: A basin approach*[14]; (Wolman and Giegengack, 2007)

3.2.1.1 Hydro-political Risk and Need for Water Cooperation

The need for water cooperation was found to be generally very high in the Nile River Basin. Historical and current tensions between the riparian states, and the difficult geo-political situation of the area constitute the major determinants of risk. The areas where hydro-political risk was found to be extremely high are, in particular: the Nile delta and the agricultural intensely cultivated area along the river in Egypt; the Sudanese and South Sudanese portions of the basin; the portion of Ethiopia in the Blue Nile valley. Moreover, the human pressure on water resources makes the hydro-political risk very high in Rwanda, Burundi, and in the areas surrounding the banks of Lake Victoria, in particular on the densely populated Kenyan side. Geo-politics of water is particularly intense and has long historical roots in the basin. During and immediately after the colonial period, the downstream countries' agricultural productivity (in particular Egypt and Sudan) was heavily protected with bilateral treaties, as for instance the 1929 and the 1959 agreements. These treaties did not take into consideration the needs of some upstream countries, like Ethiopia. The exploitation of the hydropower potential in the upper Nile and, in particular, of the Blue Nile is currently the main source of tension in the area.

[12] http://nilebasin.org/
[13] http://nileis.nilebasin.org/content/nile-basin-water-resources-atlas
[14] http://www.fao.org/docrep/W4347E/w4347e0k.htm

Figure 10. Hydro-political Risk and Need for Water Cooperation in the Nile River Basin (Farinosi et al., n.d.)



3.2.1.2 Physical and climatic aspects

Nile River originates by two main tributaries: the White and the Blue Nile. The first springs from Lake Victoria in the Equatorial plateau in Eastern Africa. Its water flow is fed by the headwaters coming mainly from Tanzania, Burundi and Rwanda. Conventionally, the furthest upstream tributary of the Nile River is identified with the Kagera River, which, in turn, is originated by the Ruvyironza and Nyabarongo rivers, respectively from Burundi and Rwanda. The White Nile flows northwards from Lake Victoria, crossing the borders of Uganda, Congo (DRC), and South Sudan, forming the vast Sudd wetland and swamp area, and then flows through Sudan, joining the Blue Nile close to its capital Khartoum. The Blue Nile originates from the south-eastern bank of Lake Tana, in the Ethiopian's highlands, proceeds southeastwards through gorges, rapids, and waterfalls, towards the center of the country and turns westwards about one hundred kilometers north of the capital Addis Ababa. Blue Nile, flows then into the Sudanese territory following a north-western direction till merging with the White Nile and forming the Main Nile. From this point the River proceeds through the deserts in Sudan and Egypt and flows into the Mediterranean Sea in a large Delta. The Blue Nile is characterized by a high flow seasonality and represents the largest contributor in terms of discharge. The White Nile's discharge, instead, given the flow buffer effect brought by the several lakes and the large wetlands (in particular in the Sudd area) formed along its course, is more constant throughout the year. The Lower Nile was characterized by seasonal flooding: these events, occurring every year with different intensities, were extremely important for the civilizations living along the Nile Valley. Flood recession agriculture was the main food production activity, and in the ancient Egyptian civilization, the seasonal flood records were used as proxy to predict the yearly agricultural productivity, and to determine the taxes imposed. Flow regulation, jointly with hydropower and irrigation potential, were the main objectives pursued during the colonial period: a large number of hydraulic infrastructure have been installed since the beginning of the 20th century, imposing radical changes to the river regimes. Currently, the seasonal flooding of the delta is completely controlled by the manmade infrastructures (NBI, 2016; Wolman and Giegengack, 2007).

3.2.1.3 Socio-economic aspects

The Nile River basin countries have experienced extremely turbulent political periods in the recent times. Egypt, the most developed economy and the hegemonic power in the area, is facing internal political problems started with the 2011 civil protests. Sudan was afflicted by 2 extremely harsh civil wars: the first lasted for 17 years between 1955 and 1972, and killed more than 500 thousands people forcing to massive migration several hundred thousands. War restarted in 1983, it led to the independence of South Sudan in 2011, and it is still ongoing in several parts of the Sudanese territory, as in Darfur. Burundi and Rwanda were devastated by a bloody civil war and the subsequent genocide of several tens of thousands people. Uganda, Tanzania and Congo-DRC were afflicted by numerous internal tensions, which in some cases are still ongoing. Political instability rose recently also in Kenya. Some of these countries are considered among the most "Fragile States" by the Fund for Peace organization[15]. Underdevelopment and lack of access to the basic services is common especially in the southern portion of the basin: people living below the poverty line are the majority of the population in the Congolese, Rwandese, and Burundian portions of the basin. Poverty is widespread also in the other countries, with the partial exception of Egypt, main economic and military power in the basin. Rural population lives in far worse conditions respect to urban population throughout the basin, especially in the most remote areas. Level of electrification, access to improved water supply and sanitation, remain low in all the countries except Egypt. Agriculture is still the main source of income for the rural population; the industrial sector, mainly represented by mining and extraction of fossil fuels follows. Rainfed agriculture, ~ 33 million ha, is more common in the southern part of the basin, where precipitation is more abundant: in particular in Uganda, South Sudan, Kenya, and Tanzania. Main production in these areas is represented by sesame, corn, pulses, and millet. Small scale localized irrigation schemes, however, are present in the areas surrounding Lake Victoria, in particular in the Rwandese, Tanzanian, and Kenyan territories. Large scale irrigation schemes were developed in the most arid areas, as the Blue and White Nile valleys in Sudan (1.76 million ha) and the Nile valley and Delta in Egypt (3.45 million ha). Water demand for irrigation in these two countries represent 97% of the overall demand in the basin: withdrawal were estimated in ~ 66 billion cubic meters per year in Egypt and ~ 14 in Sudan. Egypt developed about 270 thousands km of irrigation network, and, due to double cropping, its crop area is about 5 million ha (FAO, 1997; NBI, 2016). Livestock production is mainly developed around Lake Victoria, South Sudan, and Ethiopia. Capture fishery is highest in the Lake Victoria, while aquaculture is extremely developed in the Egyptian reservoirs. Egypt produces about 90% of the 1.23 million tons of fishery yearly production, followed by Uganda with 8%. Navigation is developed in 9 out of the 11 states sharing the Nile basin, with Eritrea and Ethiopia isolated for topographic reasons. Hydropower potential is extremely high in the basin, and is currently the main source of tensions between upstream and downstream countries. 22 plants were already installed, for a total of 5.66 GW capacity, 2.1 GW of which represented by the only Aswan Dam at the border between Sudan and Egypt. Additional 20 GW are planned to be installed in the next future, exploiting in particular the hydraulic potential of the Blue Nile. The Great Renaissance Dam, currently under construction in Ethiopia, is expected to contribute with about 6 GW. Egypt is particularly concerned about the hydropower development in the upstream countries. Huge diplomatic efforts are being currently made to find a new satisfactory water allocation agreement among Nile states to maximize the benefit of hydropower and agricultural development upstream, without compromising downstream water uses. In 2010, a Cooperative Framework Agreement (CFA) was signed by 6 upstream countries, with strong opposition from mainly Egypt and Sudan. A new tri-lateral agreement was signed in 2015 to ease the dispute between Sudan, Egypt, and Ethiopia over the Great Renaissance Dam.

[15] http://fundforpeace.org/fsi/

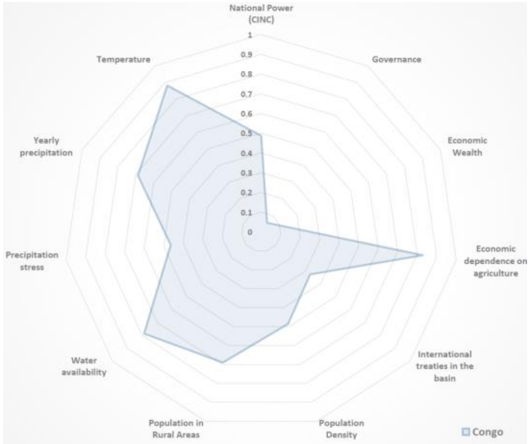
3.2.1.4 Main ethnic groups

Arabic groups (Egypt, Sudan, South Sudan), Copts (Egypt), Berber (Egypt), Beja (Egypt), Nubians (Egypt, Sudan, South Sudan), Dom (Egypt), Dinka (Sudan, South Sudan), Nuer (Sudan, South Sudan), Turkana (South Sudan, Kenya, Uganda), Acholi (Uganda), Hadendowa (Eritrea, Sudan), Sidamo (Ethiopia), Galla (Ethiopia), Gurage (Ethiopia), Ganda (Uganda), Nkole (Uganda), Chiga (Uganda), Ruanda (Rwanda), Rundi (Burundi), Sukuma (Tanzania), Gusii (Tanzania, Kenya), Masai (Kenya), Luo (Kenya), Luhya (Kenya).

3.2.2 Congo River Basin

Congo basin is the world's second largest after the Amazon Basin. It drains an area of about 4 million squared kilometers crossing the borders of 9 countries in Central-Western Africa. The basin is characterized by tropical climate, with abundant precipitation, and hosts the second largest pristine tropical forests remained.

Figure 11. Congo River Basin (left). Average normalized values of the main factors determining the Basin's hydro-political risk (right)



Need for water cooperation in the basin (average value for the basin): 0.432 (range 0-1)

Table 6. Summary of the Nile River basin main statistics.

Length	~ 4,700 km
Catchment area	~ 4,000,000 km^2
Max Elevation (Country)	~ 1,500 m (Congo DRC)
Average yearly precipitation (min - max)	~ 1,250 (~ 300 – >1,700) mm
Average discharge (min - max)	~41,200 (23,000 – 75,000) m^3 sec^{-1}
Countries in the basin (* hydrologically active)	9 (9*) – Angola*, Burundi*, Cameroon*, Central African Republic*, Congo (DRC)*, Congo (ROTC)*, Rwanda*, Tanzania*, Zambia*.
Hydrologically active area % distribution ([+] water producer; [-] water consumer; [º] neutral)	Angola (7.9% [+]); Burundi (0.4% [+]); Cameroon (2.6% [+]); Central African Republic (10.9% [+]); Congo (DRC) (62.2% [+]); Congo (ROTC) (6.7% [+]); Rwanda (0.1% [+]); Tanzania (4.4% [+]); Zambia (4.8% [+]).
Population in the basin	30 to 70 million
Main agricultural production	Coffee, palm oil, rubber, cotton, sugar, tea, cocoa, cassava, plantains, maize, groundnuts, and rice
Farming activities	Cattle, Sheep, Goat, Fisheries
River Basin Organization	Commission Internationale du Bassin Congo-Oubangui-Sangha[16], established in 2003

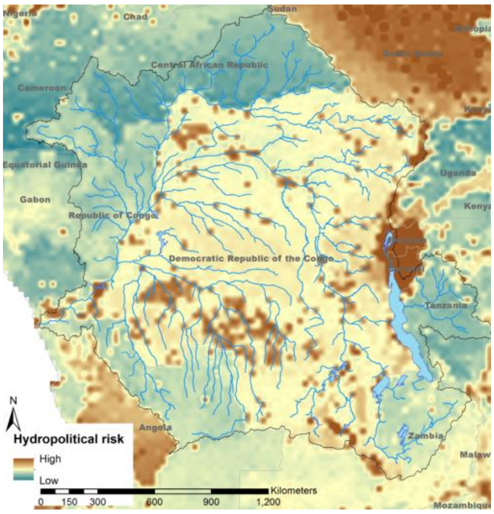
Data source: Évaluation Environnementale Post-Conflit de la République Démocratique du Congo (UNEP, 2012); Bassin du Congo (CICOS, 2017), (Runge, 2007).

[16] http://www.cicos.int/

3.2.2.1 Hydro-political Risk and Need for Water Cooperation

The need for water cooperation was found to be highest in the Rwandese and Burundian portions of the Congo Basin. Generally higher hydro-political risk was found within the Democratic Republic of Congo borders, with hotspots around the main urban settlements and in the agricultural and mining areas located in the regions east of the capital Kinshasa and in the north of the country.

Figure 12. Hydro-political Risk and Need for Water Cooperation in the Congo River Basin (Farinosi et al., n.d.)



3.2.2.2 Physical and climatic aspects

The Lulaba River, from which the Congo River originates, springs in the Katanga Plateau, in the southeastern corner of the Democratic Republic of Congo, very close to the Zambian border. The river flows northward for about 1,800 km (Upper Congo) collecting the inflow from 7 main tributaries and the outflow of major lakes, among which Lake Tanganyika. Its course is navigable for more than 650 km, until the Boyoma Falls near Kisangani, where the Congo River course officially begins. The Middle Congo flows northwest and then turns in a southwestern direction till entering the Lake Nkunda (aka Pool Malebo or Stanley Pool) where Kinshasa and Brazzaville are located. This large portion of the river is almost completely navigable. Immediately downstream, in the Lower Congo, the river forms the Livingstone (Inga) Falls and then flows to the Atlantic Ocean. The Congo River basin hosts the second largest tropical forest in the world (second only to the Amazon). The river flow remains constant throughout the year due to the different rainfall seasonality between the North and the South of the basin, divided almost perfectly in two by the Equator. Rainy season in the Northern Congo goes from March to November, while in the South between September and April. A general decreasing precipitation trend was registered after the 1960, with a consequent decrease of the river discharge (CICOS, 2017; Runge, 2007).

3.2.2.3 Socio-economic aspects

The area of the Congo River basin witnessed one of the harshest decolonization and postcolonial periods in Africa. Almost all the countries sharing the basin were devastated by terrible civil conflicts that often ended in atrocious genocides and massive refugee flows. Democratic Republic of Congo was destroyed by the First (1996-1997) and Second (1998-2003) Congo Wars, and by the Kivu Conflict (ongoing with some interruptions since 2004) totaling more than 5 million victims; Republic of Congo was hit by the 1997 Civil War destroying large part of the capital Brazzaville and causing tens of thousands civilian deaths; Central African Republic by the Bush War (2004-2007) and Civil War (ongoing since 2012); the Rwandan Civil War and Genocide (1990-1994) caused losses estimated between 500,000 and 1 million; the Burundian Genocide (1972) and Civil War (1993-2006) killed respectively between 80,000 and 210,000 and about 300,000; the Angolan Civil War (1975 - 2002) caused losses quantified in 500,000. The consequences of these catastrophic events are still impacting the population of the basin, suffering for extreme poverty, malnutrition, lack of the basic services, high mortality rate, no or limited access to healthcare, violence, sex abuse, and isolation. On the other hand, the Congo River Basin is one of the richest places on earth in terms of natural resources: minerals, such as tin, coltan, diamonds, copper, zinc, uranium, gold, nickel; fossil fuels, as oil and natural gas; forest and timber. Moreover, the basin has one of the world's highest hydropower potential. Illegal timber extraction, poor management, and overexploitation of natural resources are the main causes of environmental degradation in the basin, one of the most diverse and valuable ecosystems left on earth. Basin's population lives mainly in rural settlements, practicing small scale rainfed subsistence agriculture, animal farming, and fishery. Main source of proteins for the rural population is still represented by bushmeat, insects, and fish harvesting. Industrial cattle farming is practiced mainly in DRC and CAR by foreign agro-industrial groups. Limited access to the market, capital, and technology are the main limiting factors of the local agricultural sector. Land grabbing by multinational corporations operating in intensive agriculture is currently one of the main concerns in the area.

The Congo River Basin was estimated to host about 13% of the world's hydropower potential. Only a fraction of the theoretical capacity is currently installed: 40 plants are operating in the basin, with almost the majority of the installed capacity being represented by the Inga I (354 MW) and Inga II (1,424 MW) power plants in the Livingstone Falls, nearby Kinshasa. These plants are currently operating at reduced capacity due to lack of maintenance. A 40 GW mega dam, Grand Inga, was designed to be installed in the same area. This project could potentially supply about 40% of the African electricity needs, but the environmental and social negative externalities of the construction of this project have not yet been quantified and expected to be extremely high (CICOS, 2017; Runge, 2007; UNEP, 2012).

3.2.2.4 Main ethnic groups

More than 150 different ethnic groups are present within the area of the Congo River basin. These include: Bantu (divided in a countless number of groups); Hutus, Fulani, Kara, Pygmy (mainly belonging to the Aka, Twa, Mbuti, and Cwa groups); Luba; Mongo; Zande; Teke; Tutsis; Mangbetu.

3.3 Southern Africa

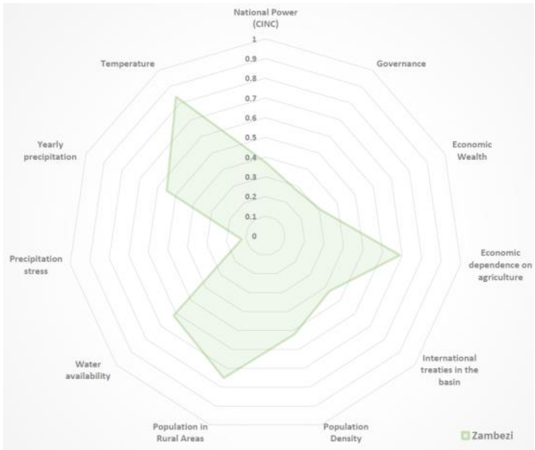
Main River Basins in the Southern Africa are:

- Zambezi
- Orange.

3.3.1 Zambezi River Basin

Zambezi basin is the fourth largest in Africa after the Congo, Nile and Niger River Basins. It drains an area of about 1.4 million squared kilometers crossing the borders of 8 countries in Southern Africa. The basin area is characterized by climate characteristics varying from subtropical in the North to temperate and arid conditions in the South.

Figure 13. Zambezi River Basin (left). Average normalized values of the main factors determining the Basin's hydro-political risk (right)



Need for water cooperation in the basin (average value for the basin): 0.431 (range 0-1)

Table 7. Summary of the Zambezi River basin main statistics.

Length	~ 3,000 km
Catchment area	1,390,000 km^2
Max Elevation (Country)	1,585 m (Zambia)
Average yearly precipitation (min - max)	~ 950 (~ 550 – 1,400) mm
Average discharge (min - max)	~3,500 (680 – 14,700) m3 sec-1
Countries in the basin (* hydrologically active)	8 (8*) – Angola*, Botswana*, Malawi*, Mozambique*, Namibia*, Tanzania*, Zambia*, and Zimbabwe*
Hydrologically active area % distribution ([+] water producer; [-] water consumer; [º] neutral)	Angola (18.4% [+]); Botswana (1.0% [-]); Malawi (8.0% [+]); Mozambique (12.8% [+]); Namibia (1.0% [º]); Tanzania (2.0% [+]); Zambia (41.7% [+]); Zimbabwe (15.6% [+]).
Population in the basin	~40,000,000 (of which ~ 7.5 million in urban areas)
Main agricultural production	Wheat, Rice, Corn, Millet, Sugarcane, Cotton, Tea, Coffee, Soybean, Banana, Tobacco
Farming activities	Cattle, Sheep, Goat, Fisheries
River Basin Organization	Zambezi Watercourse Commission[17], established in 2011

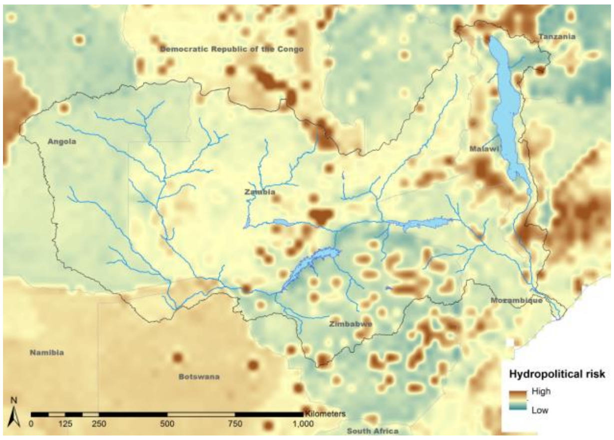
[17] http://zambezicommission.org/

Data source: *Zambezi Environmental Outlook* (ZAMCOM et al., 2015)*; Zambezi river Basin - Atlas of the changing environment* (SADC/SARDC et al., 2012)*; and The Zambezi river basin : a multi-sector investment opportunities analysis (Vol. 3) - State of the Basin* (World Bank, 2010)

3.3.1.1 Hydro-political Risk and Need for Water Cooperation

The need for water cooperation was found to be higher in the Middle and Lower Zambezi, as well as alongside the main tributaries: Kafue, Luangwa, and Shire/Lake Malawi. The upper portion of the basin is characterized by a relative abundance of water resources and by a very sparse presence of human settlements: characteristics determining a lower hydro-political risk. Only the area of the Victoria Falls was found to be relatively more likely to experience water related issues. The Zimbabwean portion of the basin is characterized by the large economic dependency on agricultural practices by the rural population in a relatively water scarce area: a combination of factors determining the high need for water cooperation in the area. Human pressure on water resources determine the relatively high hydro-political risk in the Copper Belt and the Lusaka area in central Zambia, as well as in the area surrounding Lake Malawi.

Figure 14. Hydro-political Risk and Need for Water Cooperation in the Zambezi River Basin (Farinosi et al., n.d.)



3.3.1.2 Physical and climatic aspects

The river springs in the North-West of Zambia, almost at the border with the Democratic Republic of Congo, a sub-tropical region characterized by abundant precipitation (>1,400 mm yr-1). It flows South-West passing the Angolan border, then follows a southward direction and flows back to the Zambian territory dropping about 400 meters in 400 km. The river follows this direction for additional 800 km in a relatively flat area characterizing the Western Zambezi grasslands, it passes through the Caprivi Strip in the Namibian territory, and forms the Victoria Falls, considered the boundary between Upper and Middle Zambezi, at the border between Zambia and Zimbabwe. Downstream of the Victoria Falls, the river follows an eastward direction through the Botoka Gorges and additional 250 km of rapids and reefs till entering the impoundment of the Kariba Dam. It receives the inflows of two of its major tributaries, Luangwa and Kafue, and enters the Cahora Bassa reservoir, in Mozambique. The remaining 650 km of the Lower Zambezi between the Cahora Bassa Dam and the Indian Ocean are navigable. About 150 km from its Delta, the Zambezi River receives the flow of its third largest tributary, the Shire River, which drains the outflow from the Malawi Lake. All the major contributors of the main river flow in a southward direction from the more precipitation abundant areas in the north of the basin. The rainy season is concentrated in the summer, 4-6 months between October and March. The Zambezi Delta was characterized by large floods at the end of the rainy seasons. The seasonal flooding was considerably reduced after the installation of the Kariba and Cahora Bassa dams.

3.3.1.3 Socio-economic aspects

After the turbulent decolonization period, largely characterized by civil war, which as in the case of Angola continued till the last decade, the Zambezi River basin countries experienced a period of fast socio-economic development. The basin is particularly rich in natural resources. Main economic activities are represented by mining, agriculture, fishery, tourism, and manufacturing. Although the economy of the area is boosted by the extraction of important resources like oil, coal, cobalt, copper, and diamonds, large part of the population still suffers high poverty rate, lack of basic services, maternal and infant mortality, and low life expectancy. Agriculture represents about 17% of the overall GDP of the countries sharing the basin's territory (2% Botswana – 29% Mozambique), while industry with 32% (19% Malawi – 57% Angola), and the service sector with 51% (32% Angola – 60% Botswana) are the major contributors to the economy of the area (SAIIA, 2014). Population in the basin was estimated in about 40 million, three-quarters of which living in rural areas (50% in Zambia, 85% in Malawi), and the remaining 25% in the 21 major towns. Population living in poverty ranges between 30% in Botswana to almost 90% in Tanzania; access to clean water is pretty low (~50% in Angola, Mozambique, Tanzania, and Zambia), and the incidence of HIV/AIDS is one of the largest in the world.

Attending to a recent study (ZAMCOM et al., 2015), per capita water consumption in the basin averages around 101 m3 yr-1, ranging between 27 in Angola to 203 in Zimbabwe. The most water intense sector is agriculture, to which more than 76% of the resource is destined (42% in Botswana, ~60% in Angola and Namibia, >90% in Tanzania, Mozambique, and Zimbabwe). Small-scale rainfed agriculture represents the main source of income in the majority of the basin. Corn, wheat, cassava, rice, sugarcane, sorghum, cotton, groundnuts, and tobacco are the most important crops. Agricultural land in the basin was quantified in about 5.2 million hectares, with only about 0.25 million irrigated. Irrigation infrastructural development was identified as a priority in the Zambezi area and additional 0.51 million hectares projects were already identified. Fuelwood collection and cattle production are the main threats to the natural ecosystems of the basin, extremely important from a conservation standpoint. Fishery is the major source of income for the households living in the delta and in the wetlands along the rivers.

Hydropower potential of the basin was estimated in about 20 GW, of which only about a quarter is currently exploited, mainly in the Cahora Bassa, Kariba, and Kafue Gorge dams in Zambia and Mozambique. About 40 additional possible installations (summing up to about 13 GW of installed capacity) have been already identified in the basin. Some of these projects are currently under construction within the Southern African Power Pool (SAPP) development program. Several water transfer projects have been already designed for the basin, as for the Zambezi Water Transfer Scheme, or the North-South Carrier in Botswana.

3.3.1.4 Main ethnic groups

More than 30 different ethnic groups are present within the area of the Zambezi river basin. These include: Bemba (Zambia); Bunda (Zambia); Chewa (Malawi); Chewa/Nyanja (Zambia); Lozi (Zambia); Lunda (Angola and Zambia); Luyana (Zambia); Luchaze (Angola); Nambya (Zimbabwe and Namibia); Ndebele (Zimbabwe); Ngoni (Malawi); Nyanja (Malawi); Quioca (Angola); Sena (Malawi and Mozambique); Shona (Zimbabwe); Tonga (Zambia and Zimbabwe); Tswana (Botswana); Tumbuka (Malawi); Yao (Malawi) (SADC/SARDC et al., 2012).

3.3.2 Orange River Basin

Orange (often referred as Orange-Senqu) basin is a large transboundary catchment in Southern Africa. It drains an area of about 900 thousands squared kilometers crossing the borders of 4 countries. The basin area is characterized by temperate to arid climate characteristics, with precipitation heavily concentrated in its eastern and south-eastern portions.

Figure 15. Orange River Basin (left). Average normalized values of the main factors determining the Basin's hydro-political risk (right)

Need for water cooperation in the basin (average value for the basin): 0.522 (range 0-1)

Table 8. Summary of the Orange River basin main statistics.

Length	~ 2,200 km
Catchment area	896,368 km^2
Max Elevation (Country)	Senqu River 3,300 m (Lesotho)
Average yearly precipitation (min - max)	~ 325 (~ 35 – 1,040) mm, in extreme cases > 2,000 mm in the Lesotho Highlands
Average discharge (min - max)	Natural flow ~ 350 (35 – 825) m^3 sec^{-1} - (real average flow at the estuary, due to impoundment-driven evaporation and withdrawals: ~ 180 m^3 sec-^{1})
Countries in the basin (* hydrologically active)	4 (3*) – Lesotho*, South Africa*, Botswana, Namibia*
Hydrologically active area % distribution ([+] water producer; [-] water consumer; [º] neutral)	Botswana (8.0% [º]); Lesotho (3.0% [+]); Namibia (25.0% [-]); South Africa (64.0% [º]).
Population in the basin	~ 20,000,000 (of which ~ 7.5 million in urban areas)
Main agricultural production	Wheat, Corn, Sugarcane, Fruit, Grapes, Vegetables, Oil Seeds
Farming activities	Cattle, Poultry
River Basin Organization	Orange-Senqu River Commission[18], established in 2000 – agreement involving all the riparian states.

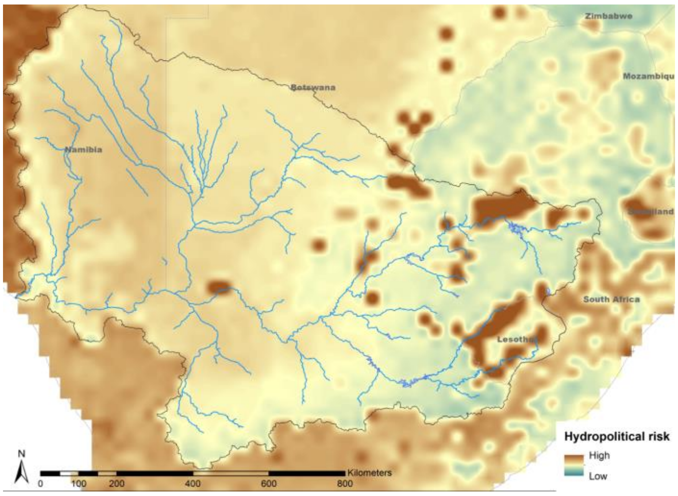
Data source: Orange River Integrated Water Resources Management Plan (ORASECON, 2007); ORASECOM Orange-Senqu River Awareness Kit[19].

[18] http://www.orasecom.org/
[19] http://www.orangesenqurak.org/

3.3.2.1 Hydro-political Risk and Need for Water Cooperation

Orange River basin water resources have been historically managed in a relatively cooperative way in both colonial and post-colonial periods. The resource is relatively scarce and unevenly distributed. Precipitation is concentrated in the eastern portion of the basin, especially in the Lesotho Highlands, where the Senqu River springs, while principal water users are represented by the South African agricultural and mining sectors. The Namibian and Botswanan portions of the basin are mostly arid, in particular in the Kalahari and south Namibian deserts, and scarcely populated. The need for water cooperation reflects the basin characteristics. It was found medium to high in the western portion of the basin; relatively low in the wettest and scarcely populated portions in the east, far from the main river branches; while, hotspots of hydro-political risk were identified in the areas where competition over water is highest: in the Basotho portion of the basin (where the Lesotho Highlands Water Project is being implemented), in the agricultural and mining dense areas of the Vaal Valley, around the industrial areas of Johannesburg, and in the most densely populated areas in the upper portions of the basin.

Figure 16. Hydro-political Risk and Need for Water Cooperation in the Orange River Basin (Farinosi et al., n.d.)



3.3.2.2 Physical and climatic aspects

The Senqu River, from which the Orange is originated, springs in the Maluti Mountains in Lesotho, an area characterized by an elevation higher than 3,000 meters and precipitation averaging around 1,200 mm per year, with peaks above 2,000 mm. Lesotho, which territory falls completely within the basin boundaries, contributes for about 40% of the total runoff of the complex and heavily modified river system. After exiting the Lesotho borders, Senqu becomes Orange. The river flows westwards through the temperate, semi-arid and arid territories of South Africa, till reaching the Atlantic Ocean spanning a total length of about 2,200 km. The Orange's largest tributary is the Vaal River, originating in the eastern part of the basin, close to the city of Johannesburg, north of the Lesotho highlands, in South African territory. The Vaal River flows westwards for about 1,200 km and discharges its flow into the Orange few km southeast of the city of Kimberley (SA). The Vaal River and the Upper Orange-Senqu section are the most hydrologically dynamic components of the basin, and represent about 80% of the total river flow. Downstream of the confluence of the two rivers, the Orange flows for more than 1,000 km through semi-arid and arid landscapes, among which the Kalahari and the South Namibian deserts. In its Middle and Lower portions, the river does not receive significant contributions in terms of flow: the main tributaries in these sections are represented by the Molopo and Fish

Rivers. However, the two catchments are almost hydrologically inactive for most part of the year, and their seasonal flow reaches the Orange only during extreme precipitation events. In this section, the Orange loses part of its discharge due to the high evapotranspiration and infiltration. The hydrological features described do not take into account the anthropogenic modifications of the river. Several water retention and transfer schemes were implemented in the upper and medium Orange and in the Vaal rivers. Of the 11,000 million cubic meters estimated natural annual runoff (corresponding to about 350 $m^3 s^{-1}$), on average, only about a half reaches the river estuary. Several dams (>40) and impoundments were installed along the main rivers: this made possible to satisfy the pressing water demand of the agricultural, industrial and mining sectors, and to buffer the high natural flow seasonality determined by the precipitations in the western portion of the basin, mostly concentrated in the period October-April. The natural river system has been heavily modified by ambitious water transfer and irrigation schemes, such as the Lesotho Highlands Water Project, and the Vaal-Harts Irrigation Scheme.

3.3.2.3 Socio-economic aspects

Although majority of the river discharge is generated in the Basotho portion of the basin, the main demand for the economic exploitation of the basin's resources is represented by the most developed economy in the region: South Africa. The most water intense sectors are represented by agriculture (~ 60% of the total water use), industry (~ 20%), and mining (~ 10%). Geographically, the largest agricultural dense areas are represented by the Vaal Valley, especially in its portion downstream of the industrial and urban areas of Johannesburg, and by the Upper and Lower Orange. Mining activities are mostly concentrated in the Upper and Middle Orange and Vaal Valley. Industrial activities are clustered in the Gauteng province, an important area that includes two major cities as Johannesburg and Pretoria and generates about 34% of the South African and 7% of the continental Gross Domestic Product. Coal, diamonds, copper, manganese, iron, gold, platinum, chromium, and uranium are among the mined materials. In particular, South Africa is the world's third largest exporter of coal, main producer of diamonds, the only world's producer of chromium, and its soils are estimated to store about half of the world's gold reserves and a significant portion of the uranium ones. Mining and industry represent the main concern in terms of water quality in the basin. Agricultural production is mainly represented by cereal and grains, vegetables, fruit, and sugarcane. The sector does not represent a major share of the South African economy, however, it is important in terms of workforce employment. Different is the scenario for Lesotho, where topography is the main limiting factor for agricultural development. Due to the aridity of the majority of the river basin, cultivable land is very limited and, in most of the cases, irrigated. New irrigation schemes are currently under development in the Middle and Lower Orange, including the Fish River basin in Namibia, a country where agriculture represent the main share of the economy and the first workforce employer. Freshwater fishery and aquaculture are not vital activities in the basin. Socio economic conditions of the population are various: income inequality in the countries sharing the basin is among the highest in the world. Access to basic services for the poorest portion of the population is still limited, especially in the rural areas. Moreover, violence and sexual abuses are common in the basin, especially in South Africa and Lesotho. The incidence of HIV/AIDS is one of the largest in the world. Hydropower production is not particularly relevant. Main potential in the South African portion of the basin has been already exploited in combination with the irrigation infrastructural development. A huge infrastructural investment is currently being implemented in Lesotho with the Lesotho Highlands Water Project, a system of tunnels and dams designed to transfer water resources to South Africa. This system (up to 1,000 MW installed capacity and pumped storage technology) is expected to satisfy the demand and generate a substantial surplus of electricity for Lesotho, with high possibility of generating income for the national economy.

3.3.2.4 Main ethnic groups

Mainly Basotho in Lesotho (among which Bakuena, Batloung, Baphuthi, Bafokeng, Bataung, Batšoeneng, Matebele); in South Africa: Bantu (Xhosa), Basotho, Bapedi, Venda, Tswana, Tsonga, Swazi and Ndebele.

3.4 Summary of the critical points

Analyzing the specific characteristics of the basins selected, the main critical points for the analysis of the African basins and the development of the African atlas of water cooperation are listed as follow:

- Climate variability and change
    - Precipitation reduction after the 1970 in the Sahelian region (impacting mainly on Niger, Senegal, Lake Chad, and Volta basins).
    - Climate variability, with potential impacts on agricultural productivity and extreme events (all basins)
    - Seasonality of precipitation and river discharge (all basins)
    - Precipitation stress
- Land use
    - Deforestation (tropical areas)
    - Soil degradation (all basins)
    - Desertification (Niger, Senegal, Upper Volta, Lake Chad)
- Agriculture
    - Scarce productivity (all basins)
    - Limited access to technology, fertilizers, market (all basins)
    - Irrigation development (all basins)
- Animal Farming – Livestock production
    - Productivity (all basins)
    - Drought impacts (all basins)
    - Nomadic farming/transhumant pastoralism. Competition farmers-herders over exploitable water and land resources. (all basins, in particular Niger, Senegal, Lake Chad, Volta)
    - Land productivity in animal farming (hectares of pasture needed per livestock head) (all basins, in particular Niger, Senegal, Lake Chad, Volta)
    - Intensive animal farming/industrial livestock production (if present)
- Fishery
    - Water quantity and quality (large natural lakes: Chad, Victoria, Tanganyika, Malawi… Main man-made reservoirs: Volta Lake, Lake Nasser, Cahora Bassa, Kariba…)
    - Impacts of river fragmentation on wild fish capture.
- Groundwater
    - Over-exploitation (Sahel)
    - Barriers to the access to shallow/deep aquifers (all)
    - Aquifer water quality (especially close to the mining sites)
- Industry
    - Mining impacts on water withdrawals and quality (all, in particular Zambezi, Congo, Niger) – linkages with the most invasive practices, such as: gold mining (mercury contamination), hydraulic mining, alluvial mining (flow diverting to mine mainly diamonds)
    - Oil industry (extraction, refining, and transportation) (Niger, Nile, Congo, Zambezi)
- Urban areas
    - Urbanization and overpopulation
    - Access to improved water supply and water sanitation
    - Wastewater collection and treatment
- Infrastructure
    - Irrigation poorly developed in the whole sub-Saharan Africa (all basins, with the exception of the tropical areas)
    - Need for more storage to buffer inter- and intra-annual seasonality (all basins)

    - Energy security (mainly in terms of electricity and in particular hydro-electricity)
    - On the other hand, impacts of flow regulation on traditional practices, such as flood recession agriculture (Senegal, Nile, Chad, Zambezi), and fishery.
    - Increasing withdrawals and evaporation impacts on water quantity (Chad, Nile)
    - Upstream/Downstream dynamics in hydropower development (Nile)
    - Water transfer (Zambezi)
    - Integration of the energy grid (as for the SAPP for the Zambezi)
    - Inland navigation – waterways
- Political
    - Political instability (in particular in the case of the Niger, Lake Chad, Nile, and Congo basins)
    - Civil conflicts
- Socio-economic
    - Population and population density
    - Access to basic services: health care (Malaria, HIV/AIDS); water supply/sanitation; (all basins)
    - Malnutrition, child mortality
    - Water fairness and efficient use as factor of production.
- Ecosystem
    - Wetlands (Niger inner delta, Chad lake; Okavango delta; Sudd – White Nile)
    - Seasonal flooding (Niger, Nile, Senegal, Chad, Zambezi)
    - River fragmentation (Zambezi, Nile)
    - Environmental flow (Nile, Niger, Senegal, Chad)
    - Water quality (All basins)
- Institutions
    - River Basin management: organizations at the river basin scale
    - Hydro-political dynamics

4 Data selection

This section describes the data collection structure and content. As mentioned in Section 2, data collection was structured in order to characterize the river basin and the water resources from both the availability and demand sides. The information collected allows to define the physical characteristics of the basin, its climatological and hydrological profiles, the geographical distribution of the main water-intense activities, and the socio economic characteristics of the population living in the area. Moreover the information coverage was structured in order to cover all the critical aspects highlighted in section 3.

4.1 Data classification, geographical and temporal resolution

Data were classified in three main groups basing on specific aspects of the analysis that will be conducted at basin level: **Biophysical** - water availability in base of the topographic, climatic and hydrological characteristics; **Water use** - main water-intense sectors, as agriculture and hydropower; **Socio-Economic** characteristics that could be relevant for water management, as governance quality, economic conditions, and population dynamics.

Data were stored directly in the format they were made available from the source and not modified in order to preserve their original characteristics.

Geographical focus was on the African continent, but also global datasets were taken into consideration, especially considering data that are collected through remote sensing. Spatial resolution varies depending on the source and the specific nature of the information taken into consideration: some data are available for specific points in space, as for instance the river flow observations; other kinds of data are available at country resolution, as in the case of mostly socio-economic variables, as for instance the Gross Domestic Product; finally, some information is available at gridded scale, with a resolution ranging between few meters to several hundred km: this is typical of remotely sensed data, as meteorological forcing or land use. Temporal resolution also varies depending on the kind of information. National socio-economic statistics are mostly available at yearly resolution, while remotely sensed data could be available at sub-daily temporal steps. Other data, such as topographic characteristics, are time invariant.

Maps and figures shown in the following subsections have to be intended as purely illustrative, they are representative of the kind of information available. A comprehensive summary of the information collected, and the related sources, is presented in **Table 9**.

4.1.1 Biophysical data

This section introduces the pieces of information that are more relevant for the characterization of the basin under the hydrological point of view. All the most important data for the analysis of the hydrological dynamics of the basins are classified in this section. Data include: topographic characteristics; river network and subbasin delineation (**Figure 17**); climatic variables, including precipitation and temperature (**Figure 18**); soil characteristics (**Figure 19**); and land cover (**Figure 20**). An eventual hydrological modeling exercise of the main basins would need to be calibrated and validated through the use of observed river discharge time series. This kind of information is not largely available in the African continent and represents one of the main limitations in the hydrological analysis of the main basins under consideration. A series of modeling exercises were conducting to reconstruct the historical time series of a selection of observation points in the area under consideration by the Global Runoff Data Centre (**Figure 20**).

Figure 17. Selected River Basins in the African continent: (left) river network and surface water, i.e. lakes and wetlands, as resulting from the analysis of the Digital Elevation Data (meters - right) (Beck et al., 2014; Lehner and Döll, 2004; Lehner and Grill, 2013; Reuter et al., 2007; USGS, 2016).

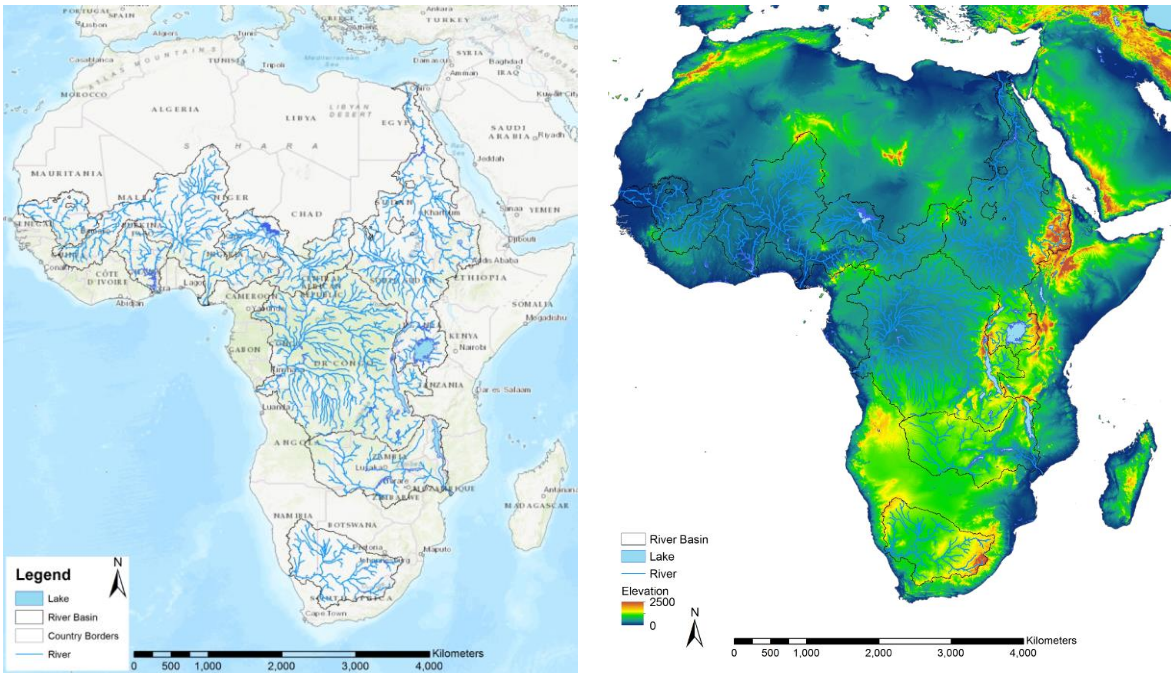


Figure 18. Average Temperature (°C - left) and yearly total precipitation (mm - right) in the study domain in the period 1997-2012 (Beck et al., 2017).

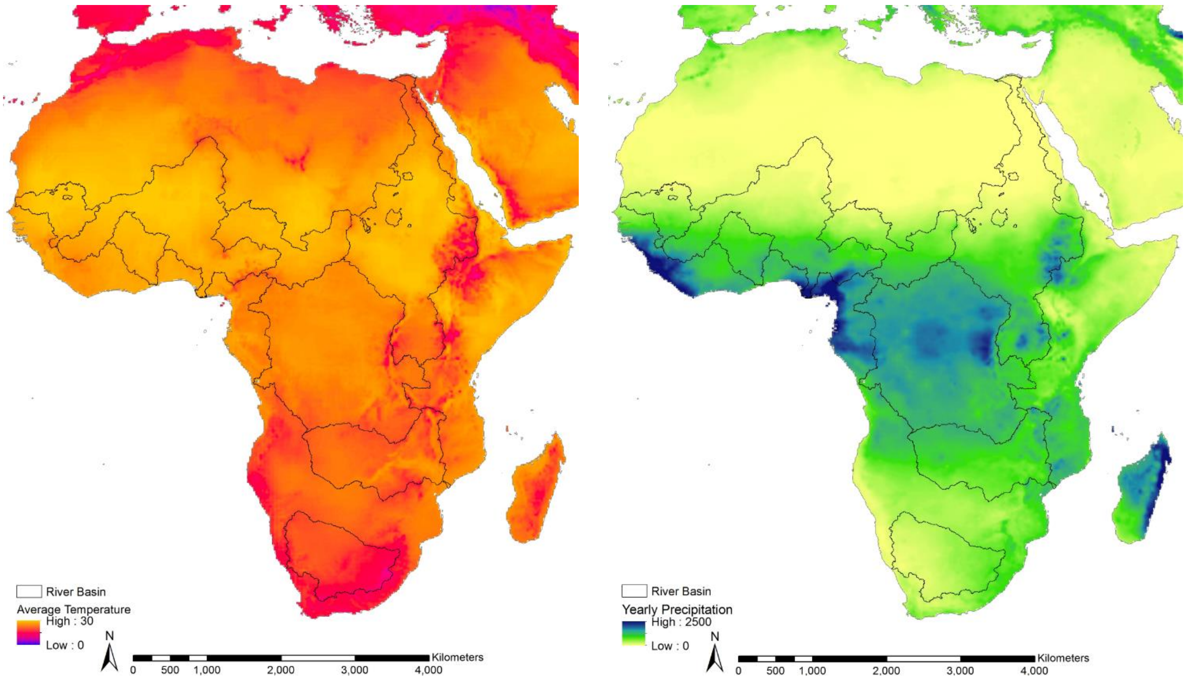


Figure 19. African Soil, Figure from Jones et al. (2013).

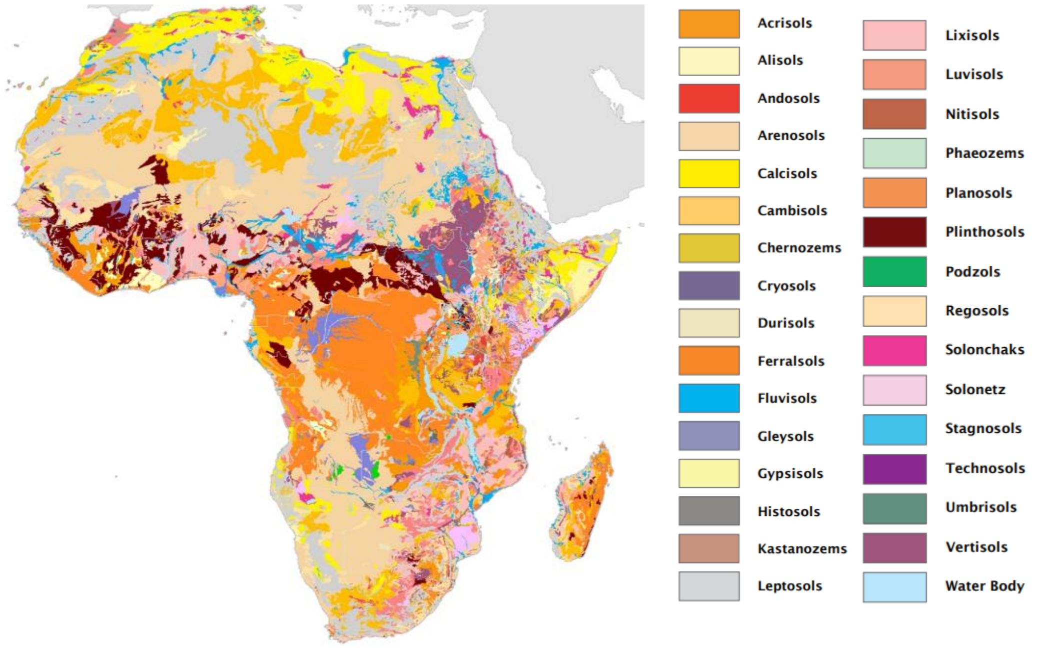


Figure 20. Copernicus Global Land Service (CGLS) yearly Land Cover (LC) map at 100m resolution for the African Continent (left) (Copernicus Service Information, 2017). GRDC gauging stations (right) (GRDC, 2017)

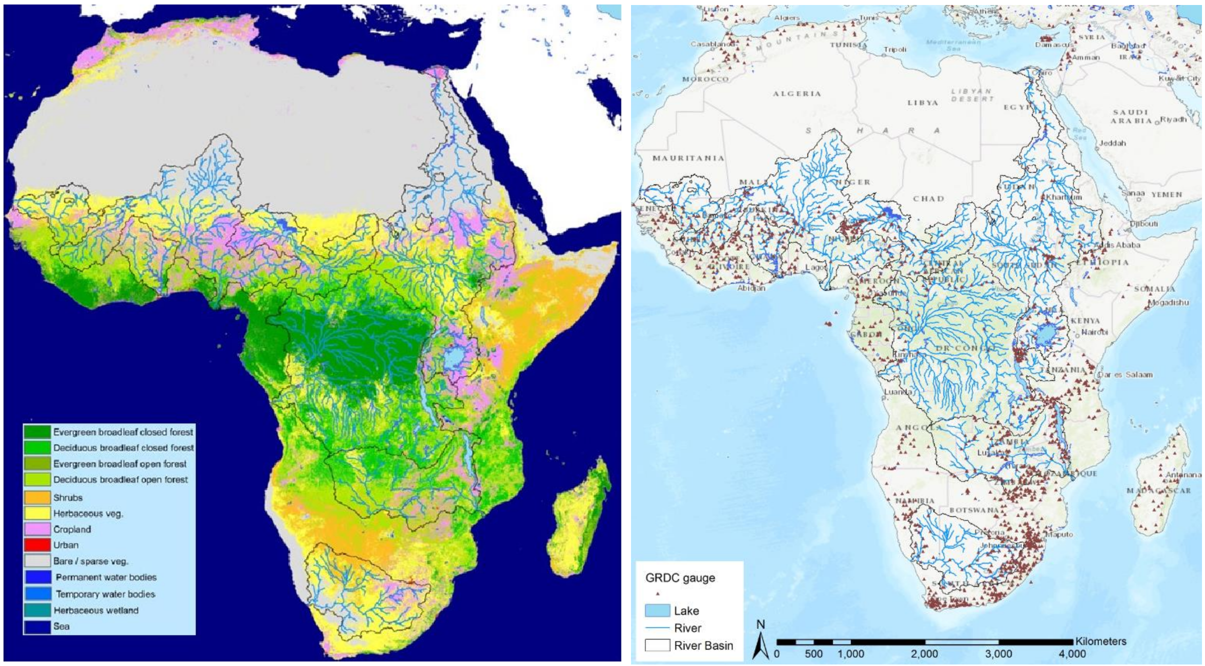


Figure 21. Global surface water monitoring data (Pekel et al., 2016)

Two additional aspects are key in the hydrological analysis of such complex hydrological systems: the dynamics of surface water (**Figure 21**), and the evolution of groundwater (**Box 1**).

Box 2. Groundwater in the African Continent

Groundwater resources are key to sustainable development, economic growth and food security in most African countries, deeper aquifers providing a safe protected long-term fresh water source and shallow ones being often exploited by local communities for their basic needs. Aquifer systems are governed by geology and tectonics, their boundaries are often distinct from surface drainage basins. Aquifers' analytical characterization, namely their geometry, and hydrogeological properties, is generally difficult to design and affected by a high degree of uncertainty, relying upon availability of local ground-based studies, remote sensed data sources, as satellite imagery and geophysics, providing limited support. Further to that, most of the information already collected is not easily accessible, as is the case for stratigraphic information derived from drilling campaigns and outcomes of pumping tests to estimate hydrogeological parameters. However, a comprehensive effort to review, homogenize and organize information on African groundwater bodies has been recently made by MacDonald et al. (2012). Estimated groundwater recharge in Africa (**Figure 22**) sensibly varies, both in space and time, consistently with meteo-climatic variations, ranging from negligible to very low rates in desert areas, as Sahara and Kalahari deserts, to high rates (above 100 mm/yr) in equatorial rainforest. On the other hand, groundwater storage, expressed as total estimated volume of available groundwater is mainly governed by geology. Thick aquifer systems located in dry regions; as Nubian sandstones, in eastern Sahara, and Iullemeden, North East of Niger River and Niamey, provide valuable unique fossil groundwater resources, extending through regions poor of or even with no surface water. The sample cases of Libya and Western Sahara perfectly highlight extreme unbalance between enormous amount of potentially available fossil groundwater resources and the negligible renewable freshwater rates.

Groundwater accessibility is another major concern (**Figure 23**). Most of the drier areas in the continent, as Sahara, African Horn and large regions in Southern Africa, are characterized by deep aquifers, water table being located hundreds of meters below the topographic surface. Groundwater exploitation in these areas demands for huge financial investments (as for instance in the case of the "Great Man Made River" in the Nubian Sandstone aquifer in Libya **Figure 23**) and poses many challenges in relation to the negligible fresh water recharge rates. Vast regions, including part of western and large extern of central and eastern Africa characterize for much lower groundwater table depth from the ground, potentially making feasible a more widespread exploitation of groundwater (i.e. hand-drilled wells **Figure 23**).

Figure 22. Recharge, groundwater storage and annual renewable freshwater –(Figure from MacDonald et al., 2012)

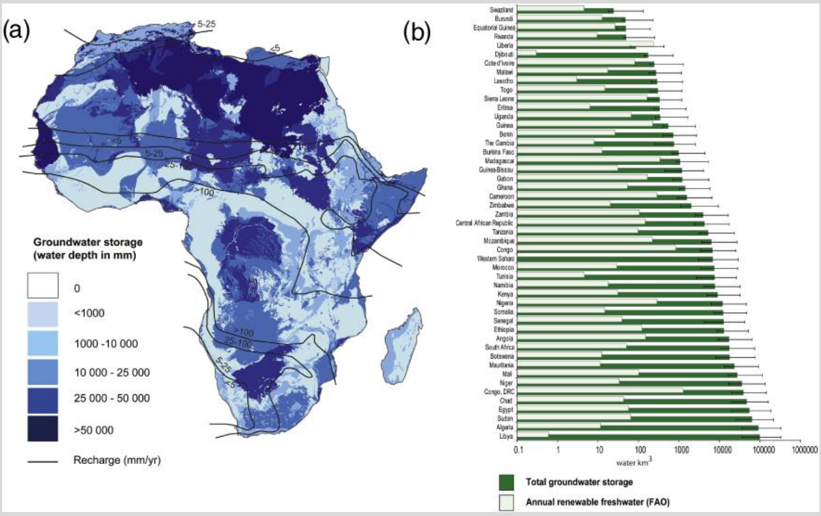
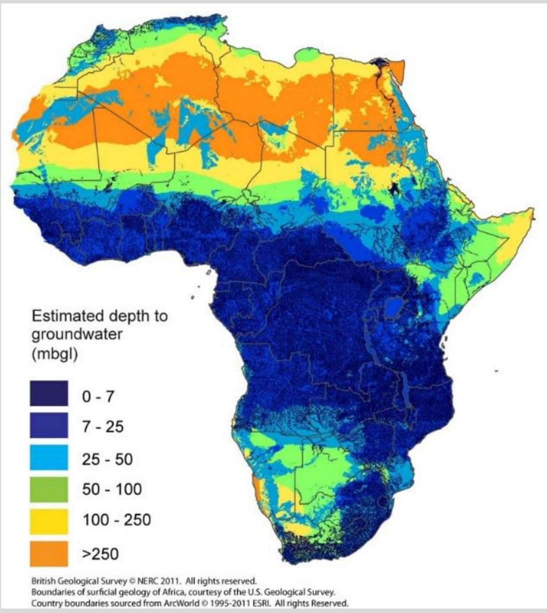


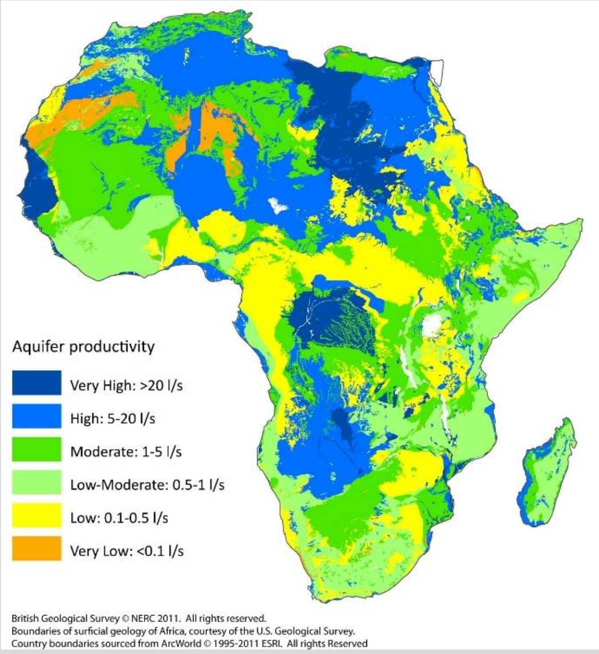
Figure 23. Estimated groundwater depth (Figure from MacDonald et al., 2012). Pipeline transportation for the Great Man Made River project in Libya[20]; hand drilling[21]



Further to accessibility to groundwater, aquifer productivity (**Figure 24**) turns to be the other key issue. It hugely varies in space, from very low to very high discharges (<0.1 l/s up to >20l/s), being generally constrained by geological formations (see patterns after major alluvial bodies as well as crystalline basement outcrops from geological map in **Figure 19**) and hydrogeological conditions (i.e. porous media, fractured bedrock).

[20] Photo credit https://en.wikipedia.org/wiki/Nubian_Sandstone_Aquifer_System
[21] Photo credit http://www.freemaninstitute.com/water.htm

Figure 24. Aquifer productivity (Figure from MacDonald et al., 2012).



4.1.2 Water Uses

Hydrological characteristics of a basin allow to give an adequate representation of the availability of water resources in a specific point in a time and space combination. But the hydrological dynamics are not only dependent on the physical characteristics of the basin. Human activities are more and more impacting on the natural river flow and, especially in the water poorest areas, water resource management and anthropogenic pressure are the most impacting factors on the natural evolution of the river regimes. The most water demanding sectors, in particular in the case of the African river basins are:

- Agriculture;
- Animal farming and fishery;
- Hydropower;
- Mining industry.

Agricultural productivity and spatial distribution of the agricultural areas are key information to understand the potential water demand of the farming sector and the productive use of the water resources; livestock production and spatial distribution of the animal farming are important proxies of the human pressure on land and water resources (**Figure 25**). Since about 65% of the African territory is characterized by arid or very arid conditions, given the fact that the most important water bodies are characterized by a large flow seasonality, impacted also by intra- and inter-annual rainfall variability, water storage infrastructure are key for the water management in the continent (**Figure 26**).

Figure 25. Example of farming and livestock production spatial distribution in the African Continent: sorghum (left), and goats heads (right) (IFPRI and IIASA, 2017; Robinson et al., 2014).

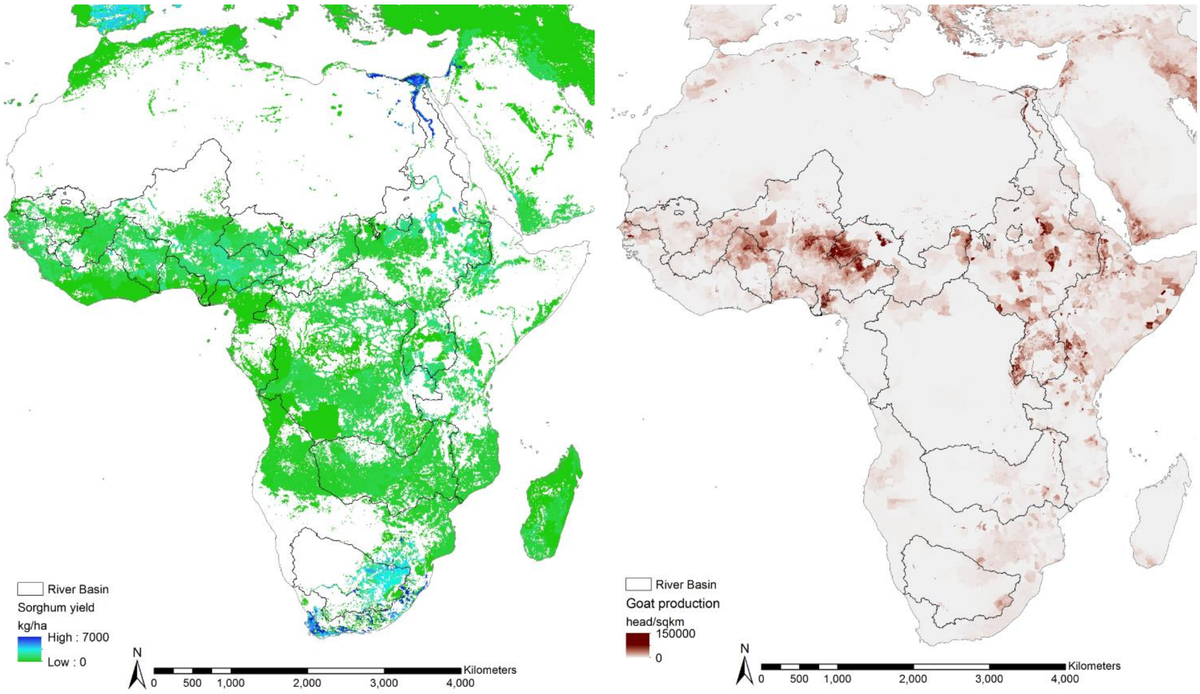
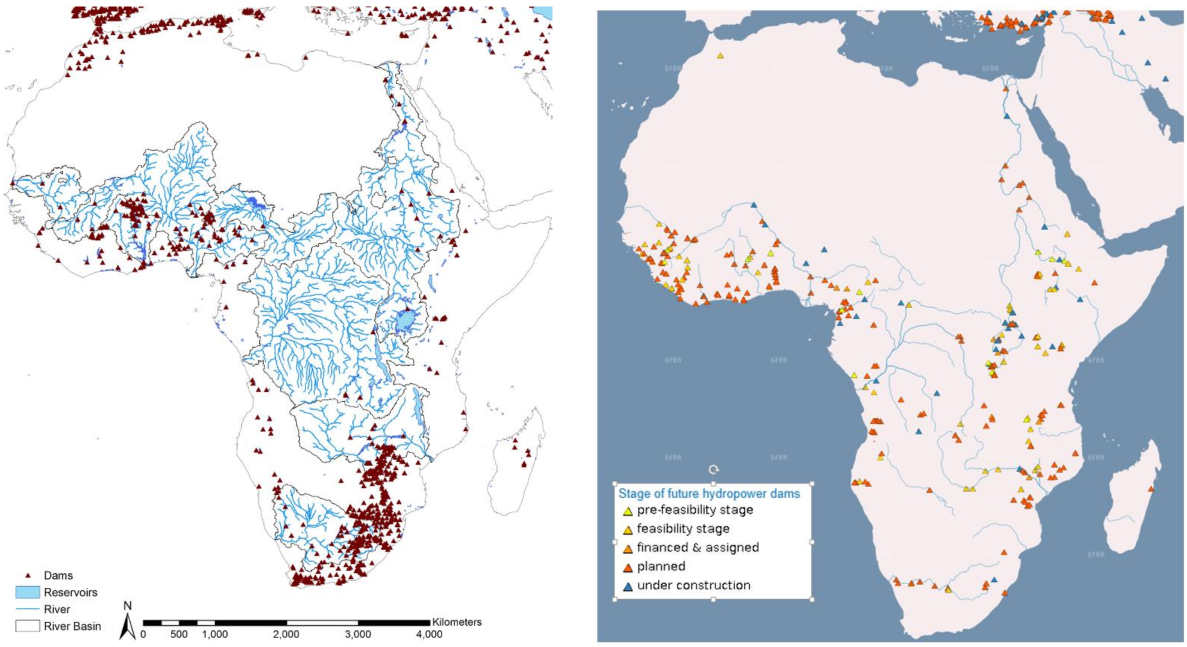


Figure 26. Water retention infrastructures in the African Continent: Existing dams and impoundments (left) (Lehner et al., 2011); future dam development (right) (Zarfl et al., 2015). Right figure credit: Global Freshwater Biodiversity Atlas[22]



[22] http://atlas.freshwaterbiodiversity.eu/atlasApp/full/index.html?map=3.4.3-global-hydropower-dams

4.1.3 Socio-economic characteristics

The analysis of the water management in the African continent is completed considering also the socio-economic dynamics that are more likely to impact (or being affected by) water uses. Therefore, the database include data as: gross domestic product and its dependency on the agricultural sector (**Figure 27**); political and military importance of the countries is represented by the Composite Index of National Capability (CINC) derived from the National Material Capabilities (NMC v5.0) database within the Correlates of War project (CoW), while the institutional quality is derived by the Worldwide Governance Indicators (WGI) project (**Figure 28**). Population dynamics are relevant to understand the historical pressure on water resources and its future evolution. Therefore, the population density data and the distribution of the population in rural or urban areas is included in the database (**Figure 29**). Ethnic groups and other cultural and traditional features are relevant for understanding the social dynamics that are likely to impact on water management at local and national level: very important are also the degree to which the areas are prone to violence and the hydro-political profile of the communities under consideration (**Figure 30** and **Figure 31**).s

Figure 27. Per capita gross domestic product (left), and economic dependency on the agricultural sector (right)

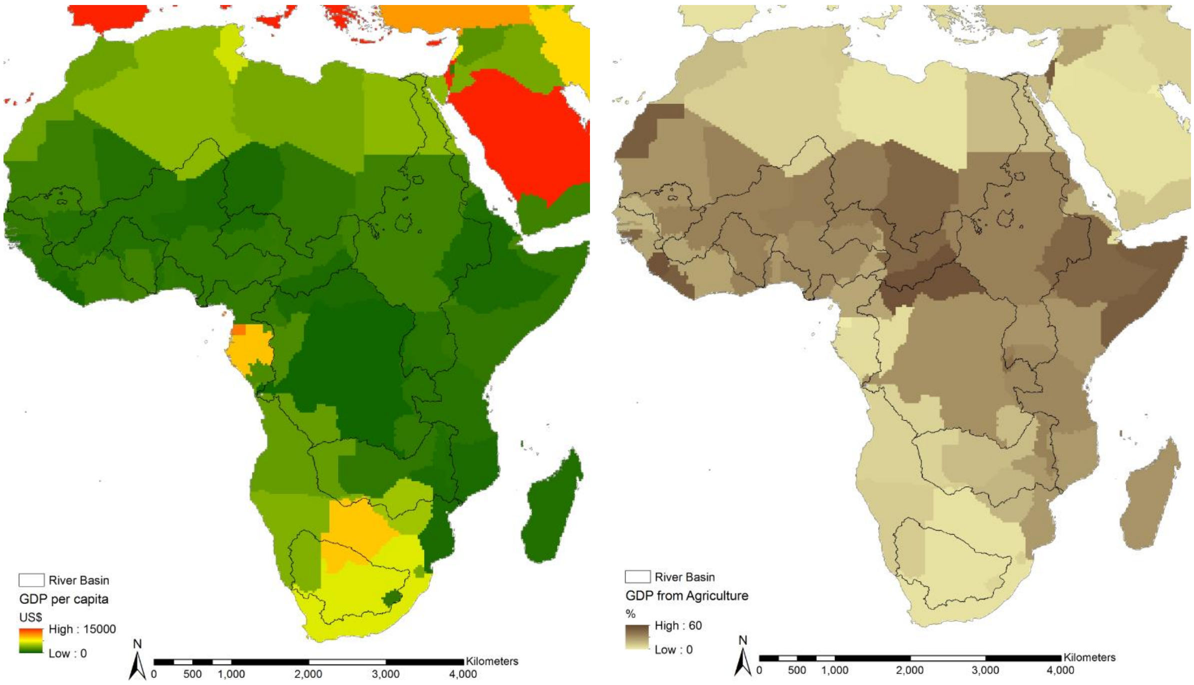


Figure 28. Composite Index of National Capability (left), and Governance indicator (right) (Kaufmann et al., 2010; Singer et al., 1972)

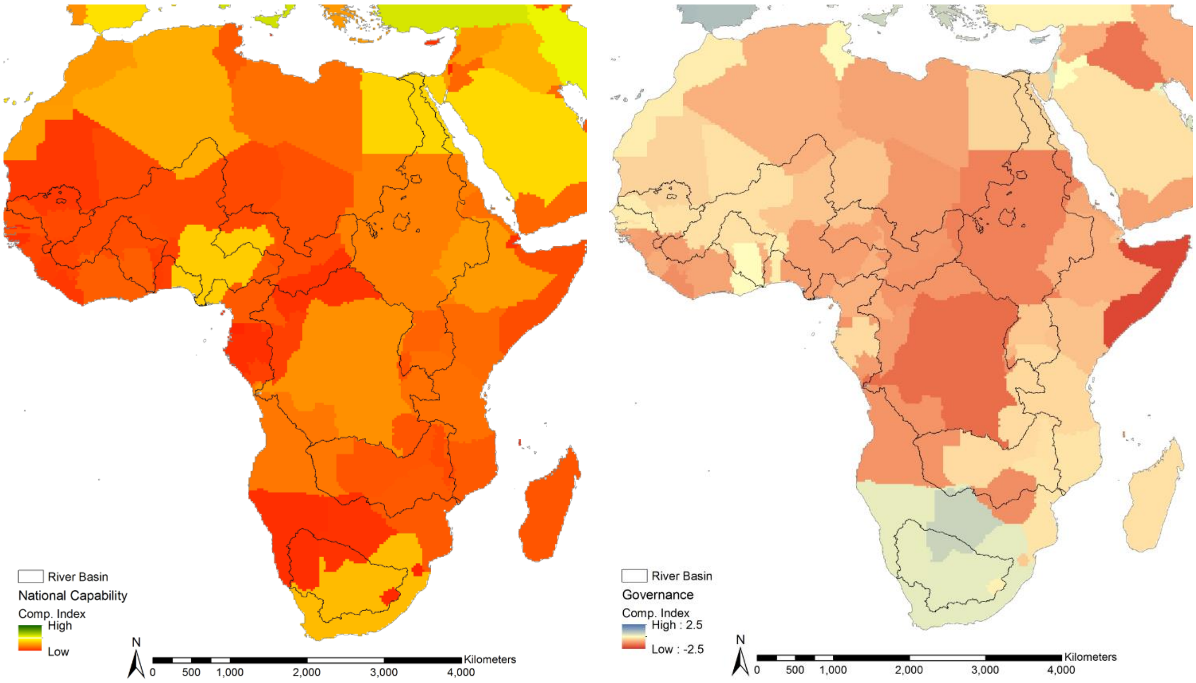


Figure 29. Population distribution in the African continent (left), and percentage of the population living in rural areas at country level (right) (CIESIN, 2015; Freire and Pesaresi, 2015; World Bank, n.d.)

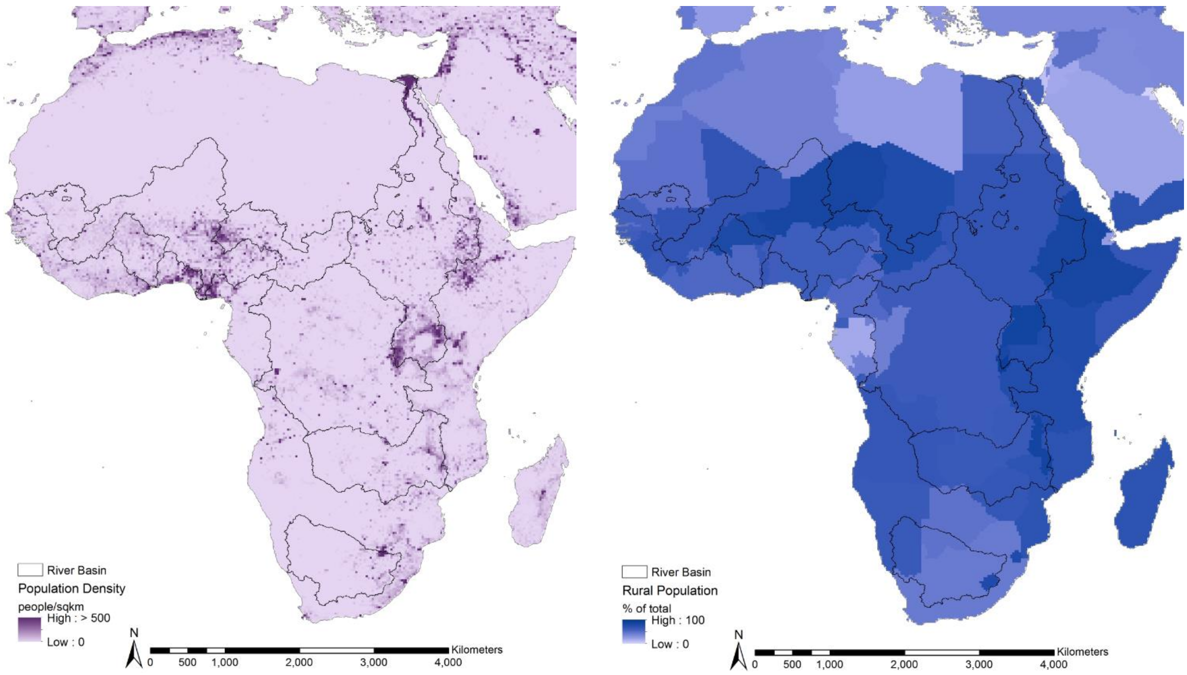


Figure 30. Ethnic Groups distribution in the African Continent (left), and spatial distribution of the episodes of violence recorded between 1999 and 2016 (right) (Raleigh et al., 2010; Vogt et al., 2015; Weidmann et al., 2010)

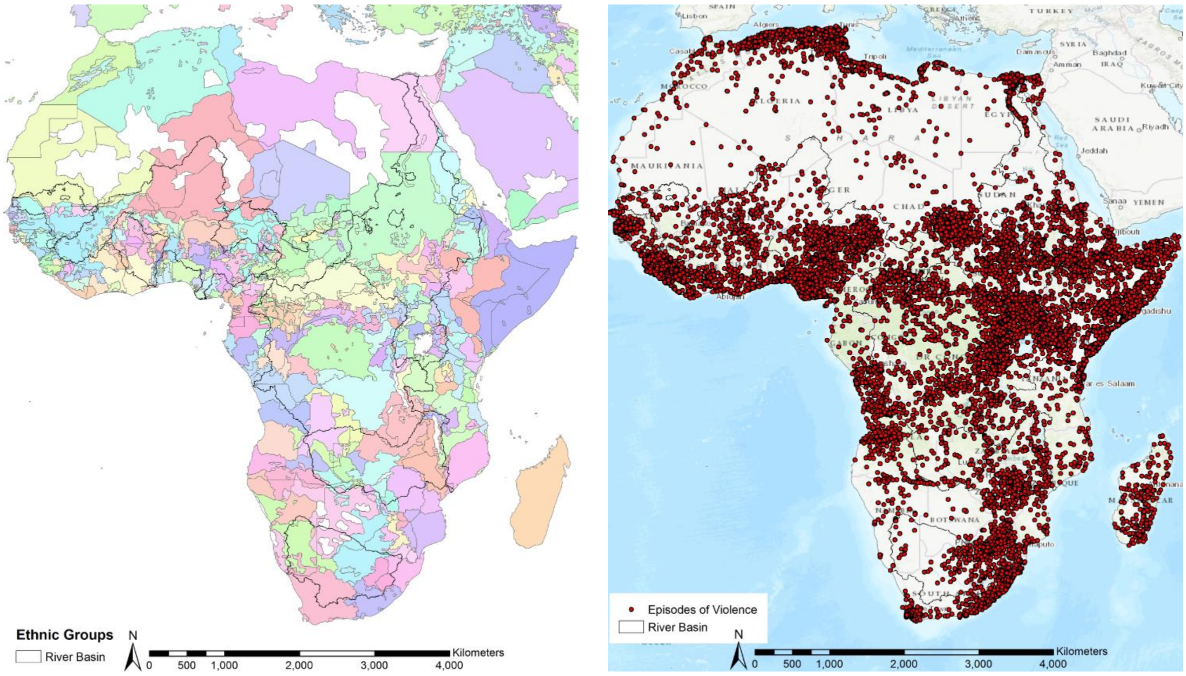
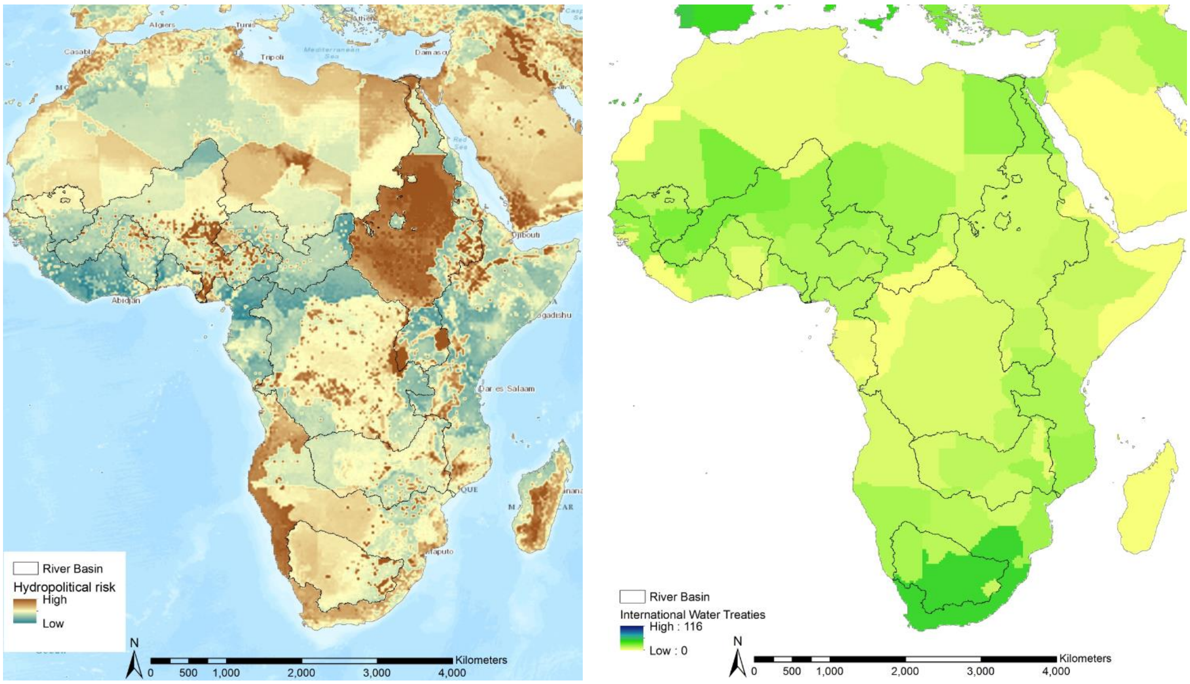


Figure 31. Hydro-political risk in the African Continent (left), and International (bi- or multi-lateral) Water Treaties (right) (De Stefano et al., 2012; Farinosi et al., n.d.)



4.2 Data repository

In this section, we present the main data and sources related to each of the topics listed in section 2. The datasets are shortly listed in a bullet point, while more detailed information, characteristics, spatio-temporal coverage, and associated references are presented in **Table 9**.

- **Climate**

— **Precipitation and temperature profile, analysis of climate variability** → Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) (Funk et al., 2015); Global Surface Summary of the Day – GSOD from the USA National Centers for Environmental Information (NCEI); Multi-Source Weighted-Ensemble Precipitation (MSWEP) (Beck et al., 2017); Global Land Data Assimilation System (GLDAS) (Rodell et al., 2004); Global Meteorological Forcing Dataset for land surface modeling (Sheffield et al., 2006).

— **Indicators about water availability** → Multi-Source Weighted-Ensemble Precipitation (MSWEP) (Beck et al., 2017); Global Land Data Assimilation System (GLDAS) (Rodell et al., 2004); Global Meteorological Forcing Dataset for land surface modeling (Sheffield et al., 2006).

- **Topography**

— **Digital Elevation Model data of the basin** → NASA Shuttle Radar Topographic Mission (SRTM) (Reuter et al., 2007; USGS, 2016).

— **Basin delineation, flow accumulation, and river network** → Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales (HydroSHEDS) (Lehner and Grill, 2013); International River Dataset (Beck et al., 2014).

- **Hydrological data**

— **Gauge station data** → Global Runoff Data Centre (GRDC) (GRDC, 2017).

— **Surface water resource mapping** → Global Lakes and Wetlands Database (Lehner and Döll, 2004); Global Surface Water (Pekel et al., 2016).

— **Groundwater resources** → Quantitative maps of groundwater resources in Africa (MacDonald et al., 2012).

- **Soil and Land use**

— **Soil** → African Soil Atlas (Dewitte et al., 2013; Jones et al., 2013)

— **Agricultural areas, forested areas, human settlements** → Copernicus Global Land Service (CGLS) yearly Land Cover (LC) map at 100m resolution (Copernicus Service Information, 2017).

- **Agriculture** (including livestock and fishery)

— **Crop production statistics, cultivated area, irrigation** → MapSPAM - Spatial Production Allocation Model - Global Spatially-Disaggregated Crop Production Statistics Data for 2005 (IFPRI and IIASA, 2017; Wood-Sichra et al., 2016).

— **Livestock production statistics** → Gridded Livestock of the World (GLW) (Robinson et al., 2014)

— **Freshwater fishery activities** → FAO Fisheries and Aquaculture Department Dataset - Global Aquaculture Production.

- **Energy**

— **Energy production in the basin (renewable and non-renewable), Hydropower statistics** → US EIA International Energy statistics (US EIA, 2017a)

- **Industry**

— **Mining** → Mineral Facilities of Africa and the Middle East (USGS, 2017).

- **Water Infrastructures**

— **Dams and reservoirs location and basic characteristics** → Global Reservoir and Dam (GRanD) database (Lehner and Döll, 2004).

— **Water sanitation and wastewater treatment** → WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP).

- **Ecosystem**

— **Protected areas**, **endangered species**, **water pollution data** → Global Diversity Patterns in Freshwater Systems (Tisseuil et al., 2013) - Global Freshwater Biodiversity Atlas[23].

- **Population dynamics**

— **Population spatial distribution** → GHS population grid, derived from the Gridded Population of the World (GPW, v4) (Freire and Pesaresi, 2015 – CIESIN, 2015); Worldpop dataset (Lloyd et al., 2017; Tatem, 2017).

— **Demographic profile** → Worldpop dataset (Lloyd et al., 2017; Tatem, 2017);

— **Migration Dynamics** → Frontex, International Organization for Migration (IOM), UNHCR, Eurostat data (as summarized in Vespe et al., 2017 - migration data collection under development).

- **Socio-economic data**

— **Basin institutional management** → River Basin Organizations (RBOs) - Transboundary Freshwater Dispute Database TFDD (Schmeier et al., 2016).

— **Governance** → Worldwide Governance Indicators (WGI) (Kaufmann et al. 2010).

— **Political power** → Composite Index of National Capability (CINC) - National Material Capability (NMC) – Correlates of War (CoW) (Singer et al. 1972)

— **Ethnic groups** → Geo-referencing of Ethnic Groups (Vogt et al., 2015; Weidmann et al., 2010).

— **Main social indicators and population socio-economic characteristics** → Expanded gross domestic product data (Gleditsch, 2002); World Development Indicator (WDI) database (World Bank, 2017).

[23] http://atlas.freshwaterbiodiversity.eu/

— **SDGs related data basing on the main indicators** → SDG Indicators Global Database (UN, 2017).

- **Violence and political stability**

— **Data about civil conflicts** → Armed Conflict Location and Event Dataset (ACLED) (Raleigh et al., 2010).

— **Possible criticalities related with water management** → International Water Event Database (IWED) – Transboundary Freshwater Dispute Database (TFDD) (Wolf et al., 2003); International River Cooperation and Conflict (IRCC) (Kalbhenn and Bernauer, 2012); International Freshwater Treaty Database (IFTD) - Transboundary Freshwater Dispute Database (TFDD) (De Stefano et al. 2012).

Table 9. Main data classified for the database, main characteristics, and corresponding source.

Group	Category	Data	Spatial coverage / resolution	Temporal coverage / resolution	Database	Reference	URL
Biophysical	Climate	Precipitation	Global / 0.25 degrees	1979 – 2015 / 3 hours	Multi-Source Weighted-Ensemble Precipitation (MSWEP)	Beck et al., 2017	http://www.gloh2o.org/
Biophysical	Climate	Precipitation	Quasi-Global / 0.05 degrees	1981 – present / 3 hourly	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	Funk et al., 2015	http://chg.geog.ucsb.edu/data/chirps/
Biophysical	Climate	Climate variables	Point data from about 9000 meteorological stations	Depending on the records available. Some from 1929 - present / daily observations	Global Surface Summary of the Day (GSOD)		https://data.noaa.gov/dataset/global-surface-summary-of-the-day-gsod
Biophysical	Climate	Climate variables	Global / 0.25 degrees	1979 – present / 3-hourly	Global Land Data Assimilation System (GLDAS)	Rodell et al., 2004	https://ldas.gsfc.nasa.gov/gldas/
Biophysical	Climate	Climate variables	Global / 0.25 degrees	1901 – 2012 / 3-hourly	Global Meteorological Forcing Dataset for land surface modeling	Sheffield et al., 2006	http://hydrology.princeton.edu/data.pgf.php https://rda.ucar.edu/datasets/ds314.0/
Biophysical	Topography	Digital Elevation Data	Global / 30 or 90 meters	Time invariant	NASA Shuttle Radar Topographic Mission (SRTM)	Reuter et al., 2007; USGS, 2016	http://srtm.csi.cgiar.org/
Biophysical	Topography	River Basin Shape, Main river network, Lakes	Global / 3 arcsec	Time invariant	HydroSHEDS dataset - Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales	Lehner and Grill, 2013	http://www.hydrosheds.org/

Biophysical	Topography	World river basins	Global / Spatial polygon	Time invariant	International River Dataset	Beck et al., 2014	http://ir-s01.ethz.ch/
Biophysical	Geology	Soil Types	African Continent	Time invariant	African Soil Atlas	Dewitte et al., 2013; Jones et al., 2013	https://esdac.jrc.ec.europa.eu/content/soil-map-soil-atlas-africa
Biophysical	Hydrology	World Lakes	Global / Spatial polygon	Static	Global Lakes and Wetlands Database	Lehner and Döll, 2004	https://www.worldwildlife.org/pages/global-lakes-and-wetlands-database
Biophysical	Surface Water	Surface water	Global / 25 m	1984 – 2015 /	Global Surface Water	Pekel et al., 2016	https://global-surface-water.appspot.com/
Biophysical	Hydrological data	Gauge station - River flow data	Point data	Time series at daily resolution	Global Runoff Data Centre (GRDC)	GRDC, 2017	http://www.bafg.de/GRDC
Biophysical	Hydrological data	Groundwater – Aquifer productivity	African Continent / 5 km grid	-	Quantitative maps of groundwater resources in Africa	MacDonald et al., 2012	http://www.bgs.ac.uk/research/groundwater/international/africangroundwater/mapsDownload.html
Biophysical	Land cover	Vegetation	Global observation - African Continent / 100 m	-	Copernicus Global Land Service (CGLS) yearly Land Cover (LC) map at 100m resolution	Copernicus Service Information, 2017	http://land.copernicus.eu/global/ http://land.copernicus.eu/global/content/first-release-land-cover-map-100m
Water Use	Agriculture	Crop rainfed and irrigated production stats and spatial distribution regarding the 42 most widely cultivated crops.	Global / 10 km	2005 / static	MapSPAM - Spatial Production Allocation Model - Global Spatially-Disaggregated Crop Production Statistics Data for 2005. Version 3.1	IFPRI and IIASA, 2017; Wood-Sichra et al., 2016	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/DHXBJX http://mapspam.info/
Water Use	Livestock production	Head density of the main species farmed	Global / 3 arc minutes	2005 / static	Gridded Livestock of the World (GLW)	Robinson et al., 2014	http://www.fao.org/ag/againfo/resources/en/glw/home.html https://livestock.geo-wiki.org/home-2/

Water Use	Fishery production	Global Aquaculture Production	Global statistics / country resolution	Depending on the records available.	FAO Fisheries and Aquaculture Department Dataset	Food and Agriculture Organization of the United Nations	http://www.fao.org/fishery/statistics/collections/en
Water Use	Water infrastructures	Dams and impoundments	Global / point data	2011 / static	Global Reservoir and Dam (GRanD) database	Lehner et al., 2011	http://www.gwsp.org/products/grand-database.html
Water Use	Water infrastructures	Planned and under construction dams	Global / point data	2014 / static	A global boom in hydropower dam construction	Zarfl et al., 2015	https://link.springer.com/article/10.1007%2Fs00027-014-0377-0# http://atlas.freshwaterbiodiversity.eu/atlasApp/full/index.html?map=3.4.3-global-hydropower-dams
Water Use	Mining industry	Mines location and statistics	African Continent / country aggregated data	1997 – 2013 / yearly	Mineral Facilities of Africa and the Middle East	USGS, 2017	https://minerals.usgs.gov/minerals/pubs/country/africa.html
Water Use	Energy	Energy statistics	Global / country aggregated data	1980 – 2016 / yearly	US EIA International Energy statistics	US EIA, 2017b	https://www.eia.gov/beta/international/
Water Use	WASH	Water sanitation and wastewater treatment	Global / country statistics	1990 – present / yearly	WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP)	WHO & UNICEF	https://washdata.org/
Water Use	Ecosystem	Bio-diversity	Global / river basin scale	Static	Global Diversity Patterns in Freshwater Systems - Global Freshwater Biodiversity Atlas	Tisseuil et al., 2013	http://atlas.freshwaterbiodiversity.eu/
Socio-economic	Demography	Population demographic characteristics	Global		Worldpop dataset	Lloyd et al., 2017; Tatem, 2017	http://www.worldpop.org.uk/data/get_data/
Socio-economic	Wealth	Gross Domestic Product (GDP)	Global / Country	1950-2011 / year	Expanded GDP data – Version 6.0	Gleditsch, 2002	http://privatewww.essex.ac.uk/~ksg/exptradegdp.html
Socio-economic	Governance	Governance indicator	Global / Country	1996-2015 / year	Worldwide Governance Indicators (WGI)	Kaufmann et al. 2010	http://info.worldbank.org/governance/wgi/#home

Socio-economic	GDP dependency on agriculture	Agriculture (% GDP) and Rural population (% of the total)	Global / Country	1960-2016 / year	World Development Indicator (WDI) database	World Bank 2017	http://data.worldbank.org/data-catalog/world-development-indicators
Socio-economic	Population density	Population	Global / 1 km	Multi-temporal (1975, 1990, 2000, 2015)	GHS population grid, derived from the Gridded Population of the World (GPW, v4)	Freire and Pesaresi, 2015 – CIESIN, 2015	http://data.europa.eu/89h/jrc-ghsl-ghs_pop_gpw4_globe_r2015a http://ghsl.jrc.ec.europa.eu/ghs_pop.php
Socio-economic	River Basin Organizations	RBOs	Global / Transboundary river basin	Multi-temporal	River Basin Organizations (RBOs) - Transboundary Freshwater Dispute Database TFDD	Schmeier et al., 2016	http://gis.nacse.org/tfdd/rbo_new.php
Socio-economic	Ethnic Groups	Ethnic Groups spatial distribution	Global / vector	2010 / static	Geo-referencing of Ethnic Groups	Vogt et al., 2015; Weidmann et al., 2010	https://icr.ethz.ch/data/greg/ https://icr.ethz.ch/data/epr/#geoepr
Socio-economic	Political power	Composite Index of National Capability (CINC)	Global / Country	1816-2007 / year	National Material Capability (NMC) version 5.0 – Correlates of War (CoW)	Singer et al. 1972	http://www.correlatesofwar.org/data-sets/national-material-capabilities
Socio-economic	SDGs indicators	Sustainable Development Goals official indicators list	Global / Country	Depending on the records available.	SDG Indicators Global Database	UN, 2017	https://unstats.un.org/sdgs/indicators/database/
Socio-economic	Historical cooperation over water	International Freshwater Treaty Database – IFTD	Global / BCU	1820 - 2007	International Freshwater Treaty Database – IFTD - Transboundary Freshwater Dispute Database TFDD	De Stefano et al. 2012	http://www.transboundarywaters.orst.edu/database/interfreshtreatdata.html
Socio-economic	Water disputes	Hydro-political interaction / Water Events	Global /Basin-Country_Unit (BCU)	1997-2007	International River Cooperation and Conflict IRCC	Kalbhenn and Bernauer, 2012	http://www.ib.ethz.ch/data.html

Socio-economic	Water disputes	Hydro-political interaction / Water Events	Global /Basin-Country_Unit (BCU)	1948 - 2008	International Water Event Database – Transboundary Freshwater Dispute Database TFDD	Wolf et al., 2003	http://www.transboundarywaters.orst.edu/database/interwatereventdata.html
Socio-economic	Conflicts	Protests, riots, strikes, inter-communal conflict, government violence against civilians, and other forms of social conflict	African Continent	1990 - 2015	Social Conflict Analysis Database (SCAD	Salehyan et al., 2012	https://www.strausscenter.org/scad.html http://ccaps.developmentgateway.org/?md5Filters=3be99f3de61b1f984b16e58cf1991694
Socio-economic	Conflicts	Battles between armed actors, violence against civilians, and rioting	African Continent	1999 - 2016	Armed Conflict Location and Event Dataset (ACLED)	Raleigh et al., 2010	https://www.strausscenter.org/strauss-articles/acled-3.html
Socio-economic	Migration	Migration flows	EU-Africa	-	Frontex, International Organization for Migration (IOM), UNHCR, Eurostat data	as summarized in Vespe et al., 2017 - migration data collection is currently under development	http://frontex.europa.eu/trends-and-routes/migratory-routes-map/ http://migration.iom.int/europe/ https://data2.unhcr.org/en/situations http://ec.europa.eu/eurostat/statistics-explained/index.php/Asylum_quarterly_report
Future projections	Climate	Climate future scenarios	Global / 0.25 degrees	1950 – 2100 / day	NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset	Thrasher et al. 2012	https://nex.nasa.gov/nex/projects/1356/ https://dataserver.nccs.nasa.gov/thredds/catalog/bypass/NEX-GDDP/catalog.html
Future projections	Population	Population trends	Global / Country	1950 – 2100 / 5 years	United Nations - Department of Economic and Social Affairs, Population Division	UN/DESA 2017	https://esa.un.org/unpd/wpp/

5 Data visualization tool

The database described in this report is organized in an online tool. The tool allows to graphically display and explore the information contained in the database.

The designed graphical tool is organized to interactively display:

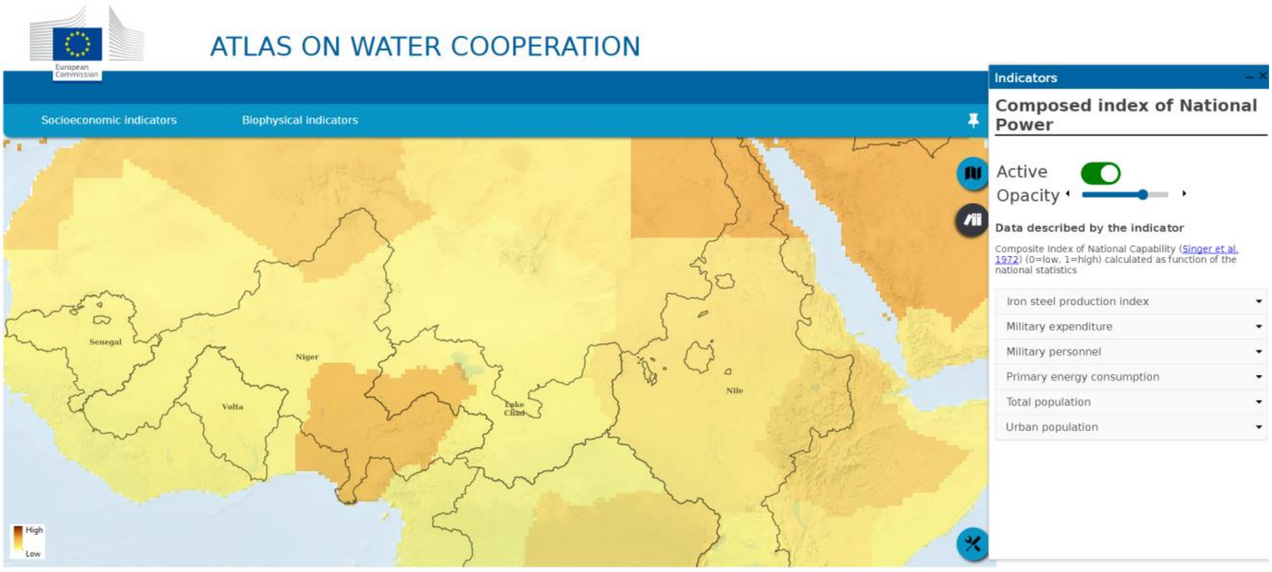
- Maps (base-maps and layers) & Map controls (zoom, overview, scale, legend);
- Functional element that allow interacting with the geographic information displayed on the map, and performing some operations over it (operation widgets; layers panels; charting tools);
- Tools aimed at managing and temporarily store the information displayed and the combinations created by the user (currently under development).

The instrument is designed to be extremely flexible and user friendly. The information is visualized at the river basin level or at raster level when available.

Data about biophysical and socio-economic variables are displayed as either raster or vectorial layers. The result is a collection of data time series with the data sampled at a certain resolution. The tool provides the controls necessary to display the data, taking into account also their temporal evolution (currently under development).

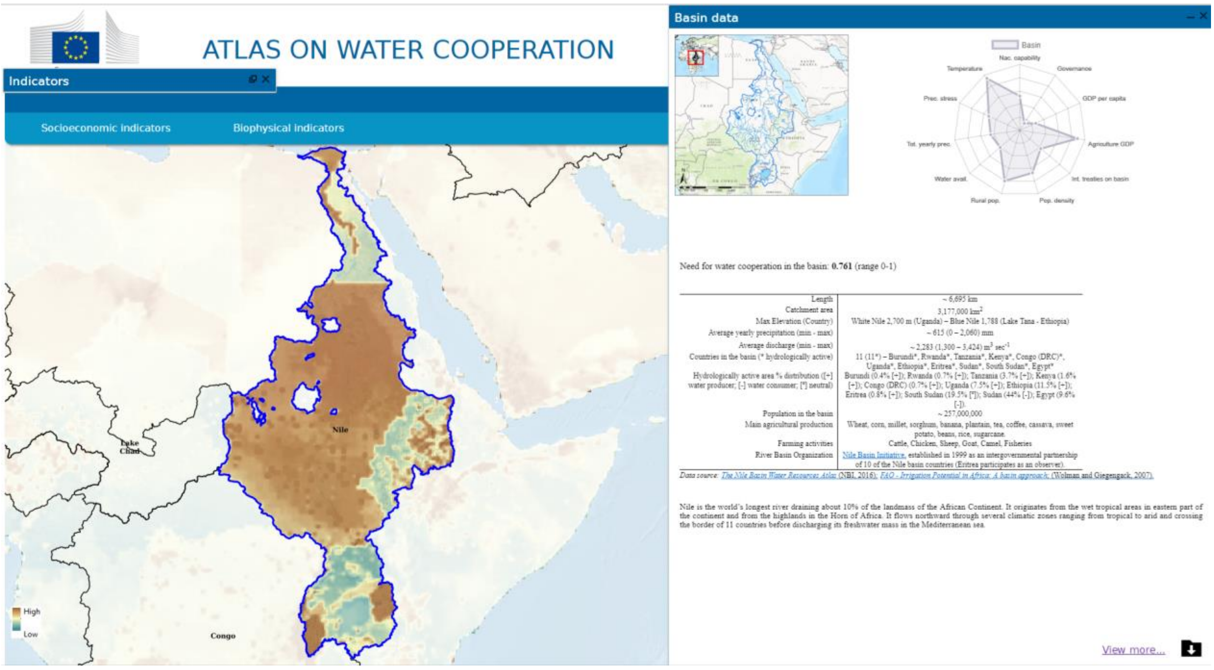
Each of the piece of information displayed is accompanied with a brief description of the data contents and source (**Figure 32**).

Figure 32. Visualization tool – example of the visualization of the Composed Index of National Capability.



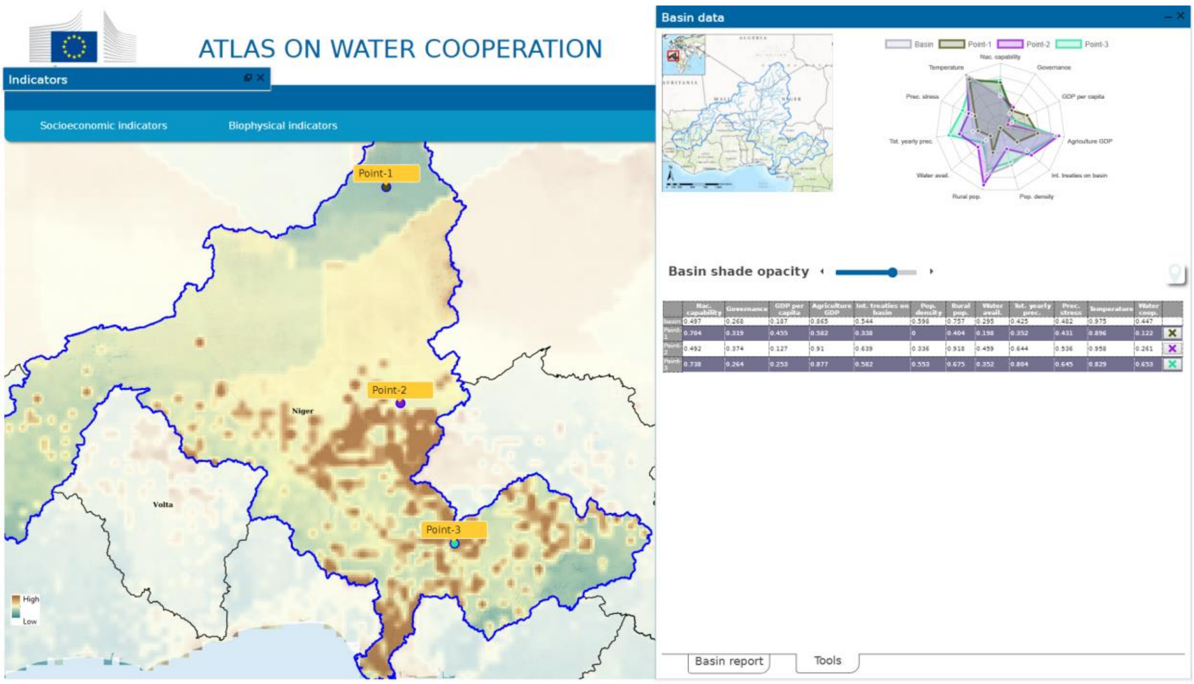
The main African basins are described in details using the information summarized in section 3. For each of the basins it is displayed a table of the main statistics accompanied by a brief text describing biophysical and socio-economic features, giving emphasis on the aspects that are considered more critical for water management (**Figure 33**).

Figure 33. Visualization tool – example of the visualization of the summary information about the transboundary basins in the African continent.



An additional functionality developed within the visualization tool allows to explore the combination of the main information displayed for a specific point. This allows to compare the distribution of the values displayed within the basin between different points and with the average values calculated for the basin (**Figure 34**). For this specific exercise, in order to ensure a full comparability, the data were normalized in a 0-1 scale using a simple min-max normalization procedure.

Figure 34. Possibility to analyze the displayed data and their relative values through the visualization tool.



6 Concluding remarks

The database described in this Report is the first step for the development of the African Atlas of Water Cooperation. The Report is composed of three main sections: a summary description of the main characteristics of the African transboundary basins selected for this study (Section **3**); the data collection, with detailed description of coverage, source and characteristics (Section **4**); and the visualization tool (Section **5**).

The selection of the basins is composed as follows: four basins in Western Africa - Niger, Senegal, Lake Chad, Volta; two basins in Central and Eastern Africa - Nile, and Congo; two basins in Southern Africa – Zambezi, and Orange.

The main critical aspects highlighted for water management in the selected basins include: climate variability and change, land use change, agricultural practices, animal farming and fishery activities, mining and oil industries, infrastructural development, loss of natural ecosystems, political instability and civil conflicts, precarious socio-economic conditions and limited access to basic services, institutional development.

The aim of the African Water Cooperation Atlas is to analyze at a detailed spatial resolution the dynamics of the listed water management related drivers and their evolution. Data availability is one of the main constraints in the successful development of this ambitious activity. Due to various reasons, in fact, the African basins and countries have been historically poorly covered from the data collection point of view. Technological evolution, especially in terms of remote sensing, and a relatively more stable political situation, at least in the Sub-Saharan Africa, allowed to increase the stock of information available in the recent past. This technical report aims at offering a detailed overview of the data currently available for the analysis of the most important drivers of water management in the African transboundary basins.

Freely available data were collected from different sources and selected in order to cover all the categories of information highlighted by the analysis of the critical factors. These include all the aspects of biophysical characteristics, water uses, and socio-economic characteristics of the main African basins. Categories and sub-categories of data were selected by analyzing the main peculiarities of the basins and the criticalities highlighted in the water management of the area under consideration. Sources have been chosen in base of data availability, quality, spatio-temporal resolution, and accessibility. In general, the most spatially detailed information were preferred: this in order to have the possibility to analyze the water management related dynamics in specific portions of the basins.

Although the database presented in this Report covers the majority of the topics highlighted, the analysis of the water management components in the domain under consideration is far from being an easy task. Despite the huge technical advancements in the collection of remotely sensed bio-physical data in the past 20 years, for instance, the lack of historical information, as for the river discharge time series, does not allow to set up a proper modeling activity of the spatio-temporal distribution of the water resources. In other cases, as for the socio-economic dynamics, historical data exist, but are available at a spatial resolution that does not allow a detailed analysis.

The database and the associated visualization tool have to be considered dynamic entities: their development will not be arrested at this stage, but they will be further developed and integrated in base of the specific data needs that the development of the African Atlas of Water Cooperation will highlight. The database development with basin specific data could be pursued tacking advantage of the collaboration with regional and local partner institutions, and through the collaboration with international organizations.

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