WATER AND AGRICULTURE IN THE ZAMBEZI RIVER BASIN

Characterization of Current Agriculture Activities, Future Potential Irrigation Developments and Food Security to Face Climate Variability in the Zambezi River Basin

A Report Submitted to the EU-Joint Research Commission

on

Assessing Water-Energy-Food-Ecosystem (WEFE) Interdependencies Across the Zambezi River Basin: Agriculture and Water

by

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EXECUTIVE SUMMARY

The transboundary Zambezi River Basin (ZRB), the fourth largest in Africa, faces many challenges from the perspective of the Water-Energy-Food-Ecosystem (WEFE) nexus, including, among many others, hydropower, reservoir multipurpose optimization and release management, rainfed and irrigated agriculture development, impact of land use and agricultural practices (including livestock and fisheries), role of ecosystem services (natural parks, wetlands), pressures on resources due to population increase and climate variability/change and extreme events risks (drought and flooding). This report dealt with the water and agriculture aspects in the Zambezi River Basin focusing on irrigated and rainfed agriculture through appropriate agricultural water management practices. This report is complementary to and has to be read in conjunction with the report from University of Malawi on agriculture and water in the Zambezi River Basin.

Agriculture is the largest water consumer in the Zambezi River Basin. Agricultural activities are dominant in Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. Interestingly, probably more than 90% of the agricultural activity in the basin is based on flood plain cultivation and rain dependent agriculture, and this is what sustains the bulk of the rural population in the Zambezi River Basin. Irrigation is important in the basin, but on a comparative basis it covers estimates from 147 000 ha to 259 000 ha only, but because it is water-use intensive, it factors significantly in the water use equation in the basin. Irrigation is estimated to consume about 3 235 million cubic meters of water currently amounting to 1.4% of the basin's renewable water resources. There is huge irrigation development potential in the basin, and indeed there are ambitious plans to triple the area under irrigation by 2025 which will increase the water for irrigation to about 4.1% of the basins' renewable water resources.

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

The water-energy-food-ecosystem (WEFE) nexus has emerged as an increasingly prominent global policy, governance and research agenda. The WEFE nexus presents an opportunity for policymakers, researchers and development agencies to integrate the sectors in order to optimise the use of the resource base, maximise synergies and minimise trade-offs and conflicts. Since the Zambezi River Basin is transboundary and there is competition for natural resources by sector (water, energy, agriculture) and by country (ZRB riparian countries), the WEFE nexus presents itself as a viable tool for resources management. An exploratory WEFE nexus analysis of the ZRB was conducted based on the indicators; water availability per capita, water productivity, food self-sufficiency, cereal productivity, energy accessibility, energy productivity and ecosystems good and services. Most of the WEFE indicators showed marginal sustainability.

The success of agricultural water management interventions will depend to a large extent on the training of the relevant stakeholders so as to capacitate them in terms of knowledge, attitude and skills. Before any training can be undertaken, typically a needs assessments has to be undertaken to determine the stake holders who require training, the type of training required and the best way to offer that training. For agricultural water management interventions, returns to training investment are best if this training is focused on those working directly with farmers and the farmers themselves. Short courses for the training of agricultural extension staff and farmers were identified, and these included; smallholder irrigation water management and crop production, dambo irrigation farming with ecosystems goods and services in mind, drip kit irrigation, operation and management for local food security, and soil and water conservation practices and conservation agriculture under rainfed agriculture. A WEFE nexus short course for policy makers, development implementers and researchers is also proposed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AU	African Union
AU-IBR	African Union – Inter-African Bureau for Animal Research
AWM	Agricultural Water Management
CA	Conservation Agriculture
CAADP	Comprehensive Africa Agriculture Development Programme
CC	Climate Change
CSA	Climate Smart Agriculture
CSR	Corporate Social Responsibility
CV	Climate Variability
DSS	Decision Support System
GDP	Gross Domestic Product
IGRAC	International Groundwater Resources Assessment Centre
ITCZ	Intertropical Convergence Zone
KAS	Knowledge Attitude Skills
LSCI	Large Scale Commercial Irrigation
LSC	Large Scale Commercial
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organisation
O&M	Operation and Maintenance
SADC	Southern Africa Development Community
SAI	Sustainable Agricultural Intensification
SARDC	Southern Africa Research and Documentation Centre
SDG	Sustainable Development Goals
SIS	Small-scale Irrigation Scheme
SWC	Soil and Water Conservation
WACOZA	Water and Cooperation within the Zambezi River Basin
WEDC	Water-Economic Growth-Livelihoods nexus
WEF	Water-Energy-Food nexus
WEFC	Water-Energy-Food-Climate nexus
WEFH	Water-Energy-Food-Health nexus

WEFE	Water-Energy-Food-Ecosystems nexus
WEL	Water-Energy-Land nexus
ZAMCOM	Zambezi Watercourse Commission
ZRB	Zambezi River Basin

1 INTRODUCTION

1.1 Background

The Zambezi River Basin (ZRB) is the fourth largest river in Africa after the Congo, Nile, and Niger River basins. It is located in Southern Africa and is coordinated between 9°00'S to 20°30'S latitude and 18°20'E to 36°25'E longitude (Figure 1) (Schleiss and Matos, 2010). The Zambezi River Basin covers an area of 1.4 million km^2 and stretches approximately 2600 km. The basin is shared by eight riparian countries (Angola Botswana, Malawi, Mozambique, United Republic of Tanzania, Zambia and Zimbabwe), with Zambia having the largest share (41%), followed by Angola and Zimbabwe which have slightly less than half the Zambian portion (18.5 and 15.6%, respectively) (Figure 1) (Schleiss and Matos, 2010). Three of the countries (Republic of Tanzania, Namibia and Botswana) have less than 2% of the river basin each.

The ZRB is commonly split into three main regions: Upper Zambezi, Middle Zambezi and Lower Zambezi (Figure 1). The Upper Zambezi is characterised by steep slopes and large wetlands. Within the Middle Zambezi is the Victoria Falls which is one of the eight wonders of the world. Lake Malawi and the Cahora Bassa dam and reservoir dominate the Lower Zambezi. Climate among the three regions varies from humid to arid with seasonal rainfall patterns as a result of the Inter-Tropical Convergence Zone (ITCZ). The three regions have almost similar seasons, with October to March being the warm and wet summer season, when 80% of the annual rainfall is received (Matondo and Mortensen, 1998). The average annual rainfall over the whole river basin is estimated to be 990 mm while the average annual evaporation is about 870 mm. The part of the ZRB which receives the highest rainfall (over 2000 mm per annum), lies in Tanzania (Cai et al., 2017). Land cover in the ZRB consists of rainfed farming, forest, bushland, grassland, open water and irrigated land. Forest and bushland take up 75% of land cover. Within the remainder 25%, rainfed agriculture occupies an estimated 13.2% of the land holding. Grassland and irrigated agriculture occupy 7.7 and 1.3% respectively (Euroconsult Mott McDonald, 2007). Agricultural activities have been the main driver of land cover changes. According to Gomo et al. (2018), approximately 16% of natural forests have been converted to crop area over the past decade.

Agriculture is the largest man-made land use around the ZRB. It is a large contributor to gross domestic product of riparian countries and livelihoods of its inhabitants. Malawi has the largest cultivated area within the ZRB (≈ 2 million hectares), followed by Zimbabwe and Zambia Angola, Botswana and Mozambique have the least area under cultivation within the basin (< 0.1 million hectares). With respect to renewable water resources, agriculture is the largest user in all riparian countries with countries such as Zimbabwe, Zambia, Tanzania, Mozambique and Malawi having more than 75% of renewable water resources being consumed by agriculture (World Bank, 2008). Despite this, there is not much information on agricultural water management (AWM) in the basin at different scales (Manzungu et al., 2017).

1.2 The Problem Defined

Before one can look at sustainable agricultural water management and its associated sustainable agricultural intensification (SAI), it is imperative that one takes stock of conditions occurring in the basin. There is a need to understand the dimension of the two key inputs of water and land into agriculture. Questions that arise include; how much land is available in the basin and of that how much is suited to agriculture and is being used thus, what typologies of agricultural practices exist in the basin and what are the key factors driving these, how much water is available in the basin and of that how much is allocated or available for agriculture, how much irrigation is taking place in the basin and what is the potential for further expansion with what water resources, what are the levels of agricultural water productivity in the basin, what options exist to improve agricultural water management, can there be trade-offs between rain fed and irrigated agriculture, and can the basin be eventually food secure? Within the context of the Water-Energy-Food-Ecosystem (WEFE) nexus, the questions are, can this be used as an approach or tool to better manage resources in the basin for sustainable energy and food production?

The above set of questions highlight the need for significant baseline research on issues to do with water, land and agriculture in the basin. Once this is established, analyses are then undertaken on what the key issues in water and agriculture and assessment done on agricultural productivity, water productivity, WEFE nexus (water and land) indicators and recommendations for the basin leadership and policy people.

1.3 Research Objectives and Research Methods

The research objectives were; to analyse the baseline conditions on agriculture (including livestock and fisheries) by gathering and processing data and by-products (land use and coverage, local practices, seasonal patterns) at ZRB scale; and to perform agriculture assessment (crops water demand, productivity and potential impact of irrigation expansion) and scenario based management practices.

A mixed-method review approach, which included combining quantitative and qualitative research or outcomes of process studies was used to compile the review. Scientific journal articles, book chapters, technical reports, dissertations, SADC database and other forms of literature were used.

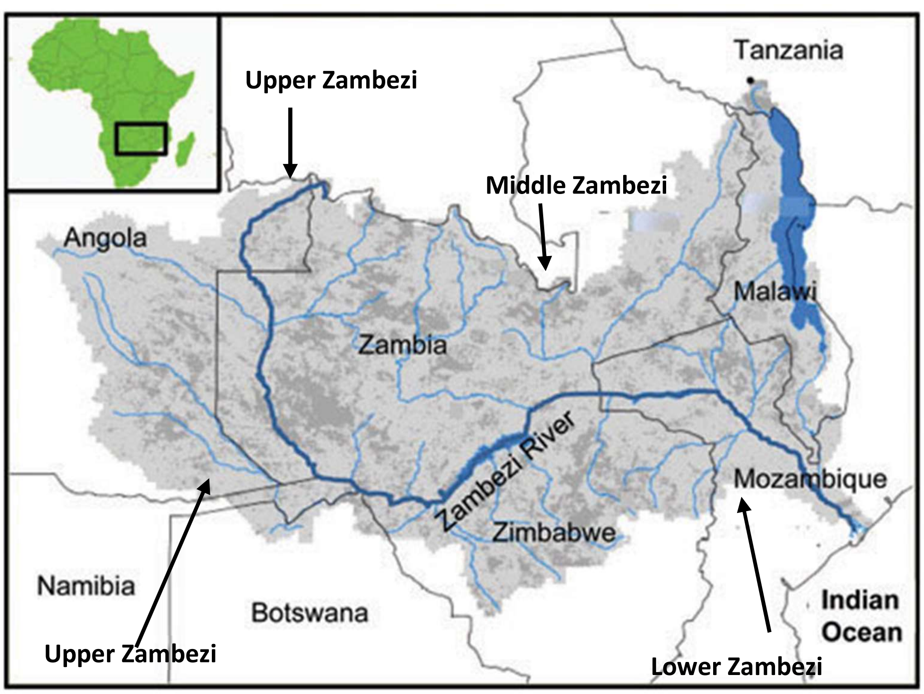

Figure 1: Picture of the ZRB position in Southern Africa, the eight riparian countries (Angola, Tanzania, Namibia, Botswana, Zimbabwe, Mozambique, Zambia and Malawi) and the three (upper, middle and lower ZRB).

2 WATER AND AGRICULTURE IN THE ZAMBEZI RIVER BASIN

2.1 Water in the Zambezi River basin

Kalene Hills in Zambia is taken as the source of the Zambezi River. Thereafter it runs for approximately 2600 km to the south and east before discharging into the Indian Ocean at the Mozambican coast. Tributaries of the Zambezi include the Kafue River, Luangwa River and Shire River. Large floodplains and swamps include the Barotse Floodplain, Chobe Swamps, Kafue Flats and Kwando Floodplain. Freshwater lakes include Lake Malawi (30000 km^2), Lake Kariba (5500 km^2) and Lake Cahora Bassa (2700 km^2). The latter two are manmade lakes (Schleiss and Matos, 2010; Cai et al., 2017).

Mean annual precipitation is about 1 000 mm of which only 8% generates discharge and the remaining is lost via evapotranspiration. Rainfall throughout the Zambezi catchment is concentrated over the summer months (October to March) in response to the ITCZ. The rain cycle gives rise to the unique patterns of run-off in each sub basin (Schleiss and Matos, 2010; Kling et al., 2014; Zimba et al., 2018). Rivers draining the steep gorges of the Central Africa plateau peak rapidly with the rain, reaching their maximum discharge between January and March and decreasing to dry season flows in October. In the Kafue River and Shire basin, flood plain systems capture flood water and delay discharge until late in the rainy season or early dry season. Mean discharge at the outlet of the basin exhibits large seasonal and intra-annual variations though its average is estimated at ≈ 3600 $m^3 s^{-1}$. Seasonality in discharge is controlled by seasonality in precipitation, retention in large floodplains and swamps as well as artificial reservoirs (Pinay, 1988).

The construction of Kariba, Cahora Bassa and other large dams in the Zambezi system has altered Zambezi runoff pattern. Kariba dam is for regulating runoff from Zambezi headwaters region of the Upper Zambezi Catchment and the Western portion of the Middle Zambezi catchment between Victoria Falls and Kariba. Regulation by the Kariba dam results in change of the timing, magnitude, duration and frequency of flooding events. The Cahora Bassa Reservoir similarly regulates runoff from the remaining Middle Zambezi catchment between the Kariba and Cahora Bassa Gorges, including regulation of flows from the Kafue River and unregulated flows from the Luangwa River as well as outflow from Kariba. Only runoff from tributaries of the Moravia Angonia and Manica Plateaus in the Lower Zambezi are said to be unaffected by river regulation (Beilfuss and Brown, 2006). Table 1 shows the water balance of the three regions of the ZRB (Pinay, 1998) (Beilfuss and Brown, 2006). Climate change forecasts show that ZRB will be affected by climate change, with runoff being sensitive to variations in climate. Rainfall is expected to decrease by 15% by 2050. Recent modelling efforts (Farinosi and Hughes, 2020) on climate change and water use scenarios showed that the relative impacts can be quite different across the whole Zambezi River basin, the greatest impacts being in the Lake Malawi/Nyasa sub-system, as well as other areas containing large open water bodies (natural and man-made), that are very sensitive to the combined effects of increased aridity. In addition, rainfall will be characterised by delayed onset with shorter and more intense rainfall events. This will have a negative impact on annual streamflow. This will ultimately affect agriculture, municipal, hydropower and ecosystems services at large (Beilfuss and Nhemachena, 2017).

Groundwater in the ZRB has not been extensively quantified. It is however an important resource in rural communities of the ZRB as they rely on it for their domestic water supply. It can also be used for irrigation. Information on groundwater resources is important for effective planning in the sustainable use of this water resources in the ZRB [Zambezi Watercourse Commission (ZAMCOM), Southern Africa Development Community (SADC), Southern African Research and Documentation Centre (SARDC), 2015)].

Water quality in the Zambezi River is generally good although there are some concerns of towns, e.g Livingstone in Zambia and Victoria Falls in Zimbabwe discharging untreated or partially treated domestic effluent into the river (McCartney et al., 2013). Despite the dilution and turbulence of the river flow, this practice is likely to have detrimental effects in the long term This problem is likely to become more severe further downstream, where several towns (e.g. Siavonga, Kariba, Chirundu and Tete) rely on water abstracted directly from the Zambezi River (McCartney et al., 2013). There has also been reports of mining activities affecting water quality in Mozambique. Although the effect of mining is currently minute, it is expected to exacerbate over time and with the rise in coal mining (Ashton et al., 2001; Nhantumbo et al., 2015). Mozambique is heavily invested in coal mining in the Tete province. The coal reserves located near the ZRB are a source of livelihood for an estimated 30 million people (Nhantumbo et al., 2015). Large scale and artisanal coal mining is reported to be polluting the ZRB, and the Regional Administration of Water in ZRB in Mozambique (ARA – Zambeze) is not enforcing law and thorough monitoring due incapacity. According to Ashton et al. (2001), the unavailability of water quality data presents a challenge on knowing the extent to which mining activities impact the ZRB. If water quality is not managed properly it will affect irrigation, fisheries, livestock and ecosystems services at large.

Table 1: Water Balance of the three Zambezi River Regions (Upper, Middle and Lower) (Pinay, 1998)

	Area of basin km^2	Precipitation	Evapotranspiration km^3	Runoff	Residual
Upper	320 000	360	245	49.2	65.8
Middle	1 118 000	830	688	74.8	67.2
Lower	1 400 000	1 317	1 000	106.4	210.6

**Residual accounts for potential groundwater recharge

2.2 Background to Agriculture in the Zambezi River Basin

Consumptive use accounts for an estimated 15 - 20% of total runoff (MacDonald, 2007, Beck and Bernauer, 2010). Dam consumes the bulk of the ZRB through evaporation in impounded water followed by agriculture. Agricultural activities in the Kafue, Kariba, Tete and Shire sub basins have the highest annual abstraction requirements for irrigation (Figure 2). Annual abstraction in Kafue accounts for 19% of the total runoff whilst abstractions in the Kariba and Tete sub basin amounts to 20% and 21%, respectively, of the abstractions occur in the Shire river (MacDonald, 2007;WACOZA, 2018). Wetland mapping an indicator of groundwater fluxes revealed that high precipitation zone in the ZRB contribute significantly to wetland expansion and ground water recharge subsequently. Wetland extent is essential in the ZRB water budget (Lowman et al., 2018). A MODIS simulation by Lowman et al (2018) revealed an exponential increase in wetland area in the ZRB with peak expansion ranging from 35 000 Km^2 to 40 000 Km^2 from the year 2007 to 2011.

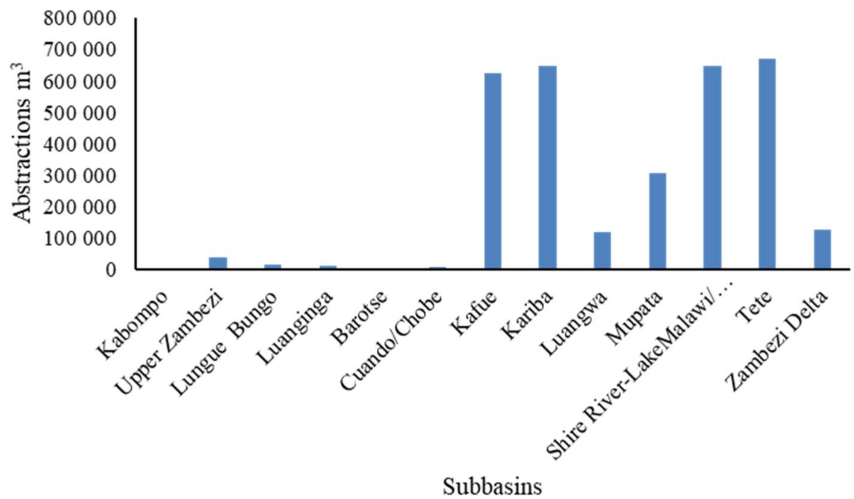

Figure 2: Sub basin abstraction requirement for irrigation Source: WACOZA (2018)

Irrigation is key driver of the agricultural based economies. Agricultural activities are dominant in Malawi, Mozambique, Tanzania, Zambia and Zimbabwe and less pronounced in Angola, Botswana and Namibia (Manzungu et al., 2017). Malawi has the highest cultivated land (19 030 km^2) followed by Zimbabwe (13 680 km^2) and Zambia (11 540 km^2) (WorldBank, 2010;WACOZA, 2018). The cultivation land area is proof that the riparian states are dependent on agriculture. The area of cultivated land is presented in Figure 3. There is a correlation between area cultivated and irrigation abstractions. For example Malawi has the largest land cultivation capacity and consequently has the largest water abstractions from the ZRB (Figure 4). Recent research by Cai et al (2017) states the cumbersome and complex exercise involved in characterising ground water in the ZRB hence limited literature on ground water.

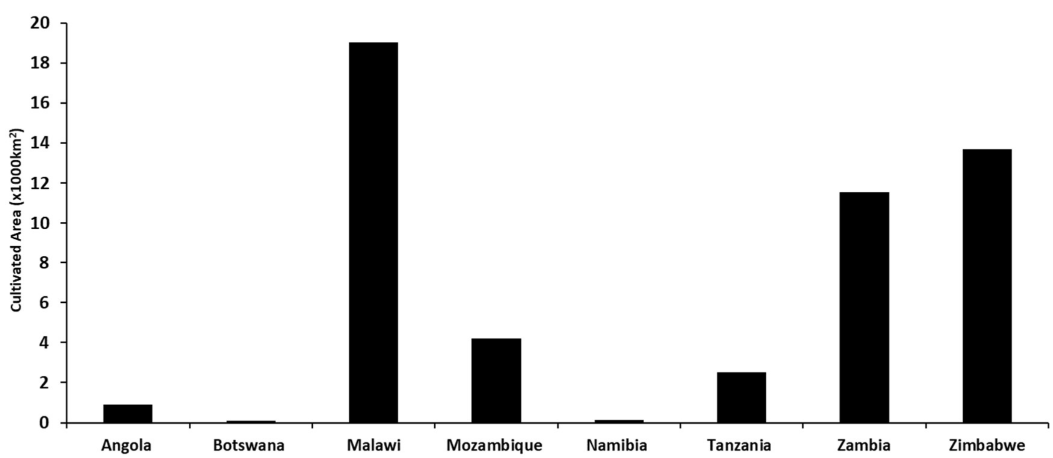

Figure 3 Riparian states cultivation land area in the ZRB. Source: (MacDonald, 2007).

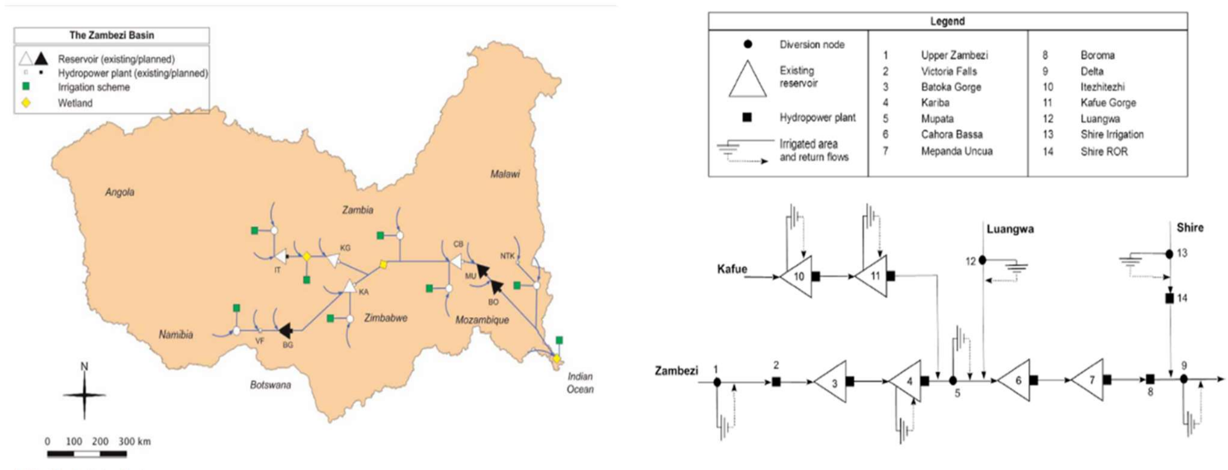

Figure 4 (a) Irrigated area and wetland development in the ZRB (after Tilmant et al, 2012) and (b) schematic of the ZRB and the associated economic activities (after Rogue and Tilmant, 2016).

2.3 Ground Water in the ZRB

The total annual runoff in the ZRB amounts to approximately 103 km^3. The International Groundwater Resources Assessment Centre (IGRAC) reports 10 transboundary aquifers; four which are located inside the ZRB perimeter and six which are partly located within the ZRB (Cai et al., 2017). The ZRB average annual groundwater recharge is estimated to be 130 km^3. The AF 14 aquifer services five countries namely Angola, Botswana, Namibia, Zambia and Zimbabwe. This qualifies it as the most shared aquifer in the ZRB (Cai et al., 2017).

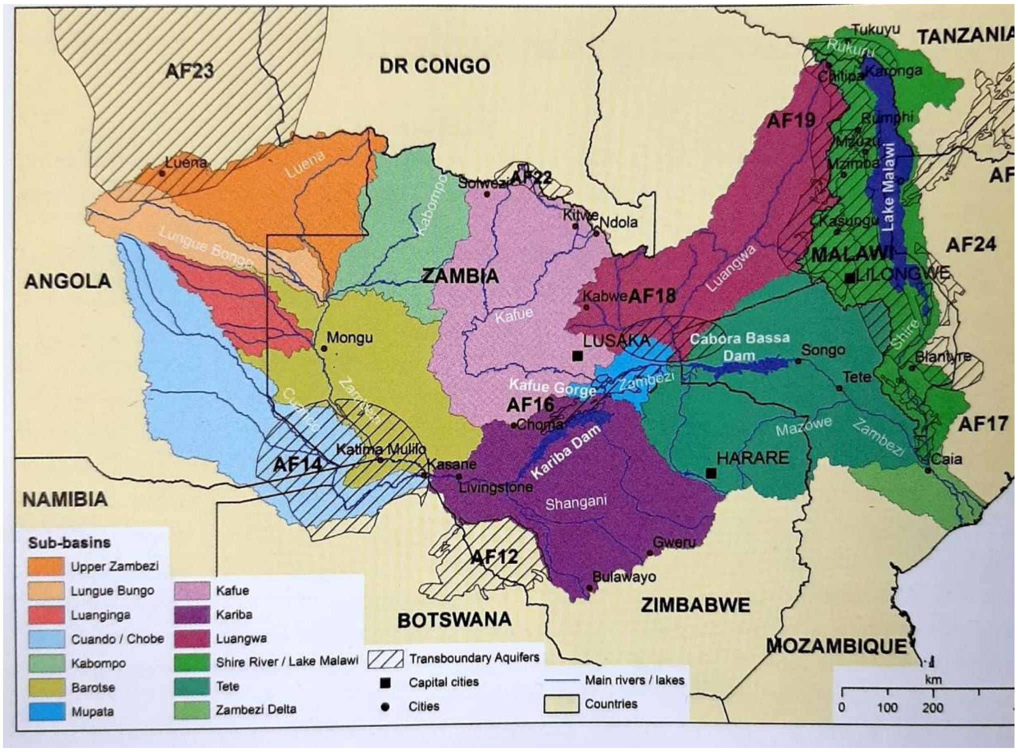

Figure 5 The ZRB subbasins and the shared aquifers (Source: Cai et al., 2017)

Groundwater utilisation is growing within the basin because of its relative availability, low capital investment and less "complicated" legal issues. Agricultural activities dominate ground water utilisation in the ZRB. Utilisation extends to irrigation, fisheries and livestock watering (Cai et al., 2017). Ground water available for irrigation is estimated to be 38.5 km^3 (Altchenko and Villholt, 2015) whilst the irrigation potential is an estimated 2.55 million ha (Figure 6 b). A summarised national groundwater irrigation use and the ground water potential is presented in Table 2.

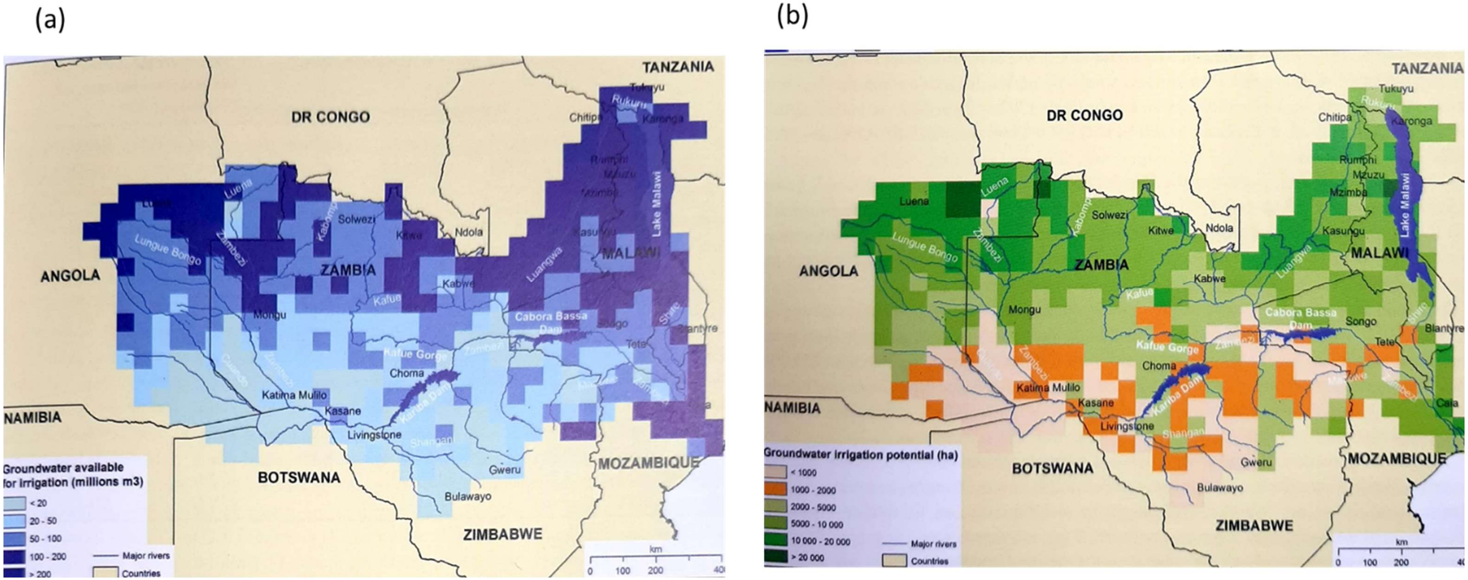

Figure 6 (a) Ground water available for irrigation and (b) ground water irrigation potential (Source: Altchenko and Villholt, 2015, Cai et al., 2017)

Table 2 Ground water utilisation and potential for irrigation in the ZRB (after Cai et al., 2017)

	Country level data from Aquastat database			Data inside the ZRB (adapted from Altchenko and Villholt, 2015)	
	% cultivated area equipped for irrigation	Total area for irrigation by groundwater (10^3 ha)	% of area equipped for irrigation by ground water to total area equipped for irrigation	Water available for irrigation (km^3)	Potential area irrigable with ground water (10^3 ha)
Angola	2.3	17.1	19.99	7.5	729.3
Botswana	0.6	0.6	44.32	0.03	1.6
Malawi	2.3	0.015	0.05	5.4	248.5
Mozambique	2.5	0.6	0.54	5.3	247.3
Namibia	0.9	1.6	21.5	0.1	3.1
Tanzania	1.8	0.4	0.21	1.5	66.2
Zambia	6.0	6.8	4.3	16.5	1152.2
Zimbabwe	4.317.1	20	11.5	2.1	114.8
Sum	0.6	47.115		38.43	2563

Manzungu et al. (2017) posited that the total agricultural economic output in the ZRB for 2015 was USD 6.5 billion all over the basin. Zambia and Malawi recorded steady but fluctuating agricultural production whilst Zimbabwe has stagnated. Agriculture contributes significantly to the GDP (Table 3).

Table 3: Agriculture contribution to national GDP adopted from WorldBank (2010)

	ANG	BOTS	MAL	MOZ	NAM	TANZ	ZAM	ZIM
Other sectors (%)	91	98	62	74	89	55	77	83
Agriculture (%)	8.8	2.4	38.4	26.1	10.8	45.0	22.8	17.4

Note: ANG = Angola, BOTS = Botswana, MAL = Malawi, MOZ = Mozambique, NAM = Namibia, TANZ = Tanzania, ZAM = Zambia, and ZIM =Zimbabwe.

Apart from contributing to GDPs, agriculture is the biggest employer in the ZRB (Manzungu et al., 2017). National level statistics on ZRB riparian statistics reveal that an estimated 26% to 80% work in agriculture. The statistics further reveal that agriculture employed more women than men (Table 4).

Table 4: Employment statistics in the ZRB Manzungu et al. (2017)

	Employment in agriculture as percent of total employment	**Female employment in agriculture as percent of total female employment**	**Male employment in agriculture as percent of total male employment**
Angola	-	-	-
Botswana	26.4	21.3	30.7
Mozambique	80.5	89.9	69.2
Malawi	64.1	69.9	58.5
Namibia	31.4	30.9	31.9
Tanzania	66.9	70	64
Zambia	52.2	53.4	51
Zimbabwe	65.8	71.6	59.9

	Employment in agriculture as percent of total employment	Female employment in agriculture as percent of total female employment	Male employment in agriculture as percent of total male employment
***Population weighted Average**	61.3	65.9	56.6

* Weighted average signifies the weighted average for each category divided by the total number of workers in the agricultural sector.

2.4 Fisheries in the Zambezi River Basin

Fishing is an important activity in the ZRB. Fishing can either be for purpose of subsistence, commercial or angling tourisms. Fisheries play an important role in food and nutrition for people in the riparian countries. For those residing close to the basin, fishing forms an important income generating activity. It is estimated that fish accounts for ≈ 10% of protein source (The WorldFish Centre, 2007). In 2016, African Union – Interafrican Bureau for Animal Resources (AU-IBAR) reported ≈ 100 fish species within the Zambezi River with the upper Zambezi boasting more species (> 85). The middle and lower basin have approximately 60 fish species. Earlier in 2007, it was reported ≈ 130 species of fish within the middle Zambezi, suggesting there has been loss of diversity over the years. This has attributed to introduction of invasive alien fish species, destructive fishing methods, pollution, human population growth and water demand for agriculture, industry and domestic uses within the basin (Tweddle and Tweddle, 2010).

Despite the importance of fishing in the riparian countries, there are still several reports of underutilized potential of fishing within the river basin and no increases in catch yields over the past decade (Table 5) (Interafrican Bureau for Animal Resources, 2016; Tweddle and Peel, 2015; Tweddle and Tweddle, 2010). There has been several calls for proper management of fishers within the riparian countries to fully utilize the potential of fishing within the river basin. Catch yields within the upper Zambezi are ≈ 7 500 tonnes per annum which is approximately half of the potential annual yield (14 000 tonnes year^{-1}) (Table 3). Zambia explores less than 50% of the fishing potential in the River and floodplains of the Middle Basin. Catch yields in Lake Kariba are 10 000 tonnes year, 25% of the potential catch yields (Interafrican Bureau for Animal Resources, 2016). Issues regarding increasing catch yields are basically a matter of management across all sectors as the increase in hydropower and irrigation demand also affect fisheries (Tweddle and Peel, 2015). All this is evident for the need for a nexus approach in policy and governance analysis across all sectors and riparian countries within the ZRB.

Table 5: Annual catch yields in the different regions of the Zambezi River Basin in the year 2000 to 2007 (Adapted from Tweedie and Tweedie, 2010).

Region	2000	2001	2003	2004	2005	2006	2007
	Tonnes						
Upper Zambezi	6 728	-	6 694	6 834	6 653	6 079	7 421
Kariba	8 863	9 306	8 818	9 003	8 768	8 008	9 776
Kafue	6 131	6 437	6 100	6 228	6 062	5 539	6 763
Lukanga	1 306	1 371	1 299	1 327	1 291	1 180	1 441
Itezhi-tezhi	2 221	2 332	2 210	2 256	2 196	2 007	2 450
Lusiwashi	2 139	2 246	2 128	2 173	2 115	1 933	2 359
Lower Zambezi	588	617	585	597	581	531	649
Total	29 976	24 374	29 837	30 422	29 671	27 283	32 866

2.5 Livestock Farming in the Zambezi River Basin

Livestock production has a long history linked with the ZRB. Archaeological evidence suggests that the first livestock to enter Southern Africa was through the ZRB (Sadr, 2015). With respect to consumptive water use, livestock production only consumes ≈ 120 million m^3 per annum representing less than 1% of total consumptive use (Euroconsult Mott McDonald, 2007; World Bank, 2008). 90% of the livestock in the ZRB is in Zambia, Zimbabwe and Malawi. The bulk of livestock in the Zambezi basin consists of cattle (Euroconsult Mott McDonald, 2007). Cattle population within the basin is ≈ 42 million heads (ZAMCOM, SADC, SARDC, 2015). Although this has risen from 35 million in 2005, level of livestock production within the basin is described to be low, with productivity still below the potential level (World Bank, 2008). Small scale livestock production relies on natural grassland and browse for feed while at the commercial level, herd is given supplementary feed. Livestock production is affected by rainfall patterns and drought due to the reliance on natural grasslands.

2.6 Rainfed and Irrigated Agriculture

According to the WorldBank (2010) an estimated 70% of the riparian inhabitants are subsistence farmers. Rainfall is the chief water supplier for the subsistence farmers. The ZRB has an uneven rainfall distribution characterised by low rainfall in the western and southern parts of the basin and high rainfall in the northern and eastern parts (Beck and Bernauer, 2011). The lower parts of the basin receive approximately 500 mm in the extreme south and southwestern parts , whereas the upper sub basins such as Kabompo, Upper Zambezi, Lungue Bungo, Kafue, Shire, and Zambezi Delta receiving an estimated 1400 mm. The rainfall variation gradient (Figure 7) influences agricultural performance. Beyer et al. (2016) reported spatial yield variations across the ZRB with the northern parts having prolonged wet seasons compared to the southern regions.

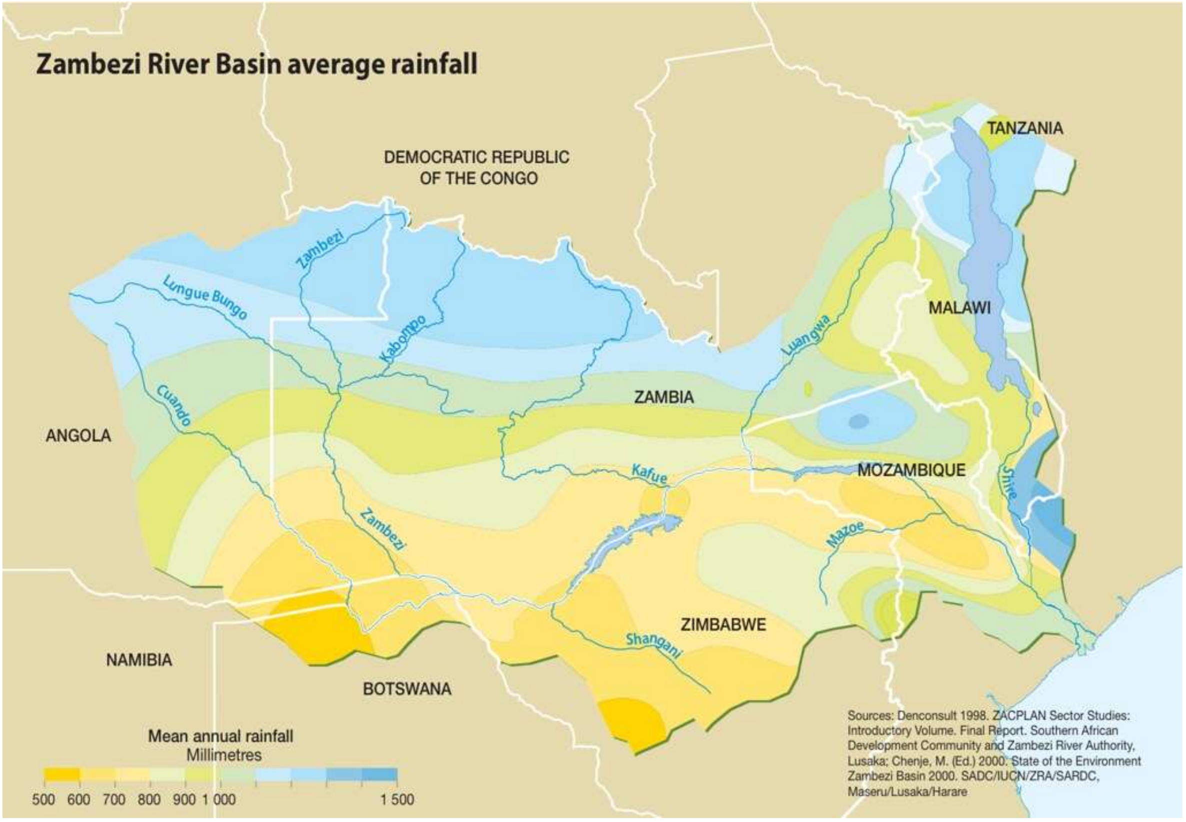

Figure 7 Mean annual rainfall variation across the ZRB.

Irrigation abstractions consume a significant amount of the basin's water. ZRB irrigation practices are typified as informal irrigation by small-scale farmers, smallholder irrigation, and commercial irrigation schemes. The informal irrigation is characterised by casual, artificial way using buckets, watering cans and hosepipes (Manzungu et al., 2017). The average land holding under informal irrigation is estimated as 200 m^2. Smallholder irrigation schemes are the riparian governments efforts to alleviate poverty. The smallholder irrigation scheme use common pool resources and average land holding per individual is 1 hectare (Dirwai et al., 2019). Commercial irrigation is done on a large scale and comprises of advanced technology and heavy machinery. Senzanje and Chibarabada (2018) summarised the different irrigation systems used in ZRB as presented in Table6.

Table 6 Irrigation systems used in the ZRB adapted from Manzungu et al. (2017) and Senzanje and Chibarabada (2018).

Technology	Description	Reason for adoption	Disadvantages
Bucket system	• Watering manually using cans or buckets • Used by poor farmers in dry spells	• Cheap • Does not require energy	• Waters very small areas
Gravity fed irrigation	• an elevated reservoir with a pipe coming out the bottom • Adopted at household level to water small areas (< 200 m^2)	• Cheap • Does not require energy	• Waters very small areas
Treadle pumps	• human-powered suction pump that sits on top of a well • Adopted by small scale farmers	• Cheap • Increased crop area (2000 m^2)	• Labour intensive
Motor pumps	• Mechanised pumps driven by electricity and fuels • Adopted by rich small-scale farmers	• Minimum labour required • Increased crop area (3000 m^2)	• Pumps require maintenance • Expensive • Uses energy which is an extra cost
Drip irrigation	• Micro-irrigation by allowing water to drip slowly to the roots of plants, either from above or below the surface of the soil. • Used for high value crops by commercial farmers • Low adoption by small scale farmers	• Has the potential to save water and nutrients • Efficient	• Pumps require maintenance • Expensive • Requires expertise
Sprinkler irrigation	• Water is distributed through a system of pipes usually by pumping • Used under commercial farming and small holder schemes	• Cheap at commercial level • Effective	• Pumps require maintenance • Energy intensive • Requires expertise
Centre pivot	• Mechanized irrigation machines used to irrigate large areas of land efficiently • Used under commercial farming	• Effective for large crop areas	• Pumps require maintenance • Expensive • Energy intensive • Requires expertise

2.7 Agricultural Water Management (AWM) the Zambezi River Basin

Agricultural water management (AWM) is generally defined as the *"management of water in agriculture in a continuum from rain fed systems to irrigated agriculture, and includes the capture, storage and drainage of any water used for agricultural production"* Manzungu et al. (2017). AWM holistically include the development, distribution and use of direct rainfall, surface water and underground sources (Mati, 2007;Manzungu et al., 2017). According to Namara et al. (2010) AWM improves human development index through increased production, enhanced employment which facilitates a stable income, and boosting nutritional status. Malnutrition bedevils SADC as evidence by the 20 million stunted growth in the region (SADC, 2019). A clear approach towards implementing AWM is key to improving livelihoods.

AWM as a multi-pronged approach fits in all the ZRB irrigation practices. AWM interventions are key to sustainable agricultural intensification (SAI). The riparian member states actively participate in economic development fora such as African Union (AU), New Partnerships of African Development (NEPAD). Active participation has led to yearly pledges of 10% of the nation's budget to support agricultural activities. The participation is aimed at fostering economic growth which subsequently alleviates poverty and boost nutritional status of the rural poor. The Comprehensive Africa Agriculture Development Plan (CAADP) blueprint advances Africa's agricultural agenda through the formation and investment in African agricultural research institutions and farmers' associations to mention a few. CAADP is built on two pillars one which promotes sustainable land use and water systems. For the period of 2002 – 2015, an estimated investments of USD 37 billion was channelled to land and water control systems in smallholder irrigation schemes (CAADP, 2006).

The ZRB riparian states possess potential for intensified irrigation. For example, Mozambique can potentially expand from 2000 ha under irrigation to 70 000 ha, signifying under-utilisation. Table 7 provides an overview on the irrigation potential in ZRB.

Table 7: Summarised irrigation potential in the ZRB adopted from WACOZA (2018)

Country	Irrigation potential (ha)	Gross potential irrigation water		Area under irrigation (ha)
		Per ha (m^3 per ha)	Total (km^3/year)	
Angola	700000	13500	9.45	2000
Namibia	11000	5000-25000	0.255	6142
Botswana	1080	5500	0.006	0
Zimbabwe	165400	10500	1.737	49327
Zambia	422000	12000	5.064	41400
Tanzania	0	11000	0	0
Malawi	160900	13000	2.092	28000
Mozambique	1700000	11000	18.7	20000
Sum of countries	3160380		37.303	146869
Total for Zambezi	3160380		37.303	

Expanding irrigation is part of the riparian states development agenda for instance, a study by Xie et al. (2014) revealed how incorporating irrigation technologies such as treadle pumps, motor pumps, communal river diversion, and small river diversions can potentially boost economic gains in sub-Saharan Africa. For each technology, Xie et al. (2014) further posited that 30 million ha can potentially adopt motor pumps, 24 million ha for treadle pumps, for small reservoirs 22 million, and 20 million ha for communal river diversions. As evidenced by literature the adoption of intensified irrigation in the ZRB is worth exploring. Manzungu et al. (2017) provided an outlook on current irrigable area and the projected increase in the ZRB (Table 8). The study further provided evidence on projected irrigation water consumption as shown in Table 9.

Table 8: Area equipped for irrigation in the ZRB adopted from Manzungu et al. (2017)

	Present irrigated area (ha)	Projected irrigated area by 2025 (ha)	Percentage increase (%)
Angola	6125	10625	173
Botswana	0	20300	-
Namibia	140	450	321
Malawi	37820	78026	206
Mozambique	8436	137410	1629
Tanzania	23140	23140	100
Zambia	74661	61259	82
Zimbabwe	108717	183431	169
Total	259039	514641	199

Table 9: Current and projected water use in the ZRB adopted from WorldBank (2010) and Manzungu et al. (2017)

Country	Year 2010		Year 2025	
	Abstraction to meet current irrigation water requirements (mcm)	Percent of ZRB renewable water resources (%)	Abstraction to meet current and future irrigation water requirements (mcm)	Percent of ZRB renewable water resources (%)
Angola	76	<0.05	207	0.1
Botswana	0	0	254	0.1
Namibia	495	0.2	2312	1.0
Malawi	134	0.1	1515	0.7
Mozambique	2	<0.05	8	<0.05
Tanzania	154	0.1	308	0.1
Zambia	879	0.4	1601	0.7
Zimbabwe	1496	0.6	4019	1.7
Total	3235	1.4	9661	4.1

Building resilience against climate change (CC) is a step in the positive direction for the riparian states. Of late the changes in precipitation amounts has had an effect on water availability in the region (IPCC, 2007). Climate smart agriculture (CSA) has potential to mitigate the adverse effects of CC in the ZRB by boosting yields and subsequently food security. Climate smart agriculture aims to reorients and transforms conventional agricultural practices by coordinating stakeholder participation (Lipper et al., 2014). According to Lipper et al. (2014) the purpose of stakeholder participation and engagement is aimed at (1) building evidence; (2) increasing local institutional effectiveness; (3) fostering coherence between climate and agricultural policies; and (4) linking climate and agricultural financing fosters.

SAI and CSA work hand in glove. A typical case study showing the complementary relationship of SAI and CSA is reported by Campbell et al. (2014). The adoption of stone bunds and zaii pts in the Sahelian region proves to be an effective way of harvesting and storing water. The stone bunds are constructed along contours to harvest the water. Zaii pits are a land management technique which comprises of shallow composted bowels in which crops are planted. A combination of these two technologies boosts small grain yields up to 1 ton/ha (Campbell et al., 2014). This combined CSA and SAI improves vegetable yields and nutritional status in the ZRB. Such innovations if implemented in the ZRB can potentially increases crop yield intensities.

3 SITUATIONAL ANALYSIS ON WATER AND AGRICULTURE IN THE ZAMBEZI RIVER BASIN

As mentioned in the previous section the identified agricultural practices in the ZRB are large scale commercial irrigation (LSCI) and smallholder communal irrigation – river diversions, storage works and pumped water supply. This section discusses the agricultural practices and their potential for intensification within the ZRB to benefit the rural population.

3.1 Large Scale Commercial Irrigation (LSCI)

Large scale commercial irrigation is characterised by vast land holding under large scale operation. LSCI is also characterised by private ownership and management . The operation is profit driven. The scale of operation is described by the operations in South Africa, Zimbabwe, Swaziland, and Mozambique's sugar cane estates. The privately-owned enterprises contribute directly to rural development by providing employment and rural infrastructure development (housing, electricity and water supply) and indirectly through corporate social responsibility (CSR). The enterprises contribute to national development through food security and exports (foreign currency earnings).

3.2 Smallholder Communal Irrigation – river diversions, storage works and pumped water supply

A bulk of smallholder irrigation schemes (SIS) in the ZRB are found in this category. The SIS are characterised by small land holding (0.1 – 2.5 ha) and shared common pool resources such as water abstraction, conveyance and water application infrastructure (Van Averbeke, 2008; Dirwai et al., 2019). The SIS have different water lifting options namely; river diversions using canals or with low lift, storage works with canal diversions or storage with low lift, and also pumped water using electricity or engines of one form or the other. The water lift mechanism is dependent on location. The SIS governance varies from schemes that are farmer led and managed to government owned and managed SIS. Government led SIS perceivably to perform better than their counterparts. Government support extends to extension services, providing a budget for operation and maintenance (O&M). However, farmer led SIS have reduced reliance on government hence the farmers tend to take care of their infrastructure strictly. Limited government intervention was reported to have pushed the farmers to adopt a more commercial model in their operations. For example, the farmer led SIS in the ZRB engage in cash crop farming. Reports by Giordano et al. (2012) and Senzanje (2016) highlighted how these SIS operate efficiently and how they are financially viable.

The relevance of smallholder communal irrigation in ZRB cannot be mooted. Adopting this practice should be seamless considering that riparian governments are no strangers to SIS. SAI can be achieved by increased extension personnel for information dissemination. The end goal being reducing dependency on donor aid and government.

3.3 Smallholder Individual Irrigation

As the name entails, this irrigation practice is characterised by individually owned land holdings. The farmers under this arrangement are sometimes called smallholder commercial farmers. The farmers have access to bank loans as they can use the land holding title as collateral (Senzanje, 2016). The smallholder individual farmer is often well equipped, i.e., they own personal pumping units and advance irrigation technologies. The individualistic approach is fuelled by capitalism. The farmer is more concerned about growing for the market. There is another dimension to this farming practice, in the South African and Zimbabwean context there exists an out-grower system. The out-grower is a smallholder individual with close ties with the LSC enterprise. The out-grower benefits through access to irrigation water, inputs and a ready market for their produce. This agricultural practice promotes individual growth and uncouples one from group or collective work where often there are conflicts.

The poverty barometer gauges poverty alleviation under this practice as “good”. The individual farmers have a commercial approach that can be nurtured and be a gateway to employment creation. Employment creation ensures stable income and sustained livelihoods.

3.4 Smallholder Communal Sprinkler Irrigation

The practice is similar to smallholder communal irrigation with river diversion. The differentiating factor is that this practice comprises of pressurised systems water application is done through sprinklers. The pressurised systems can be categorised according to energy requirement and O&M requirements. A bulk of such systems have been installed through NGO led initiatives.

Sprinkler systems can be adopted by individual farmers and under group settings such as SIS. Under individual smallholder irrigation practice the farmer either has a drag line or movable sprinklers. The system is tailored for on demand water supply which poses an energy expense on the farmers (Senzanje, 2016). Group irrigation adapts to an irrigation schedule. Technologies available are movable quick coupling irrigation systems and centre pivots that revolve around a consolidated “individual” farmland. The centre pivot system requires high levels of organisational efficiency, and lately the system has been adopted in South Africa and Swaziland. Sprinkler irrigation has a comparative short life span (10 – 15 years) over the flood irrigation canal counterparts that have an infrastructure life expectancy of 40 – 60 years.

There is a distinct prospect of adopting this irrigation practice in the ZRB. The farmers must be encouraged to go for cash crops should they adopt the sprinkler irrigation practice. This will ensure long term stability through earned income that will cater for pumping costs. The irrigation potentially saves water as compared to flood irrigation. The reported irrigation efficiencies for sprinkler irrigation flooding techniques are 75% and 40% respectively.

3.5 Smallholder Communal Drip Irrigation

Drip or trickle irrigation involves the application of low volumes directly to the crop root zone. The water application technique utilises low hydraulic pressures to drive the system. The emitter itself is a pressure regulator i.e., it dissipates the hydraulic pressure through the emission process to the required flow rate (Bresler, 1977). Drip irrigation is designed for intensified agronomy. Water saving is achieved by reducing the irrigation frequency and prolonging each irrigation interval. the disadvantage of using such a system is the expensive initial investment, field impediments due to permanently installed hardware, limited applicability since it cannot be used on low value crops such as maize (Senzanje, 2016). The mentioned disadvantages have influenced the limited adoption of drip irrigation in smallholder irrigation fraternity.

Given the high cost associated in installing and maintain drip irrigation systems farmers need to cultivate high value crops in order to have a return on investment. Drip irrigation does not facilitate that flexibility thus limiting the prospects of adoption by the ZRB smallholder farming community.

3.6 Drum and Bucket Drip Kit Irrigation

This is a simple low-cost technology (Figure 8). The system releases water at low volumes and it comprises of a suspended low volume reservoir (5 – 10 litres). The reservoir is suspended to a height of 2 m to provide enough head to operate micro-tube drippers installed on the laterals that are connected to the main line from the reservoir. The system works in conjunction with a treadle pump to supply the reservoir (Daka, 2006). The technology was pushed into sub-Sahara Africa by the UN Food and Agricultural Organisation (FAO) under the Special Programme on Food Security (SPFS) in the 1990s (Senzanje, 2016). The bucket drip kit irrigation is suitable for backyard gardens. The approach can be used for vegetable production which can boost nutritional status for the ZRB inhabitants. However, there is doubt on the capability of the drip kit to ensure food security.

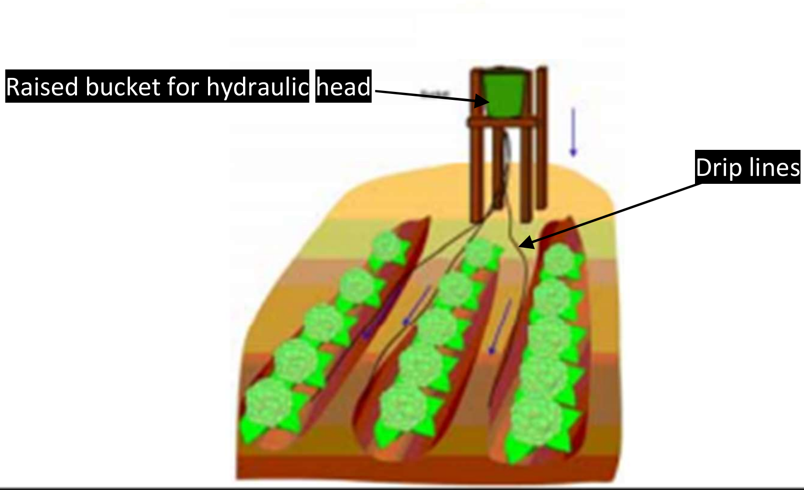

Figure 8 A typical raised bucket and drip irrigation system (after Mati, 2007)

3.7 In- land Valley Swamp Irrigation (Dambos)

Dambos are an indigenous knowledge that comprise of cultivated lowland interfluves that store moisture (Figure 9). The interfluves provide moisture through capillary rise. In flooded areas the dambos are perfect growing sites for rice. Land management practices like raising ridges/beds facilitate crop diversification (Daka, 2006). Dambos are predominant in the lowlands of Zambia with 3.6 million ha under dambo irrigation and 100 000 ha is cultivated during the rainy season. Dambo farming has the following advantages; (i) increased cropping intensities, increased yield, (ii) late or early crop production, (iii)low operational costs, and (iv) increased farm incomes (Daka, 2006;Senzanje, 2016). Before operation prior knowledge of water table recharge rates is required to avoid over abstract.

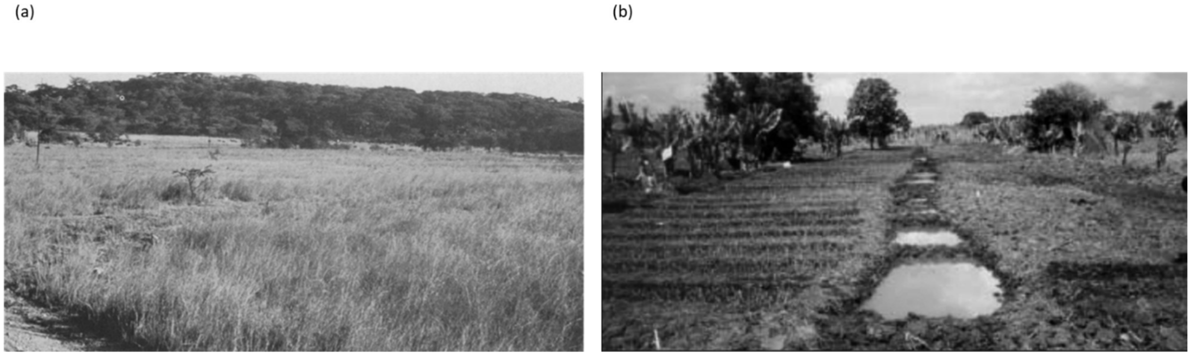

Figure 9 A partially grazed dambo in Zimbabwe (after Roberts, 1988) and (b) Mugabi dambo in Zambia (after Tempelhoff, 2008).

The indigenous nature of the practice offers a low-cost opportunity for adoption in the ZRB. There is a low external input requirement, however, limited knowledge on water table fluctuations amongst the farmers poses a challenge of overuse.

3.8 Soil and Water Conservation and Conservation Agriculture under Rainfed Agriculture

In the crop production continuum, the ZRB farming practices translate from blue water to green water. Sub-Sahara Africa depends on rainfed agriculture for food production (Rockstrom *et al*., 2010; Vidal, *et al*., nd). Soil and Water Conservation (SWC) entails the optimal usage of rainwater with emphasis on infield and ex-field rainwater harvesting. In-field rainwater harvesting (IRWH) is characterised by harvesting the rain where it falls whilst ex-field rainwater harvesting (ERWH) is all about harvesting runoff from roads, etc (Senzanje, 2016).

Conservation agriculture (CA) is defined as *"practices that aims at minimal soil disturbance coupled with permanent soil cover combined with reasonable crop rotations"* (Senzanje, 2016). CA has three pillars namely; (1) minimum soil disturbance, (2) mulching, and (3) the practise of crop rotations. As like CSA and SAI, CA and SWC work hand in glove to promote AWM for SAI. The resultant practices achieved from CA and SWC are *fanja juu* terraces, micro-basins, stone bunds, *zai* pits, tied ridges, contour farming, and mulching just to mention a few.

Micro-basins are meant to retain water in-situ and slow down run-off. The structures are 1.0 m long and less than 50 cm deep (Previati *et al.,* 2009). The holes are dug pre-rain season to prepare for moisture collection (Thiefelder *et al.,* 2012). Zai pits are designed to maximise crop production (Figure 10). The pits are dug in alternate patterns that are more or less a meter apart, with basins that are 30–50 cm wide and with a depth of 10–20 cm (Renner and Frasier, 1995). *Zai* pits can fit about 10–15 seeds of sorghum or millet and are usually dug during the dry season. The sowing is done at the beginning of the rainy season or during the dry season (Sedibe, 2005; Senzanje, 2016).

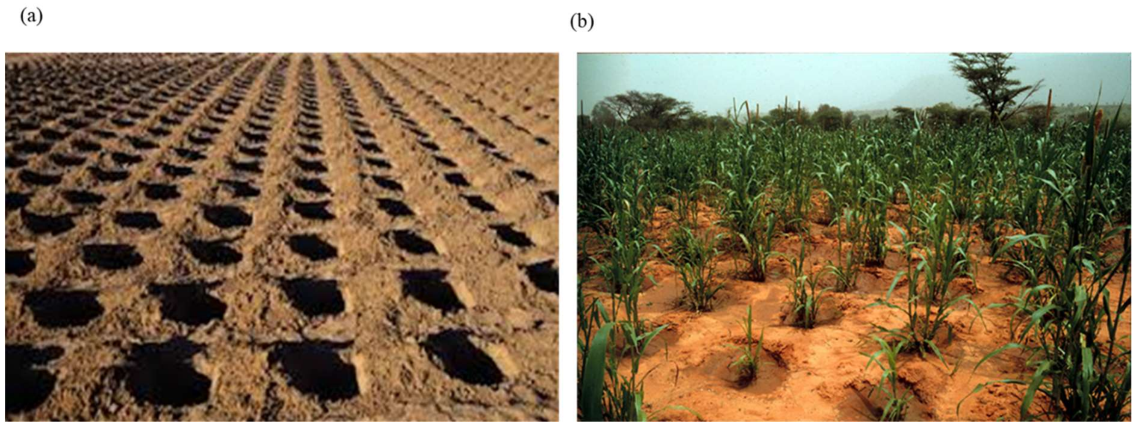

Figure 10 (a) Zai pit system in preparation and (b) a typical zai system accommodate maize crops (Source: Google images)

Fanya juu terraces are constructed with an embankment that is put in an upslope position and are usually constructed along the contour to capture rainfall, especially in semi-arid regions, and come in various dimensions averaging 0.6 m deep and 0.6 m wide and a bund measuring 0.4 m high (FAO, 1993). *Fanya juu* designed to improve plant growth, by minimising water and soil loss. According to WOCAT (2007) *Fanya juu* construction is labour intensive and to construct one over a hectare on 15% slope would take 90 man-days. Figure 11 depicts a typical Fanyaa juu.

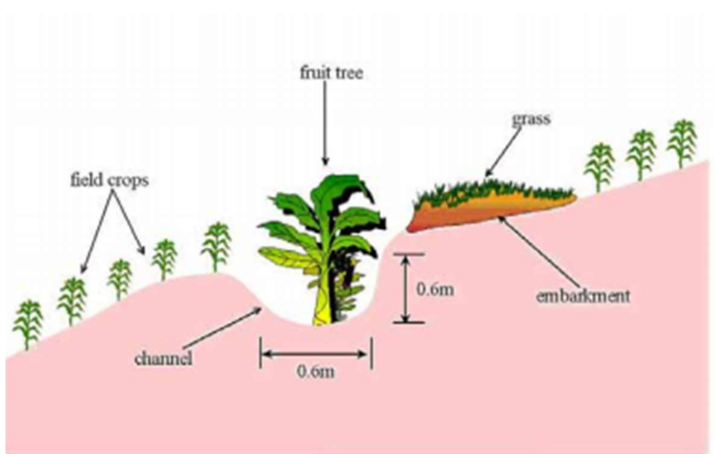

Figure 11 A typical *Fanya Juu* (Source: Mati, 2007)

Tied ridging involves creating ridges that are 0.2 m to 0.3 m high with a spacing of 0.75 m wide (Figure 12). The ties can be prepared either before, during or after planting (Brhane, *et al.*, 2005). Tied ridging is meant to minimise runoff and prevent soil erosion. Another effective method practiced in the ZRB is called contour farming which involves cultivating across the slope or farming along the lines of equal contour (FAO, 1998; Senzanje, 2016). Another equally important approach is soil mulching, which involves covering the soil surface with crop residue with the intention to minimise wind and water erosion. Other benefits derived from soil mulching are reduced evapotranspiration thus maintaining optimal soil moisture levels, improving soil infiltration, and soil aggregate stability (Giller, *et al*., 2009; Senzanje, 2016).

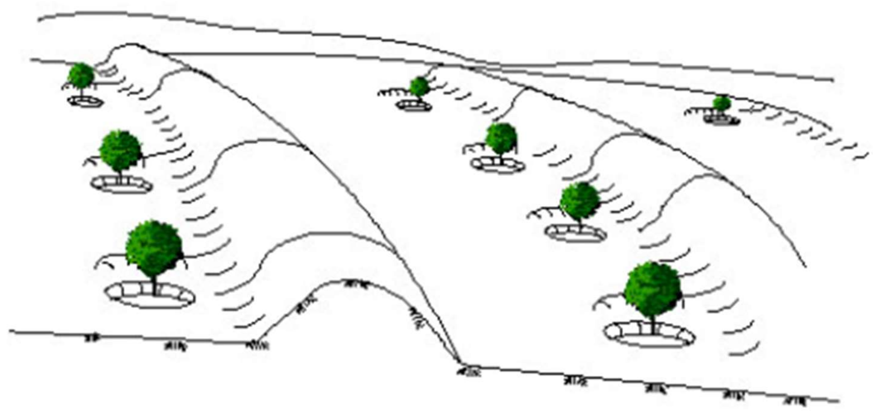

Figure 12 Typical ridging (source: Mati, 2007)

The combined use of SWC and CA offers adoptable and low-cost approaches to AWM in the ZRB. The derived benefits will subsequently lead to increased water use efficiency (WUE). Enhanced WUE translates to improved yield and food security. The flexibility of the practices makes them applicable at various spatial scales i.e., from smallholder to large scale commercial farming. The practices require low input and less technical knowledge. The adoption of these practices must be extensively encouraged for adoption in the ZRB. Suitable irrigation methods should be implemented to complement the low-cost AWM practices.

3.9 Analysis of the Agricultural Water Management Interventions

A thorough qualitative analysis on the selection matrix gives a cost benefit picture necessary to explore and assess the suitability of each AWM practice in the ZRB. On paper, it is relatively easy to push for an AWM practice onto the farmers without careful consideration of the socio-economic factors that prevail in the community. The next analysis will focus on the AWM practices and the ease of implementation and the cost associated with implement the system in the ZRB. A comparative analysis on the discussed AWM practices for sustainable agricultural intensification is given in Table 9 below

The small scale irrigation with river diversion and storage practice is considered universal since it is adoptable by 5 of the 8 riparian states. Its applicability over a wide range of soils makes it a possible option for adopting. The success around this AWM practice in the ZRB is partly attributed to government interventions through rehabilitation and revitalisation programmes. Dambo irrigation farming is another viable option because of the low capital investment. The initial capital investment ranges from USD 50 – USD 100 per ha. As mentioned priori, the social capital required for O&M is cumbersome. The drip kit and bucket irrigation practice is another low capital investment practice that can be adopted by the ZRB farmers. The limited applicability hinders upscaling, however, the system registered successes in Malawi and limited success in Zimbabwe. AWM applicability depends on agricultural revenues and locality. Agricultural revenue earns a stable income for the ZRB irrigators whilst the surplus can be directed for technology adoption and upscaling.

The uptake of a practice is dependent on the ease of adoption. As mentioned before, if a practice deviates from the customary and cultural norms, the farmers are most likely to return to habit. The listed AWM practice (see Table 10) can be further assessed for “practice readiness” by the farmers, and prospects for scaling up (Table 11). Factors such as cost, profitability, and complexity just to mention a few can be indicators for assessing the readiness for adoption of a practice. Table 12 shows a best bet selection matrix based on the above mentioned indicators.

Table 10: Qualitative comparison of the agricultural water management interventions (AWMI) found in and proposed for the ZRB.

Criteria	**Agricultural water management intervention (AWMI)**						
	Smallholder irrigation with river diversion	**Smallholder irrigation with pressurised system**	**Dambo irrigation farming**	**Drip kits (including bucket and drum)**	**Small reservoirs**	**Soil & water conservation including conservation agriculture**	**Comments/Notes**
Quick and tangible benefits	Medium	Medium	High	High	Medium	Medium	Benefits of smallholder irrigation take time since these are medium to long term type of investments.
Low risk of failure	No	No	Yes	Yes	Yes	Yes	Technologies like drip kits and soil and water conservation have low risk of failure because they are simple.
Presence and assurance of market opportunities	Situation dependent	Situation dependent	Situation dependent	Not applicable	Situation dependent	Situation dependent	Markets and marketing channels are usually situation dependent and cannot be predicted in advance for any technology.
Innovation and new technology	No	No	No	Yes	No	Yes	Strictly speaking smallholder irrigation, dambos and small reservoirs are not new or innovative technologies.
Aspiration to change by individuals and community	No	No	Yes	Yes	No	Yes	Dambo irrigation, drip kits and soil and water conservation technologies are normally driven or initiated by individuals or communities.
Need for champions of change	Low	Low	Medium	High	Medium	High	Smallholder irrigation is normally government or donor driven, so the need for champions of change is low.
Need for social capital	High	High	High	Low	Medium	High	For most of the interventions, the farmers need to invest social capital for success, especially in cases where they are group or communal activities.

Criteria	Agricultural water management intervention (AWMI)						
	Smallholder irrigation with river diversion	**Smallholder irrigation with pressurised system**	**Dambo irrigation farming**	**Drip kits (including bucket and drum)**	**Small reservoirs**	**Soil & water conservation including conservation agriculture**	**Comments/Notes**
Need for participatory approaches involving communities	High	High	High	Low	High	Medium	Smallholder irrigation, dambos and small reservoir irrigation requires that communities participate so this is a key requirement for their success.
Property rights and ownership elements in place	Low	Low	High	Low	High	High	For dambos, small reservoirs and soil and water conservation the issue of property rights or ownership (or access) is important, whereas for smallholder irrigation its mainly 'permission to irrigate' that operates.
Supportive policies in place	Medium	Medium	High	Low	Medium	Medium	Supportive policies are required to a certain extent for most of these technologies, but this is high for dambo farming as in some cases this is outlawed or not supported.

Table 11: Comparison of up scaling of best bet options of AWMI in the ZRB in terms of ideal conditions for the intervention and estimated costs of the intervention

No.	AWM Intervention	Ideal conditions in which intervention is suited	Estimated cost of the intervention (per relevant unit)[a]	Examples of evidence of sustainability or success or longevity (location)	Example references
1	Small scale irrigation with river diversion and storage	Applicable and adaptable to a wide range of conditions: • Soils: coarse to fine textured • Topography: 0.05% to 1% (or more for short furrows) • Typical stream sizes: 2 to 15 l/s per m width • Command area: from 1 ha to 1000 ha • Distance from water source: up to 5 km (to contain development costs)	Variable development cost: • US$10 000 per ha (or more depending on land levelling requirements)	Found in all countries in the sub-region: • South Africa • Zimbabwe • Malawi • Mozambique • Zambia • Kenya • Tanzania **NB**: Most of these are government developed and regularly receive assistance for revitalisation or rehabilitation	Micheal (1981) Savva and Frenken (2002) Inocencio, *et al*., (2007) Svendsen, *et al*. (2011) Merrey (2012)
2	Small scale pressurised irrigation with motorised pumping	Applicable and adaptable to a wide range of conditions: • Soils: coarse to fine textured • Topography: 0% to 15% • Typical application rates: 3 mm/hr (clays) to 50 mm/hr (coarse sand)	Costs depend on mode of development: • US$5 000 to 25 000 per ha (or more depending on distance from water source)	Mainly found in: • Zimbabwe • South Africa • Swaziland **NB**: These are also largely supported by government or donors	Micheal (1981) Savva and Frenken (2001) ARC (2003) Inocencio, *et al*., (2007) Svendsen, *et al*. (2011) Merrey (2012)

No.	AWM Intervention	Ideal conditions in which intervention is suited	Estimated cost of the intervention (per relevant unit)[a]	Examples of evidence of sustainability or success or longevity (location)	Example references
		• Operating pressure: 10 m to 4.0 m • Command area: from 1 ha to over 100 ha • Distance from water source: up to 2 km (to contain capital development costs)			
3	Dambo irrigation farming	Widely applicable: • Water: Existence of shallow water table • Water depth: up to 5 m during the dry season • Topography: 0.8% to 3.5% • Soils: medium to fine textured • Command area: depends on extent of wetland but could be tens of ha	Generally no 'formal' development costs, but the gradual investment by the farmers over time. Costs include: • Land preparation • Sinking of shallow wells • Purchase of treadle pumps, if required (US$50 to US$100 depending on type)	Widely practiced in the following countries: • Malawi • Tanzania • South Africa • Zimbabwe • Zambia	Dambo Research Unit (1987) Daka (2006)
4	Drip kits (including drum and bucket)	Simple, but limitations exist: • Soils: medium to fine textured • Command area: 15 m^2 (bucket kit) to 1000 m^2 (drum kit). Can also	Investment cost vary depending on size: • <US$50 to US$400 (depending on set-up, from 15 m^2 to 500 m^2)	Some successes in: • Kenya • Malawi • Ghana Limited success in the following countries:	Sijali (2001) Daka (2006) Merrey (2012) Kadyampakeni *et al.*, (2014) Rohrbach, *et al.*, (2006)

No.	AWM Intervention	Ideal conditions in which intervention is suited	Estimated cost of the intervention (per relevant unit)[a]	Examples of evidence of sustainability or success or longevity (location)	Example references
		have farm kits that are able to command >1000 m^2 • Operating pressure: 0.5 m (bucket kit) to 5 m (drum kit) • Water quality: <50 mg/l suspended solids, and < 500 mg/l total dissolved solids • Water pH: <7.0 • Water bacterial population: <10 000 (number/ml)		• South Africa • Zimbabwe (Failure was mainly because of deep water tables, slightly large land holding sizes and a preponderance for commercial agriculture in the population)	
5	Small reservoirs	Applicable and adaptable to a wide range of conditions: • Site: must preferably have high storage ratio (to minimise construction costs) • Site: must preferably have clay pan or unfractured bed rock to minimise seepage losses • Size: impounded volume less than 1	Costs vary according to method of construction: • <US$1/$m^3$ storage capacity to US$210/$m^3$ storage capacity if constructed using oxen and manual labour • Cost are much higher for development undertaken by mechanised means	Small reservoirs are a common feature: • All over sub-Saharan Africa	Senzanje and Chimbari (2002) RELMA (2005) Sawunyama, et al., (2006)

No.	AWM Intervention	Ideal conditions in which intervention is suited	Estimated cost of the intervention (per relevant unit)[a]	Examples of evidence of sustainability or success or longevity (location)	Example references
		million m^3 or wall height less than 8 m • Catchment area: 2 km^2 to 5 km^2 • Catchment protection: need catchment conservation to minimise siltation problems from soil erosion			
6	Soil and water conservation practices (including conservation agriculture)	The various practices are applicable to a wide range of conditions: • Rainfall: ideally should be above 450 mm per annum • Soils: medium textured to fine textured soil • Climate: arid to humid	Costs are very variable: • From a few US$ for such practices as micro-basins • US$336[1]/ha for practices such as terracing and contouring .	Successful examples of soil and water conservation are found in many places in the sub-Saharan Africa in countries such as: • Ethiopia • Tanzania • Malawi • Zimbabwe • South Africa (including very success uptake by commercial farmers)	Noble, *et al.*, (2005) Mati (2007) Oweis and Hachum (2009)

[1] Estimates as per Morgan (2009). Full reference Morgan, RPC. 2009. Soil erosion and conservation. John Wiley & Sons. New Jersey, USA.

Table 12: Comparative analysis of technological characteristics of the proposed best bet options for the ZRB in terms of factors that influence technology (intervention) uptake (adoption) or success[2]

Technology or intervention characteristics[2]	Agricultural water management intervention (AWMI)						
	Smallholder irrigation with river diversion	**Smallholder irrigation with pressurised system**	**Dambo irrigation farming**	**Drip kits (including bucket and drum)**	**Small reservoirs**	**Soil & water conservation including conservation agriculture**	**Comments/Notes**
Complexity	Moderate	High	Low	Low	Moderate	Low	Dambos, drip kits and soil and water conservation are generally perceived as simple technologies, whereas smallholder technology can be daunting depending on the scale.
Divisibility	Moderate	Low	High	High	Moderate	High	Smallholder irrigation is not easily divisible because it is normally designed as a single entity in terms of the infrastructure, whereas dambos, drip kits and soil and water conservation technologies are readily divisible.
Compatibility	Moderate	Moderate	High	High	Moderate	High	Smallholder irrigation is normally introduced to farmers by government and donors whereas dambo are indigenous technologies,

[2] This is based on the work of several authors that include; Rogers (1995), Cornish (1998), Kuypers *et al*. (2005), Brhane *et al*. (2006), Knowler and Bradshaw (2006), Damanpour and Schneider (2008), Erenstein et al., 2008, Tesfahuneg and Wortmann (2008) , Thiefelder (2013), among others. Strictly speaking these characteristics have to be linked to the socio-economic conditions of the communities or individuals to which the technology is being purveyed. [2]The technology characteristics are briefly defined as follows: *Complexity* = ease or difficulty in the understanding of an intervention, *Divisibility* = ability to use subcomponent(s) of the innovation or intervention package, *Compatibility* = the ease with which an innovation or intervention can be adapted to fit the resources, existing beliefs and values of the farmers , *Acceptability* = the adoption prospects of intervention or innovation when still in the inception stage, *Trialability* = the degree to which a certain aspect of a technology or intervention can be experimented on, *Observability* = the degree to which the results of the intervention or innovation are visible to others, *Cost* = how much it costs to adopt/uptake and implement the intervention, *Profitability* = the yield increase and profit realised after the adoption of an innovation.

Technology or intervention characteristics[2]	Agricultural water management intervention (AWMI)						
	Smallholder irrigation with river diversion	**Smallholder irrigation with pressurised system**	**Dambo irrigation farming**	**Drip kits (including bucket and drum)**	**Small reservoirs**	**Soil & water conservation including conservation agriculture**	**Comments/Notes**
							and drip kits can easily be adapted to fit farmers' situations making them much more compatible.
Acceptability	Moderate	Moderate	High	Moderate	Moderate	High	As with any technology when introduced, its acceptability tends to start off slow and then increase once farmers gain in confidence (the so-called concept of 'diffusion of innovations')
Trialability	Low	Low	High	High	Moderate	High	It's generally not easy to try out some individual aspects of smallholder irrigation, but one can try out aspects of drip kits or soil and water conservation practices.
Observability	High	High	High	Low	High	moderate	With the exception of drip kits, for all the other interventions the results are easily observable and can make an impact at once (positive or negative).
Cost	High	High	Low	Low	Moderate	Low	See Table 1 for cross referencing on costs
Profitability	Moderate	Moderate	High	Low	Moderate	Moderate	It all depends on the cropping enterprise, market access and attendant costs of production. Dambos tend to be low cost interventions with decent profit prospects. Drip kits tend to be small

Technology or intervention characteristics[2]	Agricultural water management intervention (AWMI)						
	Smallholder irrigation with river diversion	Smallholder irrigation with pressurised system	Dambo irrigation farming	Drip kits (including bucket and drum)	Small reservoirs	Soil & water conservation including conservation agriculture	Comments/Notes
							and so the profits are also low (in a relative sense).

4 WATER – ENERGY – FOOD NEXUS IN THE ZAMBEZI RIVER BASIN

4.1 WEF Nexus and its Variants

Globally the demand for water, food and energy is continually increasing due to rapid population and economic growth in concert with accelerated urbanisation and changing lifestyles. It is projected that by 2030 the global population will need at least 40% more water, 35% more food and 50% more energy (FAO, 2014). By 2050, a 70% increase in global food demand is predicted. It is projected that by 2025, 40% of the global population will be prone to severe water stress. According to the UN SDG report 2018 (UN, 2018), water insecurity remains high and accelerated progress is needed to meet the Sustainable Development Goals (SDGs) 2 (zero hunger – meaning food security) and 6 (clean water and sanitation – meaning water security). Global energy demand is projected to rise by 25% until 2040, hence putting into doubt the attainment of SDG 7 (affordable and clean energy – meaning energy security). In the past decade or so, the water-energy-food (WEF) nexus has emerged as an increasingly prominent global policy, governance and research agenda (Allouche, 2011; Middleton et al., 2015). Conceptually, the WEF nexus means that water security, energy security and food security are inextricably linked and, more importantly, actions in any one sector will impact in one or both of the others. Basically, the WEF nexus defines the tight interconnectedness between water, energy and food – meaning management of each of these cannot be done in isolation, must be in an integrated manner. The WEF nexus approach seeks to maximize potential synergies and identify and minimise areas of potential conflicts in natural resources management for sustainable development. During the late 2000s and early 2010s, the WEF nexus emerged as an integral approach to sustainably manage these three resource sectors, following the convergence of ideas from various political events, academic research and reports, as well as policy papers.

Water, energy, food and other land-based resources form an intricate web where resource use and availability rely heavily on each other (Pardoe et al., 2018). In reality the WEF nexus can be viewed in the following complex interactive relationships (Zhang et al., 2018);

(i) water for food – in excess of 70% of global freshwater withdrawal goes to food production,

(ii) water for energy – water is needed for energy extraction, electricity generation, refining and processing in the energy sector,

(iii) water for energy and food – hydropower generation exhibits energy-water-food-environment connectivity,

(iv) agriculture and land for energy and water – agriculture has a dual role as an energy user and supplier in the form of bioenergy, and furthermore, agriculture production impacts the water sector through its effects on land condition, runoff, groundwater discharge, water quality, and land/water availability for other purposes,

(v) agriculture, water and the environment – over-abstraction from surface water affects the minimum environmental flow that is required to maintain ecosystem services, over-abstraction of groundwater aquifers leading to salt water intrusion on coastal areas and upconing of deep salinized groundwater;

(vi) energy for food and water – directly or indirectly, for transportation, processing, packaging, and so on, and

(vii) energy for water supply and sanitation services – including activities such water pumping, water distribution networks, water and wastewater treatment, and the like. These interactions can be incredibly complex, be multidirectional and very difficult to quantify, both in space and time.

In the past few years, the scope of the WEF nexus has been expanded to include many other areas of interest, depending on the exigencies of the time and place. Over and above the traditional WEF nexus, the following nexus have also been explored, to mention a few:

- Water-Energy-Food-Ecosystem (WEFE) nexus
- Water-Land-Energy-Food (WLEF) nexus
- Water-Land-Food (WLF) nexus
- Water-Energy-Land (WEL) nexus
- Water-Energy-Food-Climate (WEFC) nexus
- Water-Energy-Food-Health (WEFH) nexus
- Water-Economic Growth-Livelihoods (WEDL) nexus

From the above list, a quick look is taken with respect to the WEFE and WEFH nexus, before focusing on what is applicable and relevant to the ZRB.

By definition, the WEFE nexus describes the close interlinkages of the water, energy, and food sectors, and how they rely on and impact ecosystems. Primarily it focuses on the interdependencies between achieving water, energy and food security for human well-being, i.e., basic services and economic development, while ensuring ecologically sustainable use of globally essential resources (Carmona-Moreno, et al., 2018). The WEFE nexus attempts or aims to integrate resources management and governance across the multiple sectors of food, energy, water, and ecosystems. In practical terms, the WEFE nexus helps to improve understanding and systematic analysis of the interactions between the natural environment and human activities in these three sectors. This will develop more coordinated and sustainable management of natural resources across sectors, levels, and scales. The key principles or pillars of the WEFE nexus can be itemized as follows (Carmona-Moreno, et al., 2018):

- *Understand the interdependence of resources within a system across space and time* – Such an understanding will provide integrated solutions that contribute to the sustainability of water, energy, food security policy objectives and to maintaining healthy ecosystems.
- *Recognize the interdependence between water, energy, food and ecosystems* – Such recognition then promotes rational and inclusive dialogue and decision-making processes and efficient use of these resources in an environmentally responsible way.
- *Identify integrated policy solutions to optimise trade-offs and maximise synergies across sectors* – Integrated policy solutions encourage mutually beneficial responses that enhance the potential for cooperation between all components, and public–private partnership at multiple scales.
- *Ensure coordination across sectors and stakeholders* – Such coordination enables synergies and increase solution sustainability.
- *Value the natural capital of land, water, energy sources and ecosystems* – The valuing of natural resources encourages governments and business to support the transition to sustainability, e.g., using nature-based solutions.

The basis of the WEFE nexus is that the world's natural resources are increasingly coming under pressure and their exploitation is becoming unsustainable, thus negatively impacting ecosystems which then fail to provide the intended ecosystems goods and services (EGS). The drivers for this unsustainable exploitation, as previously mentioned include (Carmona-Moreno, et al., 2018);

population increases, economic development, rapid urbanisation, and the dreaded climate change and climate variability. The major benefits of utilising the WEFE nexus approach are (Carmona-Moreno, et al., 2018); (i) exploitation of co-benefits to improve overall system performance, (ii) streamlining development and improving resilience, and (iii) stimulating policy coherence and multipurpose investments. Lastly, managing the application of the WEFE nexus as a tool for natural resources management should be a consultative process involving all the main stakeholders. That WEFE nexus process involves the key steps that mainly encompass; (i) nexus assessment, (ii) provision of evidence, (iii) scenario development, and (iv) generating response options.

On the other hand, the WEFH nexus is an extension of the basic WEF nexus but with a focus on health. Coincidentally, the Covid-19 pandemic of 2020 has cast a huge focus on the WEF nexus and health since there is a close linkage between water and health aspects. Health aspects take on multiple dimensions and feature significantly in the SDGs, especially under SDG 2 (zero hunger) and the link to water through agricultural production and food security, as well as SDG 6 (water and sanitation) – all these embody health in one way or the other (Mabhaudhi, et al., 2019; Nhamo, et al., 2020). The increasing significance of water for agriculture and energy for food and nutrition as well as for health (both in terms of benefits and risks) is recognized now as never before (Schaefer-Preuss, 2015). Yet links between and among the water, agriculture, energy, food/nutrition, and health communities are weak, with serious implications for the effectiveness of efforts to improve health and nutrition. Furthermore, according to (Schaefer-Preuss, 2015) ready access to safe drinking water and sanitation, as well as more nutritious and diversified diets, can accelerate progress in reducing water-borne diseases, malnutrition and diet-related chronic diseases and infections. Improved nutrition and by that health, in turn, can reduce poverty for the 1.4 billion people living on less than US$1.25 a day. A greater focus on the role of women in agriculture – as potential mediators of household and individual food, and nutrition security and health – as well as on the allocation of food within households – could accelerate improvements in the nutrition and health of vulnerable household members, including women, infants and young children. Insufficient water supply, healthy diets, and poor water quality, a lack of energy or inconsistent energy, as well as unreliable or unsafe food supplies have innumerable implications for health – particularly when these factors are combined. Human health outcomes, and the UN SDGs, like ending poverty, improving education and creating drinkable and high-quality water, depend on all three elements – water, energy, and food – working together to maximize the quality of life (William, 2020). Hence the significance of the WEFH nexus in the generalized WEF nexus debates.

With the above summary and for the purposes of this report, the focus will be on the WEF and WEFE nexus as they are much more applicable to the context of the Zambezi River Basin. The pressure on natural resources (water, land and energy) and the need for harmonious development while sharing transboundary resources in the Zambezi River Basin demand holistic approaches to the management of such resources. The WEF nexus is best placed as a tool for such resources' sustainable management.

4.2 WEF Nexus as a Tool for Sustainable Resource Management

Since the start of the last decade (2010 onwards), different groups of researchers, academics and policy people have investigated the WEF nexus, each group approaching the analyses from particular points of interest, be it political, social, or scientific perspectives. Unlike Integrated Water Resource Management (IWRM), which is water-centric in nature, the goal of the WEF nexus is to approach resource management more holistically by utilising a multi- or poly-centric philosophy. Each resource sector within this nexus has an equal weighting. The WEF nexus presents an opportunity for policymakers, researchers and development agencies to integrate the sectors in order to optimise the use of the resource base, maximise synergies and minimise trade-offs and conflicts.

In recent years, a substantial amount of research effort has been directed toward exploring the WEF nexus approach from different perspectives and these included; calculation of resource flows and their interdependencies, technology assessment and policy applications, and quantifying system performance (Zhang et al., 2018). A sizeable amount of literature discusses the WEF nexus in terms of the concept, simulation tools, governance, and implementation (Zhang et al., 2018). The WEF nexus has been applied in various contexts worldwide, and this makes it applicable for addressing the water, energy and food insecurities issues in the Zambezi River Basin. Food and Agricultural Organisation of the United Nations (FAO, 2014) applied the WEF nexus as; a conceptual framework for natural resources governance, a tool for decision support systems (DSS), a perspective to resource management, an analytical approach for solution-seeking in natural resource management, a conceptual framework for political analysis, and as a web-based tool for management decisions.

The success in applying and managing the WEF nexus depends on several factors as briefly outlined here. Firstly, and importantly, the challenge is on all practitioners to adopt 'inclusive and sustainable' approaches in managing water, energy and food production – inclusive meaning involving private and public sectors, and sustainable referring to not violating environmental requirements. Next, the nexus must be applied in an integrated approach (proper and integrative), i.e., considering all essential factors or issues, highlighting the significance of certain solutions (e.g., payment for ecosystem goods and services), downplay the appropriateness of others (e.g., biofuel production from food crops). Third, it is imperative to define and quantify the interconnectedness between water, energy and food for use in policy and planning. Fourth, there is a need for easy to use WEF nexus tools, with requisite data, for all to use for policy and planning, i.e., comprehensive, inclusive and multi-scale nexus tools (e.g., WEF Nexus Tool 2.0) (Daher and Mohtar, 2015). Lastly, there is a need for data that is good in quantity and quality and also in space and time.

The WEF nexus, as research and the operational tool, offers several advantages compared to other approaches. These advantages include;

- (i) achieving goals in a sector through targeted interventions in another sector,
- (ii) filling in knowledge gaps, promoting new technologies and generating cross-sectoral data,
- (iii) enabling policymakers to think of trade-offs, synergies and impacts of their decisions,
- (iv) promoting coordination of activities and hence integrated resources management,
- (v) promoting involvement of all key stakeholders,
- (vi) promoting sharing of experiences and learning from best practices, and more importantly, and
- (vii) promoting optimal, efficient and productive utilization of natural resources.

Admittedly, the WEF nexus has limitations or disadvantages, and these include; requisite data to operationalise the WEF nexus may not be available (in quantity and quality), it is not always possible to identify interactions on a quantifiable basis, and the success of the WEF nexus depends, to a large extent, on the will of decision-makers and operators to make the critical decisions and undertakings.

4.3 WEFE Nexus for the Zambezi River Basin

With the above background, an exploratory WEFE nexus analysis for the ZRB was attempted. The main reason for the WEFE nexus analysis are two-fold; first it allows for the inclusion of ecosystems goods and services (EGS) to the original WEF nexus. EGS are very important in the ZRB as water and other natural resources serve many purposes for the benefit of all life in the basin (more is discussed about this in the sections to follow). Secondly, the WEFE nexus, as discussed above, allows for the analysis of the water, energy, and food sectors, and their reliance on the ecosystems and the consequent impact on the same ecosystems.

4.3.1 WEFE nexus sustainability Indicators and pillars

Of significance is the need to first define the (sustainability) indicators and pillars that sustain the indicators. For each sector (water, energy, food, ecosystem) there are a set of indicators and pillars that are applicable, although these are not necessarily prescriptive and could be changed depending on location and circumstances. As is the case with the WEFE nexus application it has both spatial and temporal scales, and this becomes an important consideration in a place like the ZRB which is made up of a number of different countries with varied constraints and priorities.

Whilst the indicators and pillars for water, energy and food securities have widely been defined, the ones for ecosystems are not necessarily well defined or developed, despite them being also important in the WEFE nexus analysis. If and when these are defined, they still need to be measured against acceptable sustainability classification categories so that practical interpretation can be made. Given the goods and services provided by ecosystems, the indicators can be based on service and the welfare of people (e.g., in the ZRB), or provision to a stable natural environment (e.g., in the ZRB) or sustainability of the water systems in the basin (e.g., river flows) or indeed a combination of the above. Since by definition ecosystem good and services tend to refer to the welfare of people, the indicators for this discussion will be based on the availability and accessibility of goods to people in the basin.

Notwithstanding these differences, a set of standard WEFE nexus indicators and pillars are presented in Table 12.

Table 13: Sustainability indicators and pillars for the WEF nexus (from Mabhaudhi et al., 2020)

Sector	WEF Nexus Indicator	Units	Pillars
Water	Proportion of available freshwater resources per capita (availability)	m^3/capita	Affordability Sustainability Safety
	Proportion of crops produced per unit of water used (productivity)	\$/m^3	
Energy	Proportion of the population with access to electricity (accessibility)	%	Reliability Sufficiency Energy type
	Energy intensity measured in terms of primary energy and GDP (productivity)	MJ/GDP	

Sector	WEF Nexus Indicator	Units	Pillars
Food	Prevalence of moderate or severe food insecurity in the population (self-sufficiency)	%	Accessibility Availability Affordability Stability
	Proportion of sustainable agricultural production per unit area (cereal productivity)	Kg/ha	
Ecosystems	Proportion of ecosystems goods and service value per capita (value)	$/capita	Accessibility Sustainability Availability
	Water provisioning per capita (availability)	m^3/capita	
	Environmental flow requirements (sustainability)	%/MAR	

The WEFE nexus performance indicators are then categorised in terms of sustainability, ranging from a lowly 'unsustainable' to 'highly sustainable' as indicated in Table 13.

Table 14: WEFE nexus classification categories of performance indicators

Indicator	Unsustainable	Marginally sustainable	Moderately sustainable	Highly sustainable
Water availability (m^3/per capita)	< 1 700	1 700 – 6 000	6 001 -15 000	> 15 000
Water productivity (US$/$m^3$)	< 10	10 - 20	21 - 100	> 100
Food self-sufficiency (% of pop)	> 30	15 - 29	5 - 14	< 5
Cereal productivity (kg/ha)	< 500	501 – 2 000	2 001 – 4 000	> 4 000
Energy accessibility (% of pop)	< 20	21 - 50	51 - 89	90 - 100
Energy productivity (MJ/GDP)	> 9	6 - 9	3 - 5	< 3
Ecosystem goods and service ($/cap)	No clear standards			
Ecosystem goods and service water provisioning (m^3/capita)				
Environmental flows (% of MAR)				10 – 15%

4.3.2 WEFE Natural Resource Potential (natural endowment)

The following sections briefly discuss the resource endowments in general terms in the Zambezi River Basin. These have been presented in detail in other reports of this whole study. Fundamental to this discussion is that water is the key to the interconnectedness in addressing energy and food security with sustainable development that takes into account ecosystems.

4.3.2.1 Water resource potential (both surface and groundwater)

The Zambezi River measures approximately 2700 km from its source in Zambia to the outlet in Mozambique into the Indian Ocean, and being shared by 8 riparian states – Angola, Botswana, Namibia, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. The ZRB is divided into 13 sub-basins based on surface water distribution. Regarding groundwater, 10 transboundary aquifers are currently identified in and across the basin. The river's mean annual discharge (long-term) at the outlet is 4134 m^3/s (World Bank, 2010). The ZRB total basin area is an estimated 1.3 million km^2 with some 40 million people (about a third of the total population of the 8 riparian states). The average annual surface runoff is 103 km^3 and mean annual groundwater recharge of 130 km^3 for a combined total of 233 km^3 (Cai, et al., 2017).

4.3.2.2 Energy resource potential (hydropower energy)

The ZRB is key in the southern Africa region in terms of energy generation, and indeed historically, hydropower generation turned out to be the largest economic use of water in the basin (Euroconsult Mott MacDonald, 2007). With an average annual power generation estimated at 30 TWh, this is valued at US$1800 million/year (assuming a US$60/MWh value of electricity) (Euroconsult Mott MacDonald, 2007). The ZRB has great power generation potential estimated at close to 18000 MW with only about 5000 MW currently developed (Tilmant, 2017), but plans afoot to develop a further 2700 MW generation capacity.

4.3.2.3 Land resources (irrigable land area)

The issue of land and irrigation in the ZRB has been discussed at many fora and irrigation is considered one of the highest consumers of water in the basin. Overall, some 5.2 million ha are under cultivation in the basin, predominantly in Malawi, Zambia and Zimbabwe. 72% of the ZRB population is involved in agriculture as a form of livelihood strategy. Currently 259039 ha are under irrigation in the basin (from the 183000 ha equipped for irrigation because of double cropping) and this is planned to rise to 514641 ha in 2025 – 5 years from now (Manzungu et al., 2017)! The total irrigation potential in the basin is estimated at more than 3 million ha (World Bank, 2010). Irrigation currently is estimated to consume 3235 million m^3, making up 1.4% of the ZRB renewable water resources. This is envisaged to grow to 9661 million m^3 by 2025 making up 4.1% of the basin's renewable water resources.

4.3.2.4 Ecosystems (size of wetlands, forests, etc.)

An ecosystem is a complex and dynamic combination of plants, animals, micro-organisms and the natural environment, existing together as a unit, and depending on one another (European Commission, 2009). Strictly speaking, ecosystems underpin all human life and activities. The earth's ecosystems provide humanity with a wide range of benefits known as 'ecosystem (or ecological) goods and services'. Ecosystem goods and services (EGS) are the economic benefits (goods and services) arising from the ecological functions of ecosystems. These goods and services provided by ecosystems are important to sustaining well-being, and to future economic and social development. Four different kinds of ecosystem goods and services have been identified and these are all vital to human health and well-being (European Commission, 2009):

- *Provisioning services* supply the goods themselves, such as food, water, timber and fibre.
- *Regulating services* govern climate and rainfall, water (e.g. flooding), waste, and the spread of disease.
- *Cultural services* cover the beauty, inspiration and recreation that contribute to people's spiritual welfare.
- *Supporting services* include soil formation, photosynthesis and nutrient cycling, which underpin growth and production

Water resources are a crucial environmental good for the function of the human societies and the ecosystems. Moreover, water is an important input for the economy and an indispensable factor for economic growth.

Until recently the value of EGS went largely unrecognised in economic and financial decision-making (McCartney and Nyambe, 2017) and typically considered in analyses as "free public goods". Similarly, EGS were not explicitly addressed in the WEF nexus (Hulsmann, et al., 2019), hence the need for WEFE nexus analysis.

The ZRB social and economic value of EGS is considered massive. In terms of ecosystems, the ZRB comprises of miombo woodlands, grasslands, savannah, agricultural lands and wetlands (McCartney and Nyambe, 2017). The miombo woodlands cover some 45% of the basin at an area of 607523 km^2. A major feature of the basin are wetlands comprising marshes, swamps and seasonally inundated floodplains covering about 4.7% of the basin for an area of 63266 km^2 (McCartney and Nyambe, 2017). This area does not include dambos, smaller wetlands occurring under a wide range of ecological conditions. Riparian read swamps are also found on the upper course of many of the tributary rivers. About 50% of the basin population is concentrated within and around wetlands.

The ZRB woodlands, wetlands and grasslands provide a wide range of EGS to people both within and outside the basin. The provisioning services include (McCartney and Nyambe, 2017);

(i) Water provisioning for the urban and rural population through surface and ground water (199 Mm^3), industrial and mining (145 Mm^3), irrigated agriculture (1478 Mm^3), livestock watering (113 Mm^3) and reservoir evaporation (16989 Mm^3) for a total of 18924 Mm^3.
(ii) Recession agriculture covering about 113000 ha.
(iii) Livestock grazing supporting about 41 million head of cattle in the basin whose value accrue to the ZRB through sales, meat, milk and draft animal power with an estimated financial gross value of US$11.93 million in 2010.
(iv) Fisheries, comprising both subsistence, commercial and angling tourism totalling some 71400 – 77450 metric tons per annum valued at US$49.7 million in 2015.
(v) Other provisioning services provide for basic needs such as food, shelter and health. Important products include; poles and construction materials for rural dwellings, wild foods (fruits, honey, tubers, etc), fuel wood, indigenous medicines and health supplements, just to mention a few.

The regulating services include (McCartney and Nyambe, 2017);

(i) Flow regulation through flood plains (decrease flood flows and increase low flows), headwater wetlands (increase flood flows and decrease low flows) and miombo forests (decrease flood flows and decrease low flows).
(ii) Water purification as it flows through wetlands.
(iii) Carbon sequestration (both above and below the ground) functions of grasslands, forests and wetlands.

The cultural services of the ecosystems in the ZRB include (McCartney and Nyambe, 2017);

(i) Social systems and practices of communities that are dependent on the seasons and the wetland flows and forests. The most famous being the 'Kuomboka' practice in the Barotse floodplains of Zambia.
(ii) Tourism is big business in the region and was estimated at US$457 million in 2007.

It is quite apparent that EGS in the ZRB are quite extensive providing a wide range of services. The main problem one encounters during a WEFE analysis is to put a truly reflective value to the EGS of the basin, and how to properly express it so that it brings about the true meaning and value. Despite such challenges, efforts have been made towards estimating the value of the EGS in the ZRB. Drawing on the work reported by McCartney and Nyambe (2017) the total value of the EGS in the ZRB are estimated conservatively at US$1341 million/year to US$1542 million/year for an average of US$1442 million per year.

4.3.3 WEFE Indicators for the Zambezi River Basin

The WEFE nexus indicators for the Zambezi River Basin are presented in Table 14 for the 2018 base year, based on latest available data.

Table 15: WEFE nexus indicators for the Zambezi River Basin

WEFE nexus	WEFE Nexus Indicator	Status	Notes
Water	Proportion of available freshwater resources per capita (availability)	503.25 m^3/capita	(1)
	Proportion of crops produced per unit of water used – irrigated (productivity)	US$2.01/$m^3$	(2)
Energy	Proportion of the population with access to electricity (accessibility)	Very low	(3)
	Energy intensity measured in terms of primary energy and GDP (productivity)	0.23×10^{-6} MW/GDP 0.46×10^{-6} MW/GDP	(4)
Food	Prevalence of moderate or severe food insecurity in the population (self-sufficiency)	No data at ZRB level	(5)
	Proportion of sustainable agricultural production per unit area (cereal productivity)	1.16 tons/ha (maize) 1.13 tons/ ha (paddy rice)	(6)
Ecosystem	Proportion of ecosystems goods and service value per capita (value)	US$36.05/capita	(7)
	Water provisioning in ecosystems goods and service per capita	473100 m^3/capita 25 m^3/capita (excluding evaporation)	(8)
	Environmental flow requirements (sustainability)	1.16% MAR	(9)

NOTES: (1) From ZRB book Chapter 2 & EuroConsult Mott MacDonald (2007 - Table 2.4); (2) From ZRB book Chapters 1 & 6 in "ZRB – Water and Sustainable Development". In other reports the Agricultural GDP in the ZRB is given as US$14 billion (World Bank, 2010 – Table 3.57); (3) No data; (4) From ZRB book Chapter 5 & Table 5.1 Tilmant (2017); (5) Mixed data and none at ZRB level; (6) From World Bank (2010 – Table 3.69) derived from FAO (2008b); (7) From ZRB book Chapter 7 and McCartney and Nyambe (2017); (8) From ZAMCOM et al (2025) Table 7.4; (9) From ZRB book Chapter 2 & EuroConsult Mott MacDonald (2007) Table 2.4.

4.3.4 Exploratory WEFE nexus analysis and interpretation for the Zambezi River Basin

The WEFE nexus analysis for the ZRB proved challenging to undertake because of data issues – both spatially and temporally, as well as conflicting data from different sources. However, it seemed most of the data from the various sources was premised and anchored to the EuroConsult Mott MacDonald (2007) reference. Secondly, for the WEFE nexus analysis to be fully utilizable, it probably needed to be undertaken at a sub-basin level or based on countries, since planning priorities and horizons differ by each riparian country. Be that as it may, the following paragraphs discuss briefly the outcomes of the WEFE nexus analysis for the ZRB.

In terms of water resources, on average the available resources per capita in the basin are on the lower side at (503.25 m^3/capita) and considered unsustainable since they fall below 1700 m^3/capita. This is not surprising given that some portions of the basin, for example on the Zimbabwe side, are relatively dry and yet other portions of the basin, for example Malawi, have high population densities. Notwithstanding this, it is acknowledged that some parts of the basin suffer from excessive water leading to floods, for example the lowlands of Mozambique. The irrigated crop water productivity, similarly is on the lower side falling below US$10/m3 and thus considered unsustainable. This is not surprising given the low levels of production by the smallholder irrigation projects in the basin typified by production for own consumption and some sale. It should however be noted that the basin also has high production agricultural activities such as the sugar cane plantations in Malawi and Mozambique, but these are purely commercial and do not involve a large proportion of the population in the basin. In summary both water availability and water productivity is unsustainable at the basin scale.

With respect to energy, although data on energy generation was plentiful, quantitative information on the extent of access to electricity by the basin population was difficult to come by. Access to electricity was generally referred to a being low for the bulk of the basin population. This is not surprising given that even at country level, access to electricity by the rural population is low. Energy intensity, based on the measure used, was highly sustainable when referenced to the basin's GPD (or even to the basin population). This is simply because the energy generated in the basin is consumed by the whole of the southern African population, and is not restricted to the ZRB only. The ZRB is considered one of the energy generation hubs of the region. The irony is found in that access to electricity by the ZRB population is low, yet energy production is high in the basin. This also flags the weakness of the WEFE nexus measure of energy intensity.

Prevalence of food insecurity at the basin level was not easy to determine as data seemed to be conflicting and also was missing for the basin per se but available at the country level. It is not in doubt that many of the rural populations in the ZRB do suffer from seasonal food security brought about by both droughts and floods, which occur regularly in the basin. Cereal productivity is considered marginally sustainable at 1.12 tons/ha for maize and 1.13 tons/ha for rice – the two cereals that constitute the base of food for the rural population. Again, these levels of productivity are not surprising given the dominance of small scale agricultural production based on small areas and low input of agro-chemicals and the lack of access to credit facilities for intensified production. By extension, such low levels of production coupled with high population increases in the region inevitable lead to food insecurity problems in the basin.

EGS assessment was interesting but difficult to assess because there are no clear standards to compare to. In terms of the economic value of EGS, these worked out at US$36.05 per capita, which when converted to a base of a day (so as to compare this to the concept of $/capita/day), comes out low. Although this measure is considered low, it is acknowledged that a large proportion of the basin population derives its livelihood from these EGS. In terms of water provisioning as an EGS, this seems healthy at 473100 m^3/capita but drops to 25 m^3/capita when evaporation is excluded, translating to about 70 l/capita/day. In terms of environmental flows, data from the ZRB is conflicting. Data base of river flows seem to indicate environmental flows of 15 to 20 % of the MAR, but when this is based on EGS, the environmental flows work out at 1.14% of the MAR. Considering the lower figure, sustainability of environmental flows is poor, but reality on the ground is something else.

In summary, the WEFE nexus yields some interesting results, but on the balance of issues, all indicators are marginally sustainable. This information can be used to plan for the future in a sustainable manner.

4.3.5 Application in future planning in the Zambezi River Basin

The main purpose of undertaking a WEFE nexus analysis is to try and establish the existing situation in place and assess if development to date is balanced in terms of the resource securities of water, energy, food and impact on the ecosystem. Once this is established, future development can then be planned and undertaken in a manner that optimises benefits and trade-offs and minimises conflicts and unsustainability.

A look at future planned development in irrigation and hydropower through the lens of the WEFE nexus reveals some interesting features. It is anticipated that area under irrigation will double by 2025 to 515000 ha consuming 9661 million m^3 of water, an increase of almost 3% in water abstraction. Such an increase will need to be accompanied by tangible benefits to justify such levels of abstraction. This means cereals agricultural water productivity will need to increase from the current average of just above 1.0 ton/ha (marginally sustainable) to more than 4 tons/ha so that it's considered highly sustainable, and worth the water that is consumed.

With respect to hydropower development, there are many projects underway in the ZRB to increase power generation so that it approaches the potential of some 13000 MW (indeed some sources put this potential at 20000 MW). From the WEFE nexus analysis it has already been shown that this is highly sustainable since the generated power will service areas beyond the basin, mainly through promoting national economic development of the riparian countries. However, this development should not be at the expense of water required for agriculture, and hence food production, or water requirements for environmental flows and other EGS in the basin and beyond.

Ecosystems goods and services take centre stage in the WEFE nexus, firstly because they provide the resource base (water, land, etc) upon which any development in the basin will be based, and secondly because the developmental activities will in turn likely negatively impact the environment. Hence ecosystems sustainability is important and must kept in balance. Meaning that the WEFE nexus is imperative at the appropriate spatial and temporal scale in the Zambezi River Basin.

5 TRAINING MATERIALS ON AGRICULTURAL WATER MANAGEMENT

5.1 Background

The success of interventions, especially agricultural ones, depend to a large extent on training of the various stakeholders involved in terms of improving their knowledge, attitude and skills (KAS). Agricultural water management interventions, by their very nature involve a number of stakeholders depending on the type of intervention. If one were to look at the technological spectrum, for example, from large scale irrigated commercial agriculture to smallholder irrigation interventions such as dambo irrigated farming and drip kits, the training requirements likewise will be varied since the stakeholders are very different. This chapter provides a brief overview of the training requirements to go with a number of the agricultural water management interventions discussed in this report.

It is worth noting three aspects of the proposed training here. First, one of the proposed training has nothing to do with agricultural water management, it is on the water-energy-food-ecosystems (WEFE) nexus. Training in WEFE nexus is proposed here because the WEF nexus has come across as an important tool for sustainable natural resources management, especially in transboundary situations such as the Zambezi River Basin. The WEFE nexus as a tool enables policy makers and development implementers to manage the deployment of natural resources (water, energy, land) in a manner that ensures synergy, balanced trade-offs and long term resources security. Consequently it is important that stakeholders in the Zambezi River Basin be trained in the WEFE nexus and its application.

The second point to note is that no training is proposed for large scale commercial farming interventions. The logic behind it is that most large scale commercial farming operations have the capacity and resources to engage consultants to provide services as and when required, and this includes training in all aspects of agricultural production.

The third aspect is that none of the proposed training, except for the one on the WEFE nexus, is targeted at researchers, academics and individuals in senior positions in agriculture. It has long been established that a lot of the practical training that is provided to academics and senior positioned individuals is rarely applied because opportunities to apply it do not arise that often in their daily work or job responsibilities. So in the proposed short course the focus is on farmers, irrigators and agricultural extension workers/officers who are at the "coal face" of farming.

The following section provide briefs on the proposed training for the various stakeholders in the Zambezi River Basin. The actual training materials details are left to the training experts to develop since they have to engage the material directly before delivery to the target stakeholders.

With advent of the Covid-19 pandemic of 2020, traditional training methods of face-to-face contact between trainers and trainees has receded into the background. Most of the training has now moved to non-contact online training. Although this might present some challenges to extension services and farmers who normally reside in areas with limited connectivity and low or poor hardware resources endowment, it worth exploring for some of the short courses proposed here.

5.2 Proposed Short Courses for the Zambezi River Basin Stakeholders

5.2.1 Water-Energy-Food-Ecosystems Nexus as a Natural Resources Management Tool – Local Scale Applications

The WEFE nexus has come into its own in recent times as a tool for natural resources management. The main objective of this short course is to equip trainees with the requisite understanding and skills to apply the WEFE nexus approach for natural resources management to ensure resource securities for the target population. The target trainees are researchers, technical officers, project implementers and policy people.

The learning outcomes of the short course are that the trainees will be able to define the WEF nexus and its relevant variants, understand the scope of application of the WEFE nexus from technical to policy aspects, define the spatial scale of applying the WEFE nexus, define the temporal scale of application of the WEFE nexus, define and identify the data requirements for use in the WEF nexus, identify and select the appropriate WEFE nexus models/software and applicable techniques, and apply the WEFE nexus to specific local scales.

Details of this short course are provided in Appendix 5A.

5.2.2 Smallholder Irrigation Water Management and Crop Production

Smallholder irrigation is the lifeline of the bulk of the peasant population in the Zambezi River Basin. Unfortunately (formal) smallholder irrigation tends to be characterized by problems of irrigation water management which consequently impacts negatively on crop production and hence failure to satisfy the objective of food security or cash crop generation. It must be emphasised that irrigation water management training must be tied to crop production. The main objective of this short course is to capacitate trainees in the practical aspects of managing irrigation water and other inputs in smallholder irrigation for enhanced crop performance for both food and cash crops. The target training groups are the agricultural (irrigation) extension staff and irrigation scheme office bearers (in a training of trainers perspective).

The short course learning outcomes will include; characterize smallholder irrigation in terms of system structure, existing management systems and operational issues; define the boundaries of smallholder irrigation system from water source to drainage lines; follow the flow and identify the control points of water in the irrigation scheme; comprehend smallholder irrigation cropping programmes, crop rotations, agronomic and cultural practices; determine an irrigation schedule and match this to water supply in the irrigation scheme; implement irrigation scheduling in smallholder irrigation; identify and describe the management and operation structures of the irrigation scheme in terms of position and responsibilities and know the irrigation scheme operational by-laws in terms of purpose and enforcement.

The details of the short course are given in Appendix 5B.

5.2.3 Dambo Irrigation Farming with Ecosystems Goods and Services in Mind

Dambo irrigation farming has been practices in the Zambezi River Basin riparian countries for a very long time, especially in Zambia and Malawi. Dambo irrigation farming is a practice that evolved organically without too much external input and therefore needs careful management to maintain the delicate balance for sustainability, and more often than not the farmers know more about it that specialists from outside, e.g., extension staff. The focus of late has been on ensuring sustained ecosystems goods and services provision in harmony with national legislation on wetlands.

The main objective of this short course is to capacitate trainees in sustainable crop production under dambo farming with the ecosystems goods and services perspective in mind. The target trainees include both agricultural extension staff and dambo farmers.

The short course learning outcomes include; trainees being able to define and identify dambo irrigation farming in a practical sense; describe the ecosystem goods and serves (EGS) obtainable from dambo irrigation farming; describe the environmental concerns pertaining to dambo irrigation farming; describe and document agricultural practices under dambo irrigation farming in terms of land preparation, crops and cropping patterns, and agronomic practices; and undertake agricultural water management under dambo irrigation farming.

The details of the short course are given in Appendix 5C.

5.2.4 Drip Kit Irrigation Operation and Management for Local Food Security

Drip kit irrigation, incorporating bucket irrigation using shallow water sources were introduced in sub-Sahara Africa and Asia as technologies for improved food security at the local scale. They have had mixed results in the region, just like any technology. The main objective of this short course is to equip the trainees with the skills and knowledge to manage and operate drip kits for crop production for local rural food security. The target trainees are both the agricultural extension staff and the farmers with drip kits.

The expectation is that at the end of the short course the trainees will be able to; identify and describe the components of a drip kit, setting up the kit and how the unit operates; describe the water quality and water filtration needs of drip kit irrigation; relate drip discharge to operating head; link dripper/emitter emission to soil wetting depending on soil type and ability to satisfy crop water requirements; and undertake crop production under drip kit irrigation within the context of local conditions.

The details of the short course are given in Appendix 5D.

5.2.5 Soil and Water Conservation and Conservation Agriculture under Rainfed Agriculture

Rainfed agriculture remains the mainstay of rural agriculture in the Zambezi River Basin. It is an acknowledge fact that formal irrigation would never be enough to go around, so it is imperative that rainfed agricultural practices that make optimal use of rain water be promoted. A whole range of soil and water conservation practices as well as conservation agriculture exist in the basin, and similarly previous efforts are acknowledged in training farmers on these aspects in the region.

The main aim of the short course is to capacitate trainees to understand and apply soil and water conservation practices including conservation agriculture in rainfed crop production. The target trainees are agricultural extension staff and smallholder farmers practicing rainfed crop production.

The short course learning outcomes are that at the end of the short course the trainees will be able to; define and describe soil and water conservation (SWC) practices applicable in rainfed agriculture for specific situations; define and describe conservation agriculture (CA) practices in the context of rainfed agricultural production in the region; and practically set out, implement and manage selected SWC and CA practices.

The details of the short course are given in Appendix 5E.

6 SUMMARY AND CONCLUSION

6.1 Summary

The transboundary Zambezi River Basin (ZRB), the fourth largest in Africa poses many challenges from the perspective of Water-Energy-Food-Ecosystem (WEFE) nexus, including, among others, hydropower, reservoir multipurpose optimization and release management, rain-fed and irrigated agriculture development, impact of land use and agricultural practices (including livestock and fisheries), role of ecosystem services (natural parks, wetlands), pressures on resources due to population increase and climate variability/change and extreme events risks (drought and flooding).

This report dealt with the water and agriculture aspects in the Zambezi River Basin focusing on irrigated and rainfed agriculture through appropriate agricultural water management practices. The objectives of the study were to understand baseline conditions on agriculture (including livestock and fisheries) by gathering and processing data and by-products (land use and coverage, local practices, seasonal patterns) at ZRB scale; and perform agriculture assessment (crops water demand, productivity and potential impact of irrigation expansion) and scenarios-based management practices. The above was accomplished through literature meta-analysis on all issues and aspects relating to water and agriculture in the Zambezi River Basin. Due to the fact that crop production consumes most of the water in the basin, the focus was on crop production and less so on fisheries and livestock as their water consumption is a fraction of crops. The main conclusions of the study are presented in the following sections.

6.2 Water and Agriculture in the Zambezi River Basin

Agriculture is the largest water consumer in the Zambezi River Basin. Irrigation is the key driver of the agricultural based economies of the basin countries with agricultural activities being dominant in Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. There exists a correlation between the area cultivated and irrigation abstractions in the river basin. Malawi, as an example, has the largest land cultivation capacity and consequently has the largest water abstractions from the Zambezi River Basin.

Over and above cropping agriculture, fisheries and livestock activities are also practiced in the Zambezi River Basin. With respect to fisheries, catch yields within the upper Zambezi are approximately 7 500 tonnes per annum and this approximately half of the potential annual yield (14 000 tonnes per annum). Zambia explores less than 50% of the fishing potential in the River and floodplains of the Middle Basin. Fish catch yields in Lake Kariba are estimated at 10 000 tonnes per year, being 25% of the potential catch yields. It is apparent that there is a substantial untapped fisheries potential in the Zambezi River Basin.

With regard to livestock farming in the Zambezi River basin, this goes back in history. With respect to consumptive water use, livestock production only consumes about 120 million m^3 per annum (representing less than 1% of total consumptive use). 90% of the livestock in the basin is in Zambia, Zimbabwe and Malawi. Cattle population within the basin is approximately 42 million heads having risen from 35 million in 2005. Notwithstanding the above, the level of livestock production within the basin is considered to be low, with productivity still below the potential levels.

6.3 Irrigation Development in the Zambezi River Basin

The Zambezi River Basin possesses immense potential for irrigation development provided a balance is established between water for agriculture and water for other needs such as energy generation and ecosystem goods and services. Currently irrigation potential in the basin stand at 3.16 million ha consuming 37.3 km^3 per annum against an actual area under irrigation measuring just under 150 000 ha. By 2025 it is projected that area under irrigation development in the Zambezi river basin will grow by more than 300%, subject to resource mobilisation. Natural such growth in irrigation will need to be carefully balanced in terms the competing needs for water in the basin.

Currently the range of irrigation practices in the basin range from large scale commercial irrigation development run by multinational corporations irrigating commercial crops such as sugar cane down to smallholder irrigation commanding less than a hectare in area and growing crops for own consumptions and a limited amount for sale run by peasant rural farmers. In terms of uplifting rural livelihoods and enhancing food security, attention needs to be paid toward the smallholder irrigated sector as it supports the bulk of the rural population in the basin.

6.4 Agricultural Water Management in the Zambezi River Basin

Agricultural water management are practices that include the development, distribution and use of direct rainfall, surface water and underground sources. These practices improve the human development index through increased production, enhanced employment which facilitates a stable income, and boosting nutritional status. Agricultural water management interventions are key to sustainable agricultural intensification, which in itself is pathway to increased production and improved rural livelihoods.

A range of agricultural water management interventions have been identified for the ZRB and these include; smallholder irrigation with river diversion, smallholder irrigation with pressurised system, dambo irrigation farming; drip kits (including bucket and drum), small reservoirs and soil & water conservation including conservation agriculture. A cross comparison of the different agricultural water management practices in terms of; ideal conditions in which the intervention is suited, estimated cost of the intervention (per relevant unit), and examples of evidence of sustainability or success or longevity (location) reveals a mixed bag of results, but most are promising at smallholder scale. Similarly a comparison of the various intervention in terms of technology or intervention characteristics such as complexity, divisibility, compatibility, acceptability and observability indicated that local evolved practices like dambo irrigation farming and smallholder irrigation score relatively high.

6.5 WEFE Nexus Analysis for the Zambezi River Basin

The WEFE nexus has emerged as an increasingly prominent global policy, governance and research agenda. Conceptually, the WEFE nexus means that water security, energy security and food security are inextricably linked and, more importantly, actions in any one sector will impact in one or both of the others. The WEFE nexus approach seeks to maximize potential synergies and identify and minimise areas of potential conflicts in natural resources management for sustainable development. The WEFE nexus presents an opportunity for policymakers, researchers and development agencies to integrate the sectors in order to optimise the use of the resource base, maximise synergies and minimise trade-offs and conflicts. Since the Zambezi River Basin is transboundary and there is competition for natural resources by sector (water, energy, agriculture) and by country (ZRB riparian countries), the WEFE nexus presents itself as a viable tool for resources management.

An exploratory WEFE nexus analysis of the ZRB was conducted based on the indicators; water availability per capita, water productivity, food self-sufficiency, cereal productivity, energy accessibility, energy productivity, and ecosystems goods and services. All of these were found to be either marginally sustainable or unsustainable, with the exception of energy generation. Hydropower generation was found to be highly sustainable although it did not benefit the bulk of the basin population, but benefits the riparian countries' economies.

6.6 Training in Agricultural Water Management in the Zambezi River Basin

Generally, the success of any intervention will depend to a certain extent on the training of the relevant stakeholders so as to capacitate them in terms of knowledge, attitude and skills. Agricultural activities are no exception to this requirement. Before any training can be undertaken, typically a needs assessments has to be undertaken to determine the stake holders who require training, the type of training required and the best way to offer that training. For agricultural water management interventions, returns to training investment are best if this training is focused on those working directly with farmers and the farmers themselves.

The following training has been identified and proposed for agricultural extension staff and farmers; smallholder irrigation water management and crop production, dambo irrigation farming with ecosystems goods and services in mind, drip kit irrigation, operation and management for local food security soil and water conservation and conservation agriculture under rainfed agriculture. Since sustainable resource management in the Zambezi River Basin is of the utmost importance to minimise conflicts, the WEFE nexus is currently being touted as an appropriate resource management tool. A short course on the WEFE nexus as a tool has also been proposed for policy makers, development implementers, academics and researchers.

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8 APPENDICES

APPENDIX 5A – WEF NEXUS SHORT COURSE

APPENDIX 5B – SMALLHOLDER IRRIGATION WATER MANAGEMENT SHORT COURSE

APPENDIX 5C – DAMBO IRRIGATION MANAGEMENT SHORT COURSE

APPENDIX 5D – DRIP KIT IRRIGATION SHORT COURSE

APPENDIX 5E – SOIL AND WATER CONSERVATION AND CONSERVATION AGRICULTURE SHORT COURSE

8.1 APPENDIX 5A – WEF NEXUS SHORT COURSE

1	COURSE TITLE
	• Water Energy Food Nexus as a Sustainable Resource Management Tool – Local Scale Applications
2	COURSE OBJECTIVE
	• To equip trainees with the requisite understanding and skills to apply the WEF nexus approach for natural resources management to ensure resource securities for the target population
3	LEARNING OUTCOMES
	At the end of the short course, the trainees will be able to: • Define the WEF nexus and its relevant variants • Understand the scope of application of the WEF nexus from technical to policy aspects. • Define the spatial scale of applying the WEF nexus • Define the temporal scale of application of the WEF nexus • Define and identify the data requirements for use in the WEF nexus • Identify and select the appropriate WEF nexus models/software and applicable techniques • Apply the WEF nexus to specific local scales
4	TARGET TRAINEES
	• Researchers, technical officers, project implementers, policy people
5	COURSE DURATION
	• 4 days
6	COURSE DETAILS
	Day 1 • Introduction to the WEF nexus concept – the W.W.W.H.W. of the WEF nexus • WEF nexus variants • WEF nexus scope of application with relevant examples from around the world • Spatial scale issues when applying the WEF nexus • Temporal scale issues in applying the WEF nexus Day 2 • WEF nexus indicators and their applicability and usability • Data issues for the WEF nexus • Data sources and actual sourcing for the WEF nexus • Data quality and data cleaning for the WEF nexus • WEF nexus models/source and other WEF nexus methodologies Day 3 • Group practical – WEF nexus problem definition and set up • Group practical – WEF nexus practical problem solving Day 4 • Group practical – WEF nexus assignment presentation and feedback to groups
7	TEACHING & LEARNING METHODS
	• Interactive lectures from WEF nexus experts • Individual trainee tasks with feedback, e.g., problem definition, problem scoping, model selection • Interactive practicals with WEF nexus experts and the trainees • Individual trainee hands on practical tasks on specific aspects, e.g., data sourcing, data cleaning, data input into WEF nexus models • Group hands on tasks on natural resources management applying the WEF nexus approach for specific defined problem cases – from the beginning to the end

	• Group feedback with critiquing and assessment to the class
8	LEARNING ASSESSMENT
	Learning outcomes will be assessed through: • Summative assessment of the theoretical aspects of the WEF nexus • Assessment of the practical project on application of the WEF nexus
9	REFERENCE MATERIALS
	1) FAO (2014): The Water-Energy-Food Nexus. A New Approach in Support of Food Security and Sustainable Agriculture.

8.2 APPENDIX 5B – SMALLHOLDER IRRIGATION WATER MANAGEMENT SHORT COURSE

1	COURSE TITLE
	Smallholder Irrigation Water Management for Food Security and Rural Livelihoods Improvement
2	COURSE OBJECTIVE
	To capacitate trainees in the practical aspects of managing irrigation water and other inputs in smallholder irrigation for enhanced crop performance for both food and cash crops
3	LEARNING OUTCOMES
	At the end of the short course the trainees will be able to: • Characterize smallholder irrigation in terms of system structure, existing management systems and operational issues • Define the boundaries of smallholder irrigation system from water source to drainage lines • Follow the flow and identify the control points of water in the irrigation scheme • Comprehend smallholder irrigation cropping programmes, crop rotations, agronomic and cultural practices • Determine an irrigation schedule and match this to water supply in the irrigation scheme • Implement irrigation scheduling in smallholder irrigation • Identify and describe the management and operation structures of the irrigation scheme in terms of position and responsibilities • Know the irrigation scheme operational by-laws in terms of purpose and enforcement • Assess strength and weaknesses of any given irrigation scheme for the purpose of improving operations and crop output • Identify cost-effective input supplies and suppliers • Identify products markets for smallholder irrigation outputs for maximised returns to producers
4	TARGET TRAINEES
	Group A. Agricultural (irrigation) extension staff Group B. Irrigation scheme office bearers
5	COURSE DURATION
	Group A: 2 days Group B: 1 day (farmers training should not take them away from their farming!)
6	COURSE DETAILS
	• Smallholder irrigation systems and schemes and rural livelihoods – food security and cash crop productions • Strengths and weaknesses of smallholder schemes and smallholder farming • Development trajectories of smallholder irrigation for sustainability of the scheme • Smallholder irrigation scheme boundaries and the related environment • Water sources and water control in smallholder irrigation • Generalities of crop production for key crops produced by smallholder irrigators • Practical irrigation scheduling (soil moisture monitoring, crops monitoring, any modern but practically possible methods). Relating irrigation scheduling to water supply constraints • Irrigation scheme management structures – position of office bearers and their responsibilities • Irrigation scheme by-laws and the smooth operation of the irrigation scheme • Identification of production inputs (seeds, fertilisers and agrochemicals) and dealing with input suppliers

	• Identifying and dealing with markets for produce from smallholder irrigation to maximise returns to the farmer
7	TEACHING & LEARNING METHODS
	Group A: • Interactive lectures in a class setting • Practical exercises in the field on characterizing the irrigation schemes, checking water control structures, irrigation scheduling and matching irrigation schedule to water supply • Group assignments/tasks to identify input suppliers and (theoretically) negotiate good service and prices • Group assignments to identify potential markets for farmers produce and (theoretically) negotiate for good prices for produce Group B: • Interactive lectures in the field with farmers • Practical group assignments in the field on topics that include crop management, irrigation scheduling and related material • Role playing in identifying and negotiating with input suppliers • Role playing in identifying produce markets and negotiating practices
8	LEARNING ASSESSMENT
	Learning outcomes will be assessed through: Group A: • In field assessments of specific tasks (e.g., water control, manual irrigation scheduling) under smallholder irrigation Group B: • Interactive question and answer sessions with feedback
9	REFERENCE MATERIALS
	FAO (1985): Irrigation Water Management – Training Manuals – Series 1 to 5 FAO (2004): Farmer Field School Methodology - Training of Trainers Manual FAO (2016): Farmer Field School Guidance Document - Planning for Quality Programmes

8.3 APPENDIX 5C – DAMBO IRRIGATION FARMING MANAGEMENT SHORT COURSE

1	COURSE TITLE
	• Dambo Crop Production with Environmental Considerations
2	COURSE OBJECTIVE
	• To capacitate trainees in sustainable crop production under dambo farming with the ecosystems goods and services perspective in mind
3	LEARNING OUTCOMES
	At the end of the short course the trainees will be able to: • Define and identify dambo irrigation farming in a practical sense • Describe the ecosystem goods and serves (EGS) obtainable from dambo irrigation farming • Describe the environmental concerns pertaining to dambo irrigation farming • Describe and document agricultural practices under dambo irrigation farming I terms of land preparation, crops and cropping patterns, and agronomic practices • Undertake agricultural water management under dambo irrigation farming
4	TARGET TRAINEES
	Group A. Agricultural extension staff Group B. Dambo farmers
5	COURSE DURATION
	Group A: 2 days Group B: 1 day (farmers training should not take them away from their farming!)
6	COURSE DETAILS
	• Dambo irrigation crop production and rural livelihoods • Dambo irrigation as a production system – ecosystem goods and services, and the associated legislation • Environmental protection and sustainability under dambo irrigation farming • Soil and land husbandry under dambo irrigation farming • Crops, crop choices, cropping programmes and crop production under dambo farming • Input supplies management under dambo irrigation farming • Post-harvest produce handling and value addition • Marketing of surplus produce from dambo farming
7	TEACHING & LEARNING METHODS
	Group A: • Interactive lectures in a class setting on dambo irrigation farming and the related EGS and environmental sustainability • Practical exercises in the field on land preparation, water management in dambo irrigation, and crop production • Group tasks to identify input suppliers and (theoretically) negotiate good service and prices • Group tasks on post-harvest practices in dambo irrigation farming • Group assignments to identify potential markets for farmers produce and (theoretically) negotiate for good prices for produce Group B: • Interactive lectures in the field with farmers including EGS and sustainability issues. • Practical group assignments in the field on topics that include crop management, water management and related material • Role playing in identifying and negotiating with input suppliers • Role playing in identifying produce markets and negotiating practices
8	LEARNING ASSESSMENT

	Learning outcomes will be assessed through: Group A: • In field assessments of specific tasks relating to dambo irrigation farming. Group B: • Interactive question and answer sessions with feedback
9	REFERENCE MATERIALS

8.4 APPENDIX 5D – DRIP KIT IRRIGATION SHORT COURSE

1	COURSE TITLE
	• Crop Production Under Drip Kit Irrigation (including Treadle Pumps)
2	COURSE OBJECTIVE
	• To equip the trainees with the skills and knowledge to manage and operate drip kits for crop production for local rural food security
3	LEARNING OUTCOMES
	At the end of the short course the trainees will be able to: • Identify and describe the components of a drip kit, setting up the kit and how the unit operates • Describe the water quality and water filtration needs of drip kit irrigation • Relate drip discharge to operating head • Link dripper/emitter emission to soil wetting depending on soil type and ability to satisfy crop water requirements • Undertake crop production under drip kit irrigation
4	TARGET TRAINEES
	Group A. Agricultural extension staff Group B. Smallholder irrigation farmers with drip kits
5	COURSE DURATION
	Group A: 1 day Group B: ½ day (farmers training should not take them away from their farming!)
6	COURSE DETAILS
	• Conceptualising drip kit irrigation as a technology – low operating pressure, low discharge, less soil wetting, water savings and high water application efficiency • The drip kit – components and functions • Setting up the drip kit in the field, as well as security issues • Water supply, water quality, water filtration and management of drip kit filters • Crop production under drip kits – linking soil wetting to meeting crop water requirements • Off season storage of drip kits
7	TEACHING & LEARNING METHODS
	Group A: • Interactive lectures on drip kits and irrigation farming • Practical exercises in the field on drip kit setting up, supplying water, filtering water and cleaning the drip kit filters • Group tasks on monitoring soil wetting and crop water requirements Group B: • Interactive lectures in the field with farmers the drip kit • Practical group assignments in the field on topics that include setting up the drip kit, supplying water and ensuring water filtration
8	LEARNING ASSESSMENT
	Learning outcomes will be assessed through: Group A: • In field assessments of specific tasks relating to drip kit irrigation Group B: • Interactive question and answer sessions with feedback
9	REFERENCE MATERIALS

8.5 APPENDIX 5E – CONSERVATION AGRICULTURE SHORT COURSE

<table>
<tr><td>1</td><td>COURSE TITLE</td></tr>
<tr><td></td><td>• Soil and Water Conservation and Conservation Agriculture for Improved Rainfed Agricultural Production</td></tr>
<tr><td>2</td><td>COURSE OBJECTIVE</td></tr>
<tr><td></td><td>• To capacitate trainees to understand and apply soil and water conservation practices including conservation agriculture in rainfed crop production</td></tr>
<tr><td>3</td><td>LEARNING OUTCOMES</td></tr>
<tr><td></td><td>At the end of the short course the trainees will be able to:
• Define and describe soil and water conservation (SWC) practices applicable in rainfed agriculture for specific situations
• Define and describe conservation agriculture (CA) practices in the context of rainfed agricultural production in the region
• Practically set out selected SWC and CA practices</td></tr>
<tr><td>4</td><td>TARGET TRAINEES</td></tr>
<tr><td></td><td>Group A: Agricultural extension staff
Group B: Smallholder farmers practicing rainfed crop production</td></tr>
<tr><td>5</td><td>COURSE DURATION</td></tr>
<tr><td></td><td>Group A: 5 days (can be staggered over time)
Group B: 5 days (staggered of some period)</td></tr>
<tr><td>6</td><td>COURSE DETAILS</td></tr>
<tr><td></td><td>• Soil and water conservation practices applicable to the Zambezi River Basin – in field rainwater harvesting (terraces, micro-basins, tied ridges, contour farming, mulching, etc)
• Conservation agriculture tenets – minimal soil disturbance, permanent soil cover and crop rotations
• Soil and climatic requirements and applicability of various SWC and CA practices
• Field design and set out of the various SWC practices
• Field design and practical on CA aspects
• Crop production practices under SWC and CA practices
• Maintenance of SWC structures</td></tr>
<tr><td>7</td><td>TEACHING & LEARNING METHODS</td></tr>
<tr><td></td><td>Group A:
• Interactive lectures in a class setting on SWC and CA
• Practical exercises in the field on design, land preparation, setting out and construction of SWC structures
Group B:
• Interactive lectures in the field with SWC and CA
• Practical group assignments in the field on topics that design, land preparation and setting and constructing SWC selected SWC structures.</td></tr>
<tr><td>8</td><td>LEARNING ASSESSMENT</td></tr>
<tr><td></td><td>Learning outcomes will be assessed through:
Group A:
• In field assessments of specific tasks relating to SWC and CA practices.
Group B:
• Interactive question and answer sessions with feedback</td></tr>
<tr><td>9</td><td>REFERENCE MATERIALS</td></tr>
<tr><td></td><td></td></tr>
</table>