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Farmer Needs and Preferences for Agriculture Water Solutions in the Ramotswa Transboundary Aquifer Area

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Executive Summary

The importance and challenge of agriculture to sustainable development in Africa In much of rural Africa, agriculture production is key to food security and community livelihoods. Agricultural productivity is nonetheless variable and – particularly in rainfed systems – vulnerable to rainfall that appears to be increasingly unpredictable. As such, identifying and implementing tools and solutions that enhance agricultural water management is a key pathway for improving food security and strengthening resilience. In arid and semi-arid contexts, however, strengthening agricultural water management – particularly when focus is placed on irrigation – often faces considerable challenges given the quantities of water required as input. Agriculture indeed typically consumes more than 70 percent of water in a given area. In some arid contexts, considerable volumes of additional water to supply to irrigation may simply not be available despite recognition for the importance of the agricultural sector.

Agriculture-Water Solutions component of RAMOTSWA-2 The Ramotswa Transboundary Aquifer Area (RTBAA), shared between Botswana and South Africa, lies in an arid context in the Upper Limpopo Basin. The Agriculture-Water Solutions (hereafter Ag-Water Solutions) component of the RAMOTSWA-2 project is focused on improving agriculture (specifically irrigation) management in the vicinity of RTBAA. It is envisaged that Ag-Water Solutions will contribute to the capacity development of smallholder farmers towards irrigation water and soil nutrient management, generate suggestions for outscaling such solutions as well as constraints to irrigated agriculture in the project area. This report takes a first step toward these goals by:

a) Reviewing the agricultural context of Botswana and South Africa as relevant to the RTBAA
b) Identifying irrigation schemes in the vicinity of the RTBAA, and selecting and evaluating a set of three schemes
c) Outlining an approach for testing agricultural water management technologies on the three selected schemes

Agricultural Context The importance of agriculture to the broader region and specific vicinity of the RTBAA is reflected in the policies and programs at both country and provincial levels such as: the National Master Plan for Agriculture and Dairy Development in Botswana, and policies developed between the International Development Cooperation (IDC) and the government of the Northwest Province in South Africa. Despite the good intentions contained in policies such as these, major challenges persist. In Botswana, improving agricultural production in Botswana is constrained by rainfall variability often manifested in drought conditions, likely at least partly associated with climate change. On the South African side of the RTBAA, it would appear that the potential for agriculture may not be fully tapped given the low employment in the agricultural sector in the Ngaka Modiri Molema District Municipality.

Three Schemes in the RTBAA To identify sites, information was collected from the representatives from the Department of Agriculture in Gaborone, the South-East District Council based in Ramotswa, the Department of Water and Sanitation (DWS), South Africa and government representatives near Zeerust. Four criteria were developed to guide the search and selection of suitable farms: farm size, purpose for production, presence of smallholder farmers, and baseline information of farms. Three schemes were ultimately selected, one in South Africa and two in Botswana:

- Glen Valley Irrigation Scheme (~50 ha in use, near Gaborone, Botswana)

- Mogobane Irrigation Scheme (~4 ha in use, near Mogobane, Botswana)
- Mothlake Irrigation Scheme (~10 ha in use, near Radikhudu, South Africa)

Evaluating the three schemes Situational analysis of the three schemes revealed several common threads and several differences (Summary Table). One common thread is that the area actually irrigated is lower than that developed—and generally lower than the area irrigated on schemes in the past. While precise values on areas should be taken with some caution, the central message is clear: increasing water scarcity has generally engendered a need to reduce irrigated area. Another commonality is the crops cultivated: Vegetables predominate, and contribute notably to local markets. Differences across schemes include: i) the actual size of schemes, which vary considerably; ii) sources of water, which vary from waste to ground to surface water from a natural spring; iii) nature and strength of the institutional arrangements supporting agricultural water management on the three schemes.

	Area in use v. Developed	**Number of Farmers**	**Crops**	**Type and Source of Irrigation**	**Challenges**
Glen Valley	~50 of 146 ha	47 farms, each leased from government	Tomato, spinach, olive, green pepper, okra, maize, butternut squash, water melon, cabbage and lettuce	Drip; Wastewater	Disruptions to Water Supply, lack of incentive to conserve when water is available
Mogobane	~4 of 10 ha	18 when accounting for all farmers and staff	Maize, cabbage, green pepper, tomatoes and lettuce	Drip; Groundwater	Water Shortage
Mothlake	~10 of 80 ha	60 farmers	Maize, cabbage, tomatoes, beetroot, lettuce and pumpkins	Furrow; Groundwater and Surface-water emanating from Dinokana eye	Water Shortage, lack of irrigation schedule

Summary Table: Irrigation Schemes in the vicinity of the RTBAA

Outlining an Approach An approach to enhancing agricultural water management on the three sites is centered on testing of water-sensing technologies: the wetting front detector and water sensing chameleon. Such technologies enable better matching of water application with plant water requirements. Key tenets of an approach aimed at testing these technologies on the three selected schemes were outlined. Training will be provided to farmers to enable them to operate and interpret the technologies on selected plots. Control sites will be selected to enable comparison of differences between plots on which technologies were tested, and those operated in a business-as-usual manner. Key parameters of measurement will include: a) soil profile, b) crop productivity, c) water efficiency or productivity, d) fertilizer use, and e) change of perception or practice. Discussions will also be held to improve understanding on constraints to adoption of such technologies, and the potential for outscaling.

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Acronyms

ALDEP	Arable Lands Development Programme
ASR	Aquifer Storage and Recovery
ASTR	Aquifer Storage Transfer and Recovery
BGI	Botswana Geoscience Institute
DEM	Digital Elevation Model
DWA	Department of Water Affairs (Botswana)
DWS	Department of Water and Sanitation (South Africa)
GDP	Gross Domestic Product
GDT	Gamalete Development Trust
GIS	Geographic Information System
HWSD	Harmonized World Soil Database
IDC	Industrial Development Corporation
IGRAC	International Groundwater Resources Assessment Centre
ISPAAD	Integrated Support Programme for Arable Agricultural Development
IWMI	International Water Management Institute
KZN	Kwa-Zulu Natal
LIMID	Livestock Management and Infrastructure Development
LULC	Land Use/Land Cover
LWPD	Livestock Water Development Programme
MAR	Managed Aquifer Recharge
MIF	Multi-Influencing Factor
MMEWR	Ministry of Minerals, Energy and water Resources
NAMPAAD	National Master Plan for Agriculture and Dairy Development
NDP	National Development Plan
NMMDM	Ngaka Modiri Molema District Municipality
NWP	North West Province
PTF	Production and Training Farms
RMLM	Ramotshere Moiloa Local Municipality
RTBAA	Ramotswa Transboundary Aquifer Area
SADC	Southern African Development Community
SED	South East District
SLOCA	Services to Livestock Owners in Communal Areas
SRTM	Shuttle Radar Topography Mission
SWC	Soil Water Content
SWM	Soil Water Monitoring
TDR	Time Domain Reflectometry
USAID	United States Agency for International Development
WFD	Wetting Front Detector
WLC	Weighted Linear Combination
WLE	Water, Land and Ecosystems
WUA	Water User Association

WUC	Water Utilities Corporation (Botswana)

1 Introduction

Agriculture is a key driver of poverty alleviation and development in rural areas in Africa. Rural agricultural development has great potential for economic diversification that can alleviate poverty and improve rural livelihoods. In light of global climate change, improved and sustainable agricultural water solutions are critical to resource-constrained smallholder farmers. In the Limpopo River Basin and shared groundwater reserves, current level of poverty and food insecurity problems underline the need for improved approaches to agricultural production. Previous studies (Sullivan & Sibanda, 2010; Mulligan et al., 2011; Zimbabwe Vulnerability Assessment Committee- ZimVac – 2011; Magombeyi et al., 2015) indeed highlight challenges in the basin including but not limited to drought, floods, poor infrastructure, unemployment, low smallholder farmer productivity, food insecurity, vulnerability to disease, poverty, low literacy level, inequitable allocation of water, insecure land tenure, fragmented policies within and across riparian basin states, low income and limited access to finance.

Limited water availability imposes a major constraint on agricultural production in the Upper Limpopo Basin. The high aridity in the upper Limpopo Basin (Alemaw et al., 2010) is coupled with unreliable rainfall (200 to 1,500 mm annually and a mean of 530 mm) with inter-seasonal dry spells (Limpopo Basin Focal Project –LBFP, 2010; Magombeyi et al., 2015). Crop production is mainly rain-fed (Hanjra et al., 2009; Sullivan & Sibanda, 2010). Sufficient food production for family consumption by farmers often last for only 8 months, with household food needs like maize meals bought from the market for four months (Cunguara & Darnhofer, 2011; Magombeyi et al., 2015). In the presence of limited water resources, income generation from rain-fed agriculture to alleviate poverty by the rural farmers in the basin will require stronger institutions, increased investments and support (Magombeyi et al., 2015).

There is a need to enhance efficiency and sustainability of agricultural water use in the Upper Limpopo – including in the RTBAA – to maximize benefits of the scarce resource. Irrigated agriculture constitutes a significant channel through which to enhance food security, employment opportunities, rural poverty alleviation and enhanced livelihoods for the growing population in these regions. In a water-constrained environment like that of the Upper Limpopo, it is critical to find approaches that make more with less – i.e., that stretch limited water resources farther. The assessment of the feasibility and best options for small-scale irrigation development in the Ramotswa Transboundary Aquifer Area (RTBAA) is one of the aims of the *2nd Phase of the RAMOTSWA Project* (RAMOTSWA-2).

Agriculture-Water Solutions component of RAMOTSWA-2 Ag-Water Solutions is focused on improving irrigation management in the vicinity of Ramotswa Transboundary Aquifer Area (RTBAA). It is envisaged that Ag-water solutions will contribute to the capacity development of smallholder farmers towards irrigation water and soil nutrient management, generate suggestions for outscaling such solutions as well as address constraints to irrigated agriculture in the project area. Ultimately, the recommendations and application of knowledge gained on Ag-Water Solutions from this project are expected to provide guidance for improving crop production, resilience and food security in the communities within the project area. Two soil water monitoring sensors (Wetting Front Detector and the Chameleon Sensor) developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land & Water, Australia may be tested on farms in the vicinity of the RTBAA.

In the context of the Ag-Water Solutions component of the RAMOTSWA-2 project, the overall objectives of this report are:

a) Review the agricultural context of Botswana and South Africa as relevant to the RTBAA
b) Identify irrigation schemes in the vicinity of the RTBAA, and select and evaluate a set of three schemes
c) Outline an approach for testing agricultural water management technologies on the three selected schemes

In what follows, one section is devoted to each of these three objectives.

2 Agricultural Context

2.1 South Africa

Generally, agricultural production in South Africa is classified into three categories: commercial production, smallholder agriculture and subsistence agriculture. Commercial production accounts for more than 90 % of the country's formal marketed agricultural output and covers 82 million hectares (~40,000 farming units); smallholder agriculture, mostly practiced by black farmers (~300,000 to 400,000 farming units) covers about 14 million hectares[1]. Subsistence agriculture is practised by about 4 million households (National Treasury, 2015); precise area of coverage is unclear. The agricultural sector in South Africa accounts for about 10% of formal employment with 650,000 employed in the sector in the first quarter of 2010; this is a notable drop from the 738,000 jobs in the sector in the first quarter of 2009 which is likely a result of global economic trends (National Treasury, 2015). The entire value chain of agriculture contributes about 12 % to South Africa's Gross Domestic Product (GDP) (Government Communication and Information System-GCIS, 2016). The area under irrigation is about 1.3 million hectares (GCIS, 2016).

The largest field crop produced in the country is maize. Maize serves as an export crop, a major source of livestock feed and as staple food it significantly contributes to food security. Major commercial production occurs in North West Province (NWP), the Free State, the Mpumalanga Highveld and the KwaZulu-Natal (KZN) Midlands on more than 8000 large farms generating more than 150,000 jobs in times of good rainfall (National Treasury, 2015). South Africa has recorded the highest production of maize in the Southern African Development Community (SADC) for more than a decade, with an average of 10.6 million tons (Mt) a year (GCIS, 2016).[2] Cereals and grains occupied more than 41.9 % of cultivated land in 2011 (National Treasury, 2015). The livestock sector in South Africa comprises of beef and dairy cattle, poultry and pigs. In terms of value, animal production contributes about 48 % to the country's agricultural output and employs about 500 000 people (GCIS, 2016).

In the North West Province (NWP), the number of agricultural households is about 214,000 out of 1,062,000 total households (Statistics South Africa, 2013). Production in the agricultural sector in the province is focused on, in descending order: poultry production, livestock production, vegetable production, other agricultural activities[3] and fodder/grazing (Statistics South Africa, 2013). In the horticultural crop sector, potatoes are mostly produced followed by oranges, onions and carrots. About 34 % of the provincial agricultural land is potentially arable with 66% classified as grazing land

[1] Primarily, the location of these farms is generally in the former homelands characterised by low production efficiency due to lack good soil, water and infrastructure
[2] Mainly comes from about 6500 commercial maize producers while the rest comes from thousands of small-scale producers
[3] Agricultural activity not mentioned such as bee keeping

while about 4% of the arable land is under irrigation(Rural, Environment and Agricultural Development, North West Provincial Government- READ NWPG, 2015).[4] The highest physical output of arable crops such as maize, sunflower and wheat are produced in the Ngaka Modiri Molema Municipality (NMMDM) (READ NWPG, 2015).[5]

The Industrial Development Corporation (IDC) has undertaken partnership initiatives with the NWP Government to support the following: development and funding of a competitive meat processing (poultry & red meat) value chain by supporting emerging black farmers and communities within the province; development and funding of a competitive field crop processing industry (soya, oil seeds, wheat, animal feeds, advanced maize processing) with a focus of increasing supply from emerging black farmers and farmers on communal land; and establishment and expansion of the aquaculture industry in the NWP in collaboration with the Rhodes University (READ NWPG, 2015). Twelve policies have been identified in the 2015 to 2020 Strategic Plan of the Department of Rural, Environment and Agricultural Development NWPG.[6] The aim is to support the National Development Plan (NDP) priorities to achieve the 2030 vision of spatially, socially and economically well integrated rural areas as well as environmental sustainability and resilience (READ NWPG RSA, 2015). Critical factors like the institutional environment, climate change, the resources needed, the legislative and regulatory environment impacting on the achievement of the outcomes are considered in the plan. The identified policies are:

1. Improving land administration and spatial planning for integrated development in rural areas
2. Improving food security through Fetsa Tlala programme[7]
3. Smallholder farmer development and support (technical, financial, infrastructure) for agrarian transformation
4. Development of Villages, Townships and Small Dorpies economies by growing sustainable rural enterprises, cooperatives and industries characterised by strong rural-urban linkages, increased investment in agro-processing, access to markets and financial services– resulting in rural job creation
5. Effectively crowding in productive investment through the agricultural infrastructure build programme
6. Growing the share of production and employment of the agricultural productive sectors - APAP
7. Workers' education and skills increasingly meeting economic needs
8. Addressing Spatial imbalances in economic opportunities through expanded employment in agriculture
9. Sustaining Ecosystems and using natural resources efficiently
10. Development and implementation of effective climate change mitigation and adaptation response
11. An environmentally sustainable, low-carbon economy resulting from a well-managed just transition
12. Enhanced environmental governance systems and capacity.

[4] Wheat and Lucerne are predominantly produced under irrigation
[5] Parts of the NMMDM also falls within the maize triangle of South Africa
[6] Medium Term Strategic Framework (MTSF) outlining departmental strategic outcome oriented goals, objectives, institutional arrangements, infrastructure and other capital plans for departmental programmes
[7] This was launched in October 2013 by the government to promote food security, address the structural causes of food insecurity and ultimately eradicate hunger

2.2 Botswana

The diamond mining sector played a major role in the transformation of Botswana's economy from one of the poorest countries in Africa in 1960s to a middle-income country in recent times. Botswana has recorded annual GDP growth above 10 % from its independence in 1966 to the late 1990s which is only comparable to China (The World Bank Group, 2015). A reduction in the level of poverty from 30.6 % to 19.4 % of the population was also recorded between 2002 to 2010 (The World Bank Group, 2015). Despite these impressive achievements, there is still persistent levels of poverty or vulnerability to poverty in Botswana's population. About 31 % are indeed classified as vulnerable, which is most often among rural households that depend on small-scale and subsistence farming (The World Bank Group, 2015).

Economic diversification remains a challenge in Botswana. The diamond mining sector remains the main driver of the economy. Diversification of Botswana's economy by improving agricultural production can reduce the reliance on mining, dependence on imported food to feed the growing population and promote environmental sustainability. Over dependency on the country's natural resources as means of livelihood and economic growth may have adverse effects on the environment (Juana, 2014).

There has been large decline in the contribution of agriculture to the national GDP (2 % in recent years compared to 46 % in 1996) and only about two thirds out of 544,000 hectares of cultivable land area are utilised (Government of Botswana – GoB, 2011). About 85% of the country's annual food grain requirement (150,000 tonnes) is imported (International Fund for Agricultural Development – IFAD, 2010). Crop production is somewhat variable between years.Between 2012 and 2013, for exmaple, yield of maize dropped from 7,677metric tons to 3,844 metric tons, sorghum yield dropped from 4,021 metric tons to 10,231 metric tons, groundnuts declined from 200 metric tons to 112 metric tons, millet production decreased from 1,959 metric tons to 1,391 metric tons and sunflower production reduced from 6,000 metric to 2,021 metric tons (Statistics Botswana, 2015). In the same reporting period, livestock population generally also decreased somewhat (cattle population dropped from 2.2 million to 2.1 million, goats from 1.6 million to 1.5 million while sheep reduced from 293,966 to 274,357).

Rainfed crop production in Botswana is mostly on small traditional farms of an average size of 5 ha. Smallholder farmers who engage in the practice are unable to provide adequate tillage as a result of majority using draught power and most times are unable to produce enough food or generate adequate income for the family (Botswana Institute for Development Policy Analysis - BIDPA, 2001). Commercial farmers in the country depend on irrigation due to high evaporation rates, and insufficient and unreliable rainfall (GoB, 2011).

Development of the irrigation sector in Botswana is on expansion of horticultural production to meet domestic demand. Proposed in the National Master Plan for Agriculture and Dairy Development is irrigation of 3,600 ha with treated wastewater (NAMPADD, 2000). SMEC and EHES (2006) reported a significant growth projection of water use for irrigation from 21.6 Mm^3 in 2010 to 50 Mm^3 by 2030. Irrigation supplies 60 % of in the horticultural produce for national consumption (Department of Water Affairs & Ministry of Minerals, Energy & Water Resources - DWA & MMEWR, 2013). Irrigation is highly concentrated in central district along the Limpopo River with high yielding wells and good soils in Tuli Block area mainly Tala Farms with 12 m deep groundwater (DWA & MMEWR, 2013). Other projects have been identified around Francistown, and two clusters identified by the Ministry of Agriculture (Glenn Valley Irrigation Scheme in Gaborone which uses secondary treated wastewater and Dikabeya which uses of dam water) (Masamba, 2009; DWA & MMEWR, 2013).

Some of the developmental initiatives by the government of Botswana to alleviate stress due to limited water resources and boost agricultural production include wastewater and bio-solids treatment in the urban areas of Gaborone, Lobatse, Selebi-Phikwe, Serowe and Tonota for crop production and technical options for water harvesting such as extracting from the sand rivers of Shashe and Motloutse for irrigation (GoB, 2011). In 2013, Gaborone region had the highest number (35,571) of active farmers in the country (Statistics Botswana, 2015).

Policies and assistance programs (agricultural support/subsidy schemes) such as NAMPAADD, the Integrated Support Programme for Arable Agriculture Development (ISPAAD), the Livestock Management and Infrastructure Development (LIMID) and the Arable Land Development Program (ALDEP) are some of the initiatives of the Government of Botswana to revitalising the agricultural sector. The majority of the support schemes are aimed at improving food security and poverty alleviation.[8]

Agricultural development in the country through NAMPAADD seeks to diversify the economy, improve agricultural productivity, promote sustainable use of natural resources, build capacity through adoption of modern technology in production systems and generate employment. The main objective of NAMPAADD is to make agriculture competitive and reduce the country's dependence on imports of agricultural produce in which it has the potential to produce locally (MoA, 2009). Emphasis on food security in NAMPAADD targets the diversification of agricultural sector from subsistence farming and its traditional practices to a more improved commercial agriculture.[9] Rainfed agriculture, Irrigated agriculture and Dairy development are the three sub sectors under the Production and Training Farms (PTF) of NAMPAADD from its inception in 2002. A *Rainfed PTF* is located at Ramatlabama[10] with the cultivation of crops such as sorghum, maize, sunflower and legumes using cost saving production technologies like minimum tillage, moisture conservation and fertilizer application; A *Dairy PTF* is at Sunnyside[11] with cows producing an average of 35liters per cow per day, demonstration and adoption of technologies such as silage preparation, feed mixing and dairy hygiene; *Irrigated agriculture PTFs* are in Glen valley in Gaborone North and Dikabeya 20 km from Palapye.[12]

The ISPAAD aims to significantly improve the productivity of the arable sub-sector by its components such as provision of draught power, potable water, seeds, fertilizers and herbicides, facilitation of

[8] The NAMPAADD Coordinating Unit was established in October 2002 after the approval of the Government White Paper No 1 of 2002 in April 2002. ISPAAD was introduced in 30th April, 2008. ALDEP Phase III and LIMID were implemented 1st April, 2007

[9] This is to be achieved through programmes that enable traditional/subsistence farmers to transform their operations to commercial level as well as to enable commercial farmers to upgrade their level of management and technology application

[10] before the boarder from Lobatse

[11] before Lobatse from Gaborone

[12] At Glen valley, there is demonstration of both protected and open field production using treated water for production of vegetables such as pepper, cucumber, lettuce and tomatoes. There is also a commercial olive oil plantation planted in May 2007. At Dikabeya, there is both open field and protected cultivation for the production of vegetables such as tomatoes, onions, watermelons, peppers, butternut and carrots- Source: MoA, 2009

access to credit and fencing and establishment of agricultural service centres (MoA, 2013). The two objectives of ISPAAD are:

i) *Rain-fed arable agriculture*: this includes increasing grain production, promoting food security at the household and national levels, commercializing agriculture through mechanization, facilitating access to farm inputs and credit, and improving extension outreach and

ii) *Horticulture development programme:* the objectives under this are to increase production level of horticultural products, create employment opportunities, diversify agricultural production base, provide essential farm inputs and selected equipment, and to improve competitiveness of the horticultural industry (Botswana College of Agriculture Consult- BCA Consult, 2012).

Livestock Management and Infrastructure Development project was created by the merging of Services to Livestock Owners in communal Areas (SLOCA) and Livestock Water Development Programme (LWDP) subsidy schemes. LIMID Phase I is composed of seven packages out of which the focus of three packages is on resource-poor households (smallstock, guinea fowl and Tswana chickens) and the remaining is on infrastructure development.[13] The objectives of the LIMID II Programme are to promote food security through improved productivity of cattle, smallstock and Tswana chickens; improve livestock management; improve range resource utilization and conservation; eradicate poverty; and provide infrastructure for safe and hygienic processing of poultry (MoA, 2010). The three broad classification of the infrastructure development component are:

i) Water development which include *borehole drilling* (assists farmers to drill borehole only), *borehole /well equipping* **(**this is for farmers who have already drilled boreholes and/or leased boreholes and the minimum lease period for leased boreholes shall not be less than 10 years), *water reticulation* (for assisting farmers to reticulate water from a water point to the grazing areas or kraals) and *borehole/well purchase* (this is for assisting farmers to purchase existing boreholes/wells);

ii) Animal husbandry and fodder support which includes construction of kraals, crushes, loading ramps and purchase of fodder processors and

iii) Poultry abattoirs consist of establishment of slaughtering facilities by the Ministry of Agriculture to produce wholesome meat products. The facilities are also managed by the Ministry pending their profitability and subsequently are handed over to local authorities or sold to private sector/parastatals (MoA, 2010).[14]

The aim of the ALDEP Phase III is to strengthen extension services, technology transfer and adoption, training and supporting previous and current beneficiaries of the programme to utilize packages

[13] This includes animal husbandry and fodder support, borehole/well equipping, borehole drilling and reticulation, borehole/well purchase and cooperative poultry abattoirs.

[14] Water development packages are mainly for group of farmers not less than 15 members who own 1 to 40 cattle each in communal areas with little underground water resources.
Animal husbandry and fodder support is meant for individuals or groups of livestock farmers and the contribution depends on farmer(s) application either individually or as a group while the poultry abattoir supports small-scale poultry farmers (a cooperative that is usually made up of not less than 15 members) to establish slaughtering facilities to produce wholesome meat in order to penetrate the market
Source: MoA, 2010

acquired (MoA, 2006).[15] The objectives of ALDEP III are to promote food security through improved crop yields, improve extension outreach, utilization of obtained packages, provision of identified farm inputs and implements and strengthening of ALDEP Demonstration Farms (MoA, 2006).[16]

There has been large decline in the contribution of agriculture to the national GDP (2 % in recent years compared to 46 % in 1996) and only about two thirds out of 543 984 hectares of cultivable land area been utilised (GoB, 2011). About 85 % of the country's annual food grain requirement (150 000 tonnes) is imported (International Fund for Agricultural Development – IFAD, 2010). A low crop performace was recorded in crop sector between 2012 and 2013 as observed in the reduction of yield of maize (7 677metric tons to 3 844 metric tons), sorghum (24 021 metric tons to 10 231 metric tons), groundnuts (200 metric tons to 112 metric tons), millet (1 959 metric tons to 1 391 metric tons) and sunflower production from 6 000 metric to 2 021 metric tons (Statistics Botswana, 2015). Emphasis on food security in NAMPAADD of Botswana is the diversification of agricultural sector from subsistence farming and its traditional practices to a more improved commercial agriculture.[17] Rainfed agriculture, irrigated agriculture and dairy development are the three sub sectors under the PTFs of NAMPAADD. Irrigated agriculture PTFs are Glen valley in Gaborone North and Dikabeya 20 km from Palapye.[18] Rainfed PTF is located at Ramatlabama[19] with the cultivation of crops such as sorghum, maize, sunflower, legumes using cost saving production technologies like minimum tillage, moisture conservation and fertilizer application. Dairy PTF is at Sunnyside[20] with demonstration and adoption of technologies such as silage preparation, feed mixing and dairy hygiene.

Major problems to improving agricultural production in Botswana include climate change and variability often manifested in drought conditions. Commercial farmers in the country depend on irrigation due to high evaporation rates, and insufficient and unreliable rainfall (GoB, 2011). Rainfed crop production in Botswana is mostly on small traditional farms of an average size of 5 hectares. Smallholder farmers who engage in the practice are unable to provide adequate tillage as a result of majority using draught power and most times are unable to produce enough food or generate adequate income for the family (BIDPA, 2001).

Due to the limited water resources and competing demands (domestic and industrial use) in Botswana, development strategies on irrigated agriculture may offer more prospects to improve agricultural production than rainfed agriculture in the country. Nonetheless, irrigated agriculture typically consumes more water than rainfed agriculture. Further, most of Botswana's water resources are shared with other countries and hence their management are subject to the SADC Protocol for Shared River Courses. The bottom line is that while there is a need to increase irrigation, Botswana

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[15] Resource poor farmers whose low farming efficiency due to limited resources are the target group for ALDEP

[16] This includes assisting eligible farmers to obtain animal draught power, fencing materials, water tanks, animal drawn farm implements including threshing machines, chaff cutters and scotch carts. In addition, extension officers assists the farmers in undertaking soil tests to acquire the recommended fertilizers

[17] This is to be achieved through programmes that enable traditional/subsistence farmers to transform their operations to commercial level as well as enabling commercial farmers to upgrade their level of management and technology application

[18] At Glen valley, there is demonstration of both protected and open field production using treated water for production of vegetables such as pepper, cucumber, lettuce and tomatoes. There is also a commercial olive oil plantation planted in May 2007. At Dikabeya, there is both open field and protected cultivation for the production of vegetables such as tomatoes, onions, watermelons, peppers, butternut and carrots using water from the dam (MoA, 2009).

[19] before the border from Lobatse

[20] before Lobatse from Gaborone

presents a somewhat challenging context for expanding irrigation. Groundwater is currently a major source of water for irrigation.

Data on current area of land under irrigation in Botswana is limited. However, Ministry of Finance and Development Planning (2010); Department of Water Affairs & Ministry of Minerals, Energy & Water Resources - DWA & MMEWR (2013) reported a range of 3 000 to 3 500 hectares which is lower than the year 2012 projection of 5 200 to 5 400 hectares by NAMPAADD requiring 51 000 Ml/year to 53 000 Ml/year respectively of total irrigation water (NAMPADD, 2000).[21] SMEC and EHES (2006) reported a significant growth projection of water use for irrigation from 21.6 Mm^3 in 2010 to 50 Mm^3 by 2030. Despite the small area under irrigation in the country, 60 % of the horticultural produce is supplied by the sector for national consumption (DWA & MMEWR, 2013). Irrigation is highly concentrated in central district along the Limpopo River with high yielding wells and good soils in Tuli Block area mainly Tala Farms with 12 meters deep groundwater (DWA & MMEWR, 2013).

Treated wastewater is used in some areas of the country as part of the development initiatives of the Government of Botswana to promote resource recovery, curb the menace of limited water resources and to boost agricultural production. Development initiatives by the government of Botswana towards achieving this includes wastewater and bio-solids treatment in the urban areas of Gaborone, Lobatse, Selebi-Phikwe, Serowe and Tonota for crop production and technical options for water harvesting such as extracting from the sand rivers of Shashe and Motloutse for irrigation (GoB, 2011). In Kanye at Seventh Day Adventist Hospital, treated wastewater by rotating bio-contactor (horizontally rotating bio discs technology) is used for irrigating trees and lawn. The same technology is also used to treat wastewater at the new prison in Moshupa for re-use in irrigation. Similarly, there are constructed wetland systems for wastewater treatment for irrigation at Jwaneng Mine, Kanye Prison, and the Tlokweng College of Education which are designed to treat 50 m^3/day, 25 m^3/day, and 20 m^3/day of wastewater respectively (GoB & United Nations Development Programme – UNDP, 2004). Proposed in NAMPADD is irrigation of 3 600 hectares with treated wastewater (NAMPADD, 2000).

2.3 The Ramotswa Transboundary Aquifer Area

Ramotswa Transboundary Aquifer Area (RTBAA) The Ramotswa Aquifer corresponds to the Ramotswa dolomitic aquifer extent mapped based on surface geology. The RTBAA is a slightly broader term than the strict boundary. RTBAA is used to capture areas in the subsurface that are hydrologically linked to the aquifer, but which lie outside the dolomitic aquifer boundaries delineated based solely on surface geology (Figure 1). The Ramotswa Aquifer is located in NWP South Africa and SED Botswana.

Ramotswa Aquifer Flight Area The flight area (area about 1,500 km2) was commonly used as an encompassing boundary within which the aquifer was found. It was used to overcome ambiguities of a precise boundary for the aquifer in phase 1 of the RAMOTSWA project. Airborne geophysical surveys were indeed conducted in within this flight area in 2016 (Figure 1).

Gaborone Dam Catchment The Gaborone catchment area, located in the Upper Limpopo River Basin (Area ~4,318 km^2, Figure 1), reflects the immediate surface water boundaries within which the Ramotswa Aquifer is located. Given the linkages between surface and groundwater, the catchment is

[21] 2004 estimates of total land under irrigation was 1,800 hectares

a very relevant scale. Phase 2 of the RAMOTSWA project treats the Gaborone Dam Catchment as its project study area.

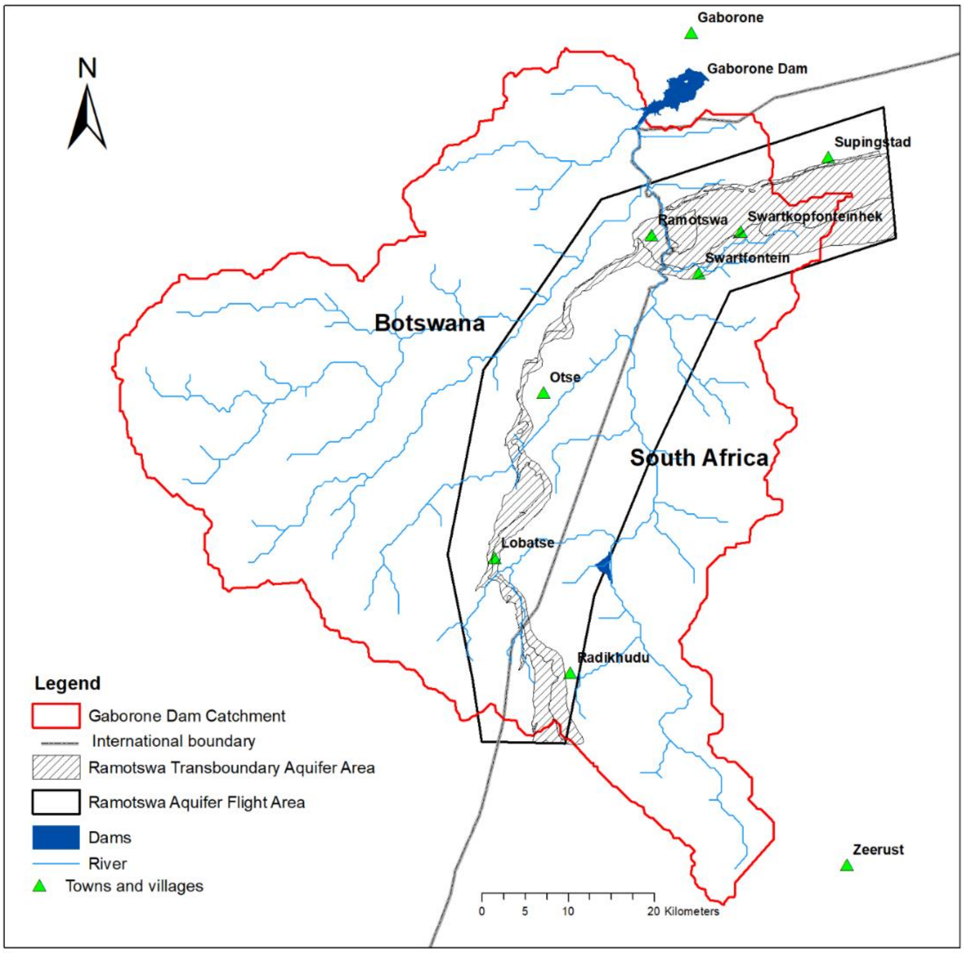

Figure 1: The Ramotswa Transboundary Aquifer Area, and associated boundaries

Population and Agriculture on the South African side of the RTBAA Based on administrative boundaries, the South African side of the RTBAA covers parts of the Ramotshere Moiloa Local Municipality (RMLM) in the NMMDM (Figure 2). The NMMDM is located on the northwestern part of the NWP and shares an international border with the Republic of Botswana. The NMMDM has a total population of approximately 843,000 (2011 estimates) and total land area of approximately 2,789,000 hectares which represents 24 % and 26 % of the total population and total number of hectares, respectively, in the NWP (NMMDM, 2012-2016). It has five local municipalities which are Mahikeng (previously Mafikeng), Ratlou (previously Setla-Kgobi), Ditsobotla, Tswaing and Ramotshere Moiloa (Figure1). To a large extent, NMMDM is rural and agricultural area with spots of a few secondary towns of Mahikeng-Mmabatho, Lichtenburg and Zeerust. Living income in NMMDM is very low (~555,000 people live below the minimum living income), the service industry (community services), manufacturing and agriculture sectors provide 44%, 3.4% and 12.9% contribution to employment, respectively (NMMDM, 2012-2016). Subsistence agriculture and game farming dominates the rural areas of RMLM; most manufacturing services are located in towns like Zeerust and Groot Marico while few active mines near Nietverdiend (RMLM, 2013).

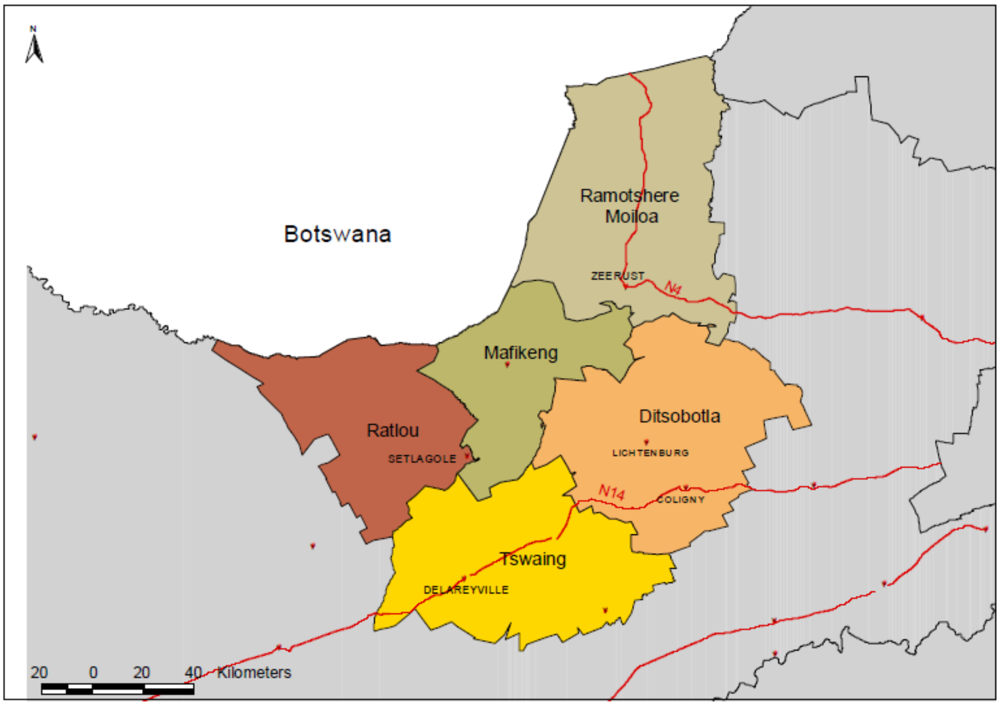

Figure 2: Map of Ngaka Modiri Molema District Municipality (Source: NMMDM, 2012-2016)

Data on 2011 agricultural households of Local Municipalities in NMMDM in NWP sourced from Statistics South Africa reveals the following on households in the vicinity of the RTBAA (Appendix 1).[22] About 14, 371 people are involved in agricultural activities in total. In descending order, their focus is poultry production, livestock production, production of other crops, vegetable production, other and fodder grazing. Most household heads (7,550) are men. The majority (13,644) of the farmers are Black Africans. Grade 1 to grade 11/Std9 education predominates the population of agricultural household heads. Income level of the household heads is between R1-R38400 (8,150 of the household heads). About 8,000 have access to piped water inside the dwelling/yard, about 5,210 have piped water outside the yard and about 1,160 no access to piped water. Regional/local water scheme (operated by a water service authority or provider) is the main source of water supplying about 9,000 agricultural households followed by households who source of water is from borehole (~3,400), water tanker (~1,460), Other (~350), River/stream (~50), Dam / pool / stagnant water (~50), Spring (~50) and Rain-water tank (~15).

Population and Agriculture on the Botswanan side of the RTBAA On the Botswana side, two urban districts (Gaborone and Lobatse) are physically in the SED (Figure 3). Among the 14 Districts in Botswana, SED is one of the smallest and it is bound to the southwest by the Southern District, to the northwest by the Kweneng District and in the north by the Kgatleng District (Figure 2). RTBAA includes the settlements of Ramotswa, Ramotswa station (Taung), Boatle and the surrounding area. Ramotswa is situated 32 km southwest from the city of Gaborone and centre of the SED with a population of 27,760 (2011 estimates). Taung and Boatle are smaller villages within its vicinity. Land use is predominantly livestock grazing and crop production is mainly wheat (the village's main industry is wheat flour production). There are three ephemeral rivers in the area which are also part of the Gaborone dam catchment and the Limpopo river basin (South East District Council, 2003; Kholoma, 2011). The ephemeral rivers are the *Ngotwane River* (located to the east of the village and forms the international boundary between Botswana and the Republic of South Africa), the Taung River which

[22] Annex 1 also contains data on the other 4 Local Municipalities in NMMDM

is a tributary of the Ngotwane River and the Boatle River which is a tributary of the Taung River. Other rivers in SED include Segoditshane, Maratadibe, Fikeng, Peleng, Mogobane and Nnywane.

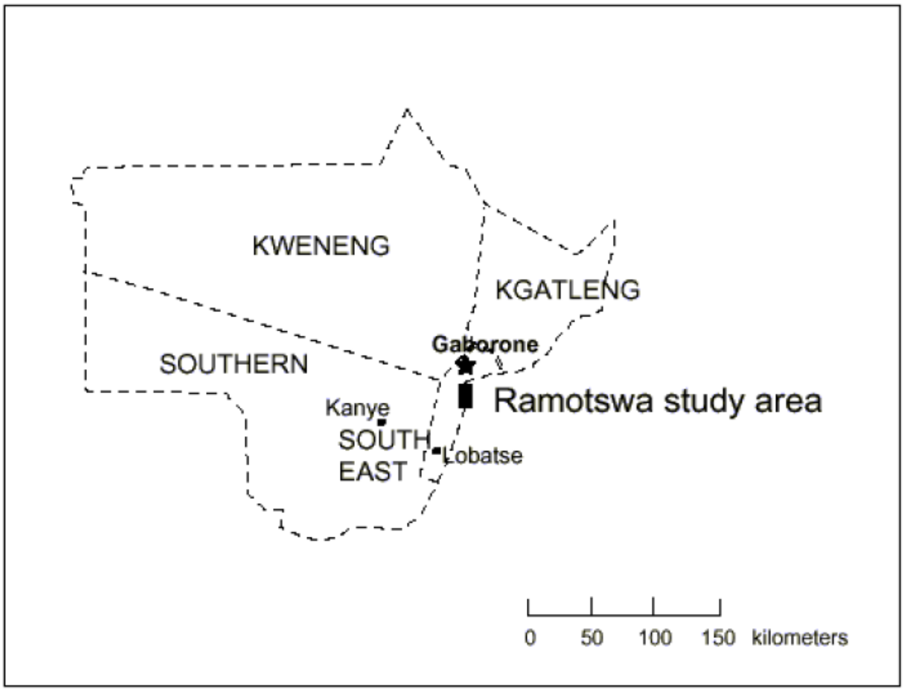

Figure 3: Location of the South East District and Ramotswa within Botswana (Source: Staudt, 2002)

Gaborone has the largest urban population and is among the fastest growing cities in Africa. Between 1991 to 2011, Gaborone has experienced a rapid population growth from 133,468 to 231,592 (Statistics Botswana, 2014). The current population (2013 estimates) is 247, 000 (United Nations, 2015). After the diamond driven socio-economic growth and development in the 70s and 80s in Botswana, major environmental and developmental challenges surfaced in Gaborone urban communities including but not limited to poverty, decline in agricultural productivity, lack of serviced land, endangered natural resources, water scarcity, absence of well organised recreational and open spaces, limited market on diversified products, high unemployment and increase in crime rate (Cavrić, 2004).

Lobatse is one of the oldest expatriate-initiated urban settlements in Botswana. It has competing land tenure systems, and is one of the highest levels of urbanisation in sub-Saharan Africa (Areola et al., 2014). It is approximately 70 km south of Gaborone, bounded on the east by the international border-South Africa. Longitude 25 30‟E approximates the western margin, while the northern and southern margins are about latitudes 24 30‟S and 25 30‟S respectively (GoB, 2003). Lobatse is surrounded by freehold farms of the SED and they are Woodlands 8-JO, Tsinani 9-JO, Traverston 10-JO, Readfontein 19-JO, and Springfield 18-JO (GoB, 2003; Areola et al., 2014). The manufacturing sector of the town is mainly agro-based industries beef processing (dominates the manufacturing industry employing a fifth of the total labour force), milling, brewery, leather tannery, bricks and tile manufacturing (GoB, 2003).

3 Irrigation Schemes in the vicinity of the RTBAA

3.1 Identifying and selecting irrigation sites

Discussions to identify potential sites In order to identify the sites for the ag-water solutions component of the project, information was collected from representatives from the Department of Agriculture in Gaborone and the SED Council based in Ramotswa. Input was also sought from professionals at Department of Water and Sanitation (DWS), and government representatives at near Zeerust, South Africa. Four criteria were developed to guide the search and selection of suitable farms (Table 1). The criteria are farm size, purpose for production, presence of small holder farmers, and baseline information of farms. Relatively few potential sites in and around the RTBAA met these criteria.

Criteria	Logic
Farm size	Farms greater than 2 hectares are of more interest because of their water abstraction rate. Also, the productivity of farms greater than 2 hectares may be higher. This includes crop yield per unit area of land and income from sales of produce per unit area of land. Farms of such sizes greater also have the advantage to access public subsidies/credit facilities. Therefore, they tend to have greater capacity for irrigation development. Conversely, plot size less than 2 hectares are less desirable because farmers are presumed to have less capacity for adoption of irrigation management technologies.
Purpose for production	The priority of traditional backyard farmers is production for household consumption/nutrition. They may have less incentive to improve productivity and sustainability. Smallholder to largescale commercial farmers are more disposed toward seeking agricultural water management improvements.
Presence of Smallholder farmers	Smallholder farmers contribute to food security at all levels (household, local and national), employment, poverty alleviation, and economic growth (Delgado, 1997; Deininger and Byerlee, 2011; Collier & Dercon, 2014; Samberg et al., 2016). It is therefore key that lessons learned from engagement with smallholders.
Baseline information on farms	Farms with baseline information such as crop yields, agronomic practices (fertilizer application rates, weed/pest management), water use and cost of energy for production are important because they provide a reference point against which WFD or chameleon-based management can be measured.

Table 1: Selection Criteria for Trial sites

Four potential sites Only four sites in the vicinity of the RTBAA – two in Botswana, and two in South Africa – met the four specified criteria (Table 2). This is believed to be consistent with a reality-on-the-ground in which irrigation is not a widely pursued activity at present. Field visits at two potential sites were conducted in June 2017 on the South African side of the border. Field visits were conducted in October 2017 on the Botswanan side of the border on two potential sites. Such visits also included efforts to identify additional sites that were not previously apparent, through insights from local knowledge. Additional schemes were not found.

S/No	Farm	Country	Coordinates
1	Ngotwane Commercial Farm	South Africa	S 25^{0}11.662 E 025^{0}48.086
2	Mothlake Cooperative farm	South Africa	S 25^{0}26.276 E 025^{0}51.557
3	Glen Valley Scheme	Botswana	S24° 40. 50 E25° 52.20
4	Mogobane Scheme	Botswana	S 24° 36.587 E 025° 57.619

Table 2: Potential Irrigation Schemes

Selecting three schemes The degree to which each site met the four criteria was considered. All farms exceeded the minimum size threshold. Purpose for production was also generally satisfied. Glen Valley and Mothlake each possessed smallholders. Ngotwane is a commercial farm, however, and Mogobane is managed as a community trust. Some baseline information was provided to us on Mogobane and baseline information on Glen Valley is available. Ultimately, a decision was taken to place focus on Mogobane, Motlake and Glen Valley irrigation schemes (Figure 4).

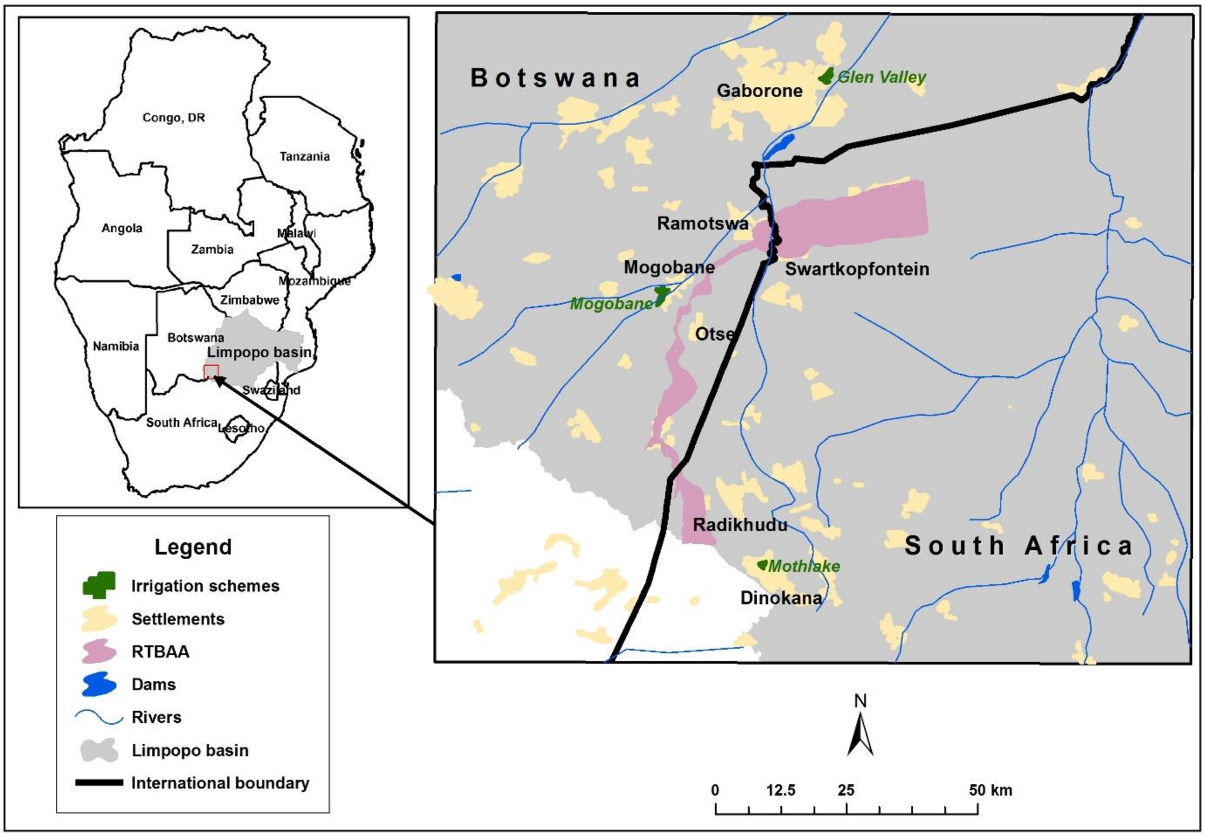

Figure 4: Selected Irrigation Schemes

3.2 Undertaking situational analyses in three selected sites

Approach This situation analysis for the Ag-Water Solutions is based on the data collected through focus group discussions and secondary data search in literature. An interview guide was developed which was used during the Focus Group Discussions (FGDs) and informant interviews (Questionnaire provided in Annex 2). Drawing on frameworks applied for analogous work (e.g., van Koppen et al., 2017), the following are the central investigative thrusts applied to each scheme and guide the structuring of the presentation of information on each scheme that follows:

- Overview
- Social Features (Number of farmers, size, year constructed, institutions)
- Physical Features (water quantity and quality, infrastructure)
- Agronomic Features (Crop choice, marketing)
- Challenges, Constraints, other issues

Importantly, the same information was not available on each scheme. While we have strived for uniformity in coverage of the different aspects shown immediately above, the different information available and provided to us in different sites meant that information presented below is not always the same across sites.

Participants The participants of the interviews were drawn from the membership of the scheme for Mothlake Irrigation Scheme. Discussions at Glen Valley took the form of a round table discussion which was held with agents from the Department of Agriculture that are responsible for the operation of Glen Valley irrigation scheme. These included the Director of Irrigation, 3 Agriculture Engineers, 1 Horticulture Specialist and Communication specialist from the Department of Agriculture (participant list for FGDs provided in Annex 3). These discussion were supplemented by meetings with 4 individual farmers at the scheme, which were selected randomly. Given the institutional structure at Mogobane, an interview was conducted with the scheme Manager and supplemented with one-to-one farmer input.

3.2.1 Glen Valley Irrigation Scheme

Overview

The Glen Valley scheme is among the development initiatives by the government of Botswana to alleviate stress to due limited water resources and boost agricultural production. The scheme uses secondary treated wastewater. Glen Valley is about 10 km northeast of Gaborone city, close to Notwane River. Its farms are situated between the Botswana Defence Force camp and the Gaborone sewage ponds. Effluent from the primary ponds in Glen Valley near the Gaborone Wastewater Treatment Plant is pumped by the irrigation division at the Ministry of Agriculture to secondary ponds for further treatment nearby (i.e., in Phakalane) and then pumped back to Glen Valley irrigation scheme to plots of private farmers (CAR, 2013).

Figure 5: Glen Valley Irrigation Scheme

Social Features

The scheme is on about 146 hectares of the designated 203 hectares of Glen Valley land. Private farms manage about 47 farms of different sizes (1-10 hectares) for the production of various arable crops. Water fees are practically not collected and no payment was made by farmers for pumps and water storage. Farmers' major investment is in the piping and control gear for drip-irrigation. Some of the problems the farmers encounter during production include unreliable water supply, frequent burst of pipes, post-harvest losses and slow response of the government to maintenance and water supply problems (Yaron et al., 2012). Nonetheless, during regular periods when infrastructure is functional, water is typically not a constraint to production.

Farmers The Glen Valley Irrigation scheme has a total of 47 farmers who lease land. Breakdown of these farmers by gender could not be obtained. Some of these farmers lease land at the scheme from government while other farmers are sub-leasing from those who acquired rights to the plots. Presumably this set of farmers employ additional staff (e.g., labourers), for which a precise number could not be determined.

Scheme Layout and Plot Sizes As noted above, the original design of the scheme covers 203 hectares but only 146 hectares is irrigable and cultivable due to other infrastructure and land development activities such as roads and buildings constructed within the original area earmarked for irrigation farming. However, many farmers have not fully developed their allocated land such that only approximately 50 hectares is under cultivation. According to the government officers, some farmers have not developed their allocated land due to lack of financial capital while others face annual fluctuations in availability of financial capital which is reflected in annual fluctuations in area cultivated.

Institutions Although a Water User Association (WUA) exists, it is not very active. Farmers are nonetheless provided technical support by the Ministry of Agriculture.

Physical Features

The scheme is operated by the Ministry of Agriculture which own the pumps and bulk water supply infrastructure from the dams to the inlet onto the farms. The government bears all the costs of pumping and delivering water to the scheme without any contribution from the farmers in the scheme. Even though a tariff was initially suggested and meters put at the beginning of the scheme in 2003, these meters have not worked and as such government has failed to collect any charges from the users. At the moment, the government pays about 25,000 Pula (~USD $21570) to the electricity supply company for pumping the water to the farmers.

Agronomic Features

Crops cultivated by farmers includes tomato, spinach, olive, green pepper, okra, maize, lucerne, butternut squash, water melon, cabbage and lettuce. Cultivation excludes root crops as this as these are presumed to pose more of a risk of contamination. Further, farmers use drip irrigation virtually exclusively, as this is presumed to present a reduced risk of contamination. Water is typically made available for 6 hours each day.

Challenges, Constraints, and other issues

As noted above, challenges existed related to burst pipes which can render water unavailable for several days at a time. Conversely, when water is available, farmers may lack incentive to conserve as there appears a lack of good-natured appreciation of the need to reduce water use; further, the lack of meters results in lack of consequences for applying water liberally. A past project on water-monitoring technologies was implemented on the scheme, with unclear results. Consulted farmers often seem to rely on observation-based methods for allocation of water to plants.

3.2.2 Mogobane Irrigation Scheme

Overview

Mogobane Irrigation Scheme is managed as a Community Trust. The proposal for the construction Mogobane Irrigation Scheme was approved in 1938, and construction was completed in late 1942. Crop production (wheat, maize, cowpea, potatoes and date palms) started the following year, 1943 (Taylor, 1977). Due to recent infrastructural problems, ten million Pula (~ USD $990,000) was awarded by the Rural Development Council under the Ministry of Local Government and Rural Development for the revitalisation of the scheme. Gamalete Development Trust – GDT (the Project Management Team for revitalisation of the scheme) reported that the funds have been used for fencing, drilling of two additional boreholes, construction of reservoir, layout of irrigation pipes with drips, electricity, van and machinery (The Botswana Gazette, 2016).

Social Features

The size of irrigated area is about 102 hectares. While the scheme's original source of water for irrigation is from the Mogobane Dam which was conveyed through a canal, the scheme now uses groundwater through a borehole that has been installed due to degradation of the canal.

While as noted the scheme has an area of 102 hectares, only 10 hectares have been developed for cultivation mostly due to lack of adequate water supply. Unlike other irrigation schemes, Mogobane is not divided into several plots as it is operated as one entity. The scheme though is subdivided depending on the type of crops grown in a particular season, which normally changes from one season to another. The image below displays the scheme layout (Figure 6).

Figure 6: Mogobane Scheme Layout

Farmers/Resource Users This scheme is managed by a scheme manager who is appointed by the Trust and supported by 10 farm labours (7 Females and 3 Males). There are also 4 security personnel on the farm, and 1 farm supervisor. An accountant and a messenger also support the Scheme Manager.

Institutional Arrangements The Mogobane Irrigation Scheme is managed by the Ba-Malete Development Trust which appointed a Scheme Manager. The current manager has a permanent appointment since April 2016. The manager is responsible for the operation and maintenance of the infrastructure and management of the agriculture production at the scheme. The scheme does not belong to a WUA. As such, it operates as an autonomous entity. In addition, it was noted that the scheme does not have any water use or groundwater utilisation permit/licence as this is not required in Botswana.

Physical Characteristics

Soil Quality Even though there is not sufficient data to substantiate the quality of soil in the scheme, the scheme manager indicated that they have experienced some difficulties with the response of certain crops in the growing season. For instance, it was reported that some crops such as pumpkins and spinach in some sections of the farm do not grow well regardless of how much water and nutrients are provided with some crop visibly wilting. This suggests that there might be an accumulation of certain salts which require investigation. Consideration should be made in the project to conduct soil tests and analysis.

Water Resources (Quantity) The scheme as indicated earlier used to get its water from the Mogobane Dam, but this is no longer an option due to poor infrastructure. The dam spillway was washed away, and the canal need some rehabilitation and refurbishment. It must be stated that the dam has sufficient water that can support expansion of production activities beyond 10 hectares. Nonetheless, the farm uses groundwater through a borehole that was sunk in the year 2015. Information on groundwater yield was not available. It is suggested that a test should be conducted using the current borehole to determine the yield.

Water Resources (Quality) During the engagements with the farm manager, there was no complaints regarding the quality of the water used for irrigation. However, the manager indicated that it would be ideal to establish the quality of water used. This is particularly important for the marketing of their vegetable produce which is mostly consumed raw. In addition, concerning soil quality, Mitchell (1976) reported that the structure of the surface soils in Mogobane Irrigation Scheme are generally poor with texture ranging from loamy sand to clay. The infiltration rate is low as clay concentration increases down the profile with observable plough pans at the surface horizon. (Mitchel, 1976; UNECA, 1983).

Irrigation infrastructure Drip irrigation kits have been installed at the scheme. Further, the scheme uses nets to prevent infestation of pests and diseases. These have been installed on 1 hectare of the piece of land and is mostly used for crops such as tomatoes.

Water infrastructure Existing infrastructure such as canals and hydrants that are dilapidated and requiring rehabilitation if they have to be functional again. It was reported by the manager that the government of Botswana is considering providing funding to rehabilitate the dam and conveyance infrastructure. As such, the scheme is in the process of developing and sinking an extra borehole to meet the water deficit.

Agronomic Features

Current crop production in the scheme include maize, cabbage, green pepper, tomatoes and lettuce. Figure 7 below highlights the total area planted for various crops in the scheme, presented as cumulative totals per annum. From this graph, it can be observed that the scheme has a higher proportion of land for butternut (23%), beetroot (19%), cabbage (14%) and maize (10%). The scheme is fully utilized in the months of May, August and September and the maximum area under cultivation is approximately 3.9 hectares. According to the scheme manager, this size is limited by available water and capacity of the pump.

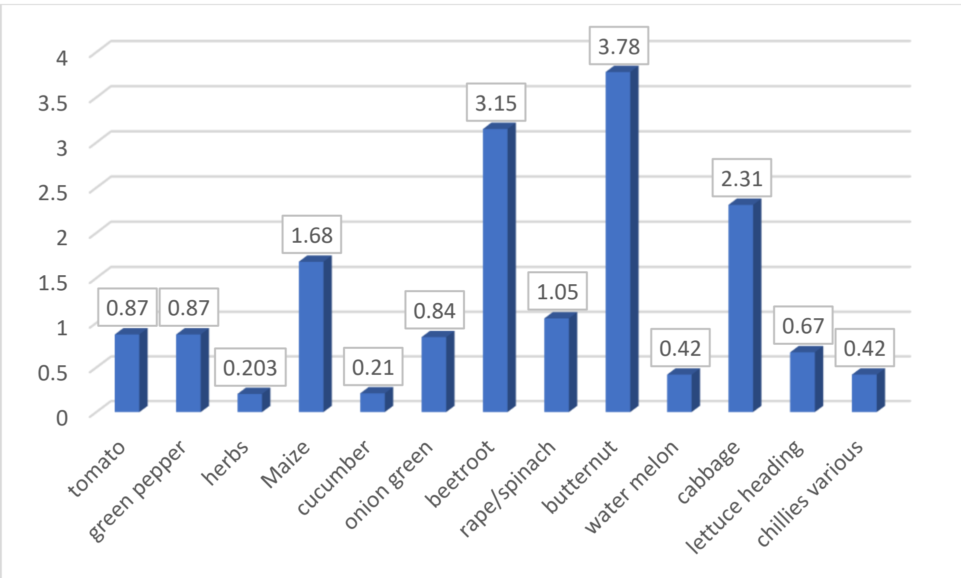

Figure 7: Total Hectares per crop, Mogobane Scheme

Crop Yield in Mogobane Regarding crop production yield, it Mogobane Scheme produces more vegetable such as cabbage and butternut than other crops on the farm (Figure 8). This can be attributed to the fact that these crops have greater marketing potential than the other crops.

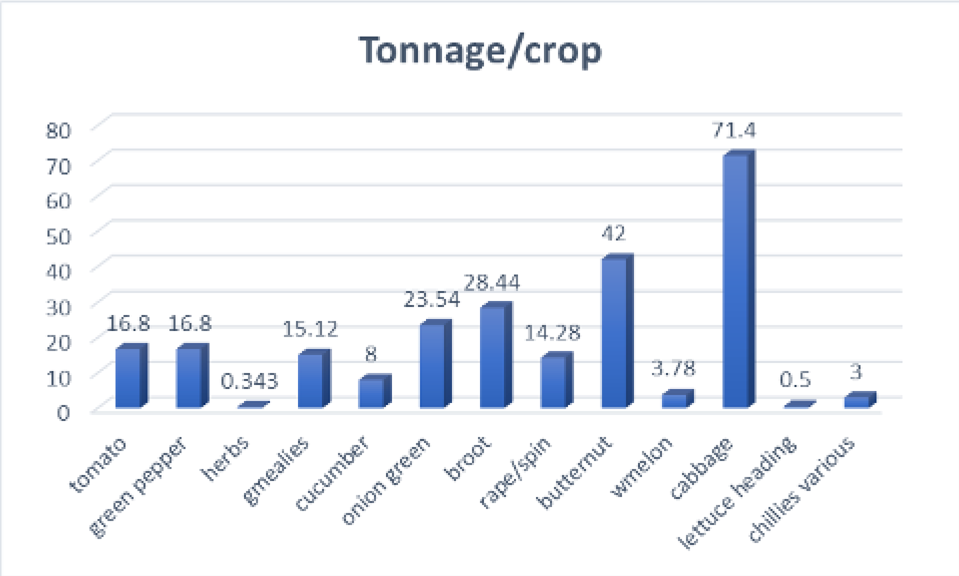

Figure 8: Crop Production, Mogobane Scheme

Agronomic Practices: Being a small irrigation scheme, Mogobane has a very well planned agronomic schedule to ensure that they conserve water on the scheme. This is done by ensuring that they don't plant crops that have a higher water requirement at the same time. They have developed a crop schedule which outlines which crops would be grown in a particular season. This ensures that they are able to optimise the use of available water.

Figure 9: Tomato Crop under netting (Photo Credit: Quinex Chiluwe)

Irrigation Management: The farm uses an established irrigation schedule which was developed by the Ministry of Agriculture. However, it must be stated that the scheme does not always follow this schedule as sometimes the crop might show the signs that it requires more water. In such cases, the farmer uses observation to determine how much water required to meet the needs of the crops. This is done due to lack of appropriate technologies that can be used to complement their existing irrigation schedule.

Markets and Marketing According to the farm manager, the scheme is considered as the bread basket for the SED as it sells its produce at major retail shops such as Choppies, Mr Vegetables, the Police College and local markets. In order to access these and other potential markets, the scheme belongs to a cooperative for the SED.

Challenges, Constraints, and other issues

Opportunities Opportunities exist for the Mogobane irrigation scheme to expand. For instance, the government of Botswana has stressed the need to reduce import of agriculture produce from neighbouring countries such as South Africa. This gives local farmers such this one a good outlook in terms of marketing opportunities. Further, the government through various banks such as Rural Development Council have offered to support schemes like this one with finances to improve their agricultural productivity. To that effect, the Trust has obtained agricultural loan from the bank amounting to BWP 5 Million (~USD $ 491 000) which has been used to install the water pump at the scheme, install the irrigation infrastructure, and buy farm equipment and inputs.

A role for monitoring Even though the scheme is not using advanced irrigation technologies except for the drip kits, there is a good opportunity to try various technologies according to the scheme manager. For instance, the manager indicated that their irrigation scheduling requires optimising, while also improving their ability to monitor soil nutrients and salinity levels to improve productivity. He also indicated that they would be interested to try technologies that would help them test and monitor groundwater quality even though their groundwater is not considered to be of any threat at the moment.

Challenges A number of challenges exist for the irrigation scheme, the most prominent one being insufficient water availability for enhancing agricultural production. This challenge is exacerbated by the poor infrastructure. Once a very vibrant scheme in 1970s, the scheme is only operational for an area of approximately 4 hectares due to broken canals resulting in the scheme relying on groundwater as a sole source. This reinforces the scheme needs to optimise its water use in order to improve agricultural production. Introducing soil moisture/water monitoring devices would considered a very important initiative for this irrigation scheme as this would enhance water productivity, particularly given that farmers often continue to lean on observation-based methods for water application.

3.2.3 Mothlake Irrigation Scheme

Overview

The Mothlake Irrigation Scheme was established in the early 1980s with a primary purpose of alleviating food insecurity and poverty within the Tribal Trust Land of Dinokana. An extensive history of the irrigation scheme has been well documented by Drummond and Manson (1993). At the time of establishment, the scheme was primarily meant for rice cultivation and up to 80 hectares of land was under cultivation. The major source of water was the Dinokana eye (a spring that flows throughout the year). With open irrigation canals, the scheme used flood irrigation and production flourished.

Social Characteristics

Resource Users/Farmers: The irrigation scheme has a total of 60 farmers where 36 are females and 24 are males each owning various sizes of plots ranging from 10 meters by 20 meters to about 20 meters by 50 meters. Of these, the scheme has a total of 18 youth farmers (30 years or less). Some farmers have been working at the scheme since the 1980s. Women constitute the larger proportion of farmers on the scheme even amongst the youths (Figure 10).

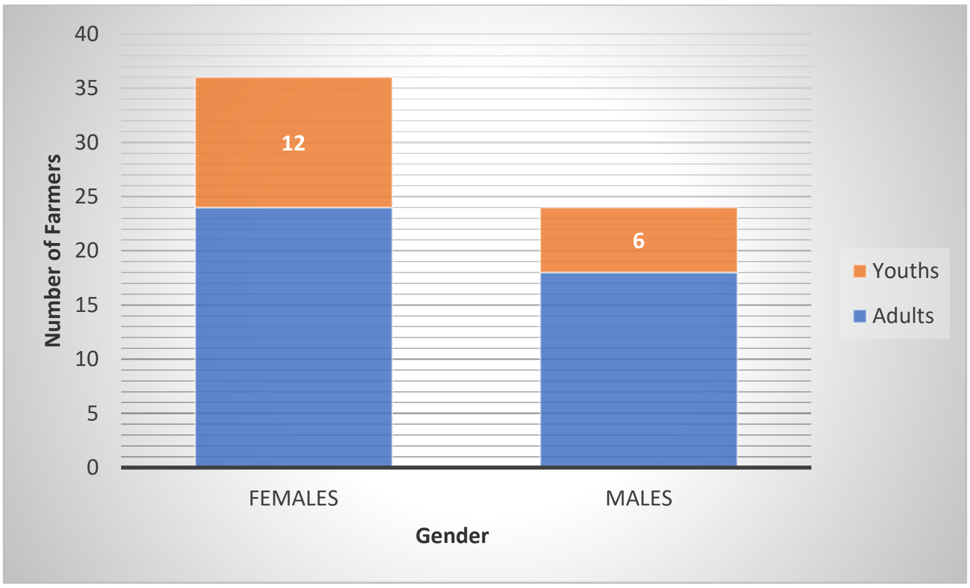

Figure 10: Farmers on Mothlake Scheme

Scheme Utilisation and Scheme Operation As indicated earlier, the scheme is operating at a fraction of its original size due to challenges to do with infrastructure and water resources. Nevertheless, the scheme has been able to operate using the available water resources by ensuring that every user takes a turn to irrigate their crop. Indeed, there is no written schedule for irrigation and every farmer irrigate whenever they want to as long as they coordinate with the fellow farmers irrigating at that particular time. A challenge, however, arises when there is peak demand for irrigation as farmers then at time enter into conflicts of irrigation schedule. Depending on the position of the farmer on the canal, a farmer may either over-irrigate or under irrigate.

Scheme Layout and Plot Sizes The layout of the overall scheme has been shown in Figure 11 below. From the image, it is evident that considerably less than half of the originally irrigable area is currently under cultivation. Currently irrigated area varies from year to year, roughly between 10 and 15 ectaresa. In the current cropping season, approximately 10 hectares was cultivated on plots ranging from 10 meters by 20 meters to about 20 meters by 50 meters.

Figure 11: Scheme Layout, Mothlake

Institutional Arrangements The scheme is managed by a committee which has 8 members, 4 of which are females. The committee was elected in 2015 and has a 5-year term. In order to manage the affairs of the scheme, they have a constitution which has been approved by the chief of the village who often intervenes when there are conflicts amongst water users. However, it was surprising to learn during the discussion that the farmers not heard of a WUA; nor were they aware of water use licences.

Physical Characteristics

The scheme is located within the lower reaches of the Maphanyane wetland that receives free flowing water from the Dinokana *Eye* (the spring). Infrastructure such as canals and a holding weir were constructed around 1980s to divert water from the *eye* to the farmers' plots. However, this infrastructure is no longer functional such that the scheme does not receive sufficient water for production. Some sections of the canal have been broken down while other sections have been colonised by trees and other plants thereby destroying the canal bed.

It should also be noted that even though the spring still produces sufficient water, most of this water does not reach the canal because of heavy siltation that has taken place at the weir site (see the picture below). Further, it must be stated that the weir site requires rehabilitation especially on the diversion structure (Figure 12) into the canal which appears to be broken down as well.

Figure 12: Diversion Structure at the Weir

After realising that the spring does not provide sufficient water for their irrigation scheme, the government supported development of two additional boreholes. However, these too are not able to satisfy the water demand at present, as they lack sufficient maintenance. One of the boreholes was vandalised and the farmers have not been able to repair it properly. Figure 13 is a night storage reservoir (NSR) which receives water from the boreholes. As evident from this photo, the reservoir is dry and cannot be used to supplement the water from the spring.

Figure 13: NSR with less than 10% water

Soil Quality There are minimal complaints from the farmers regarding accumulation of salts in the soil. However, it was noted that some crops were wilting despite providing sufficient water. This can be attributed to either high salinity levels or development of hard pan at the ploughing level preventing good root development in the soil. This shall require further investigation.

Water Resources (Quantity and Quality) In a good year, the Dinokana spring produces sufficient water to enable strong agricultural production. With a yield of 5184 m3/day (DWS, 2005) the spring has also been used by the DWS to develop a water supply scheme which provides domestic water for the community. However, the farmers feel that since the development of the water supply scheme at the site in early 2015, water for irrigation has declined as more water is pumped away to the other reservoir. Nonetheless, the poor state of the intake weir and irrigation canal may very well be responsible for their challenges to an equal or greater degree.

Agronomic Features

Although data on crop production was not available for the scheme during the assessment, the farmers indicated that crops they normally grow include maize, cabbage, tomatoes, beetroot, lettuce and pumpkins. Data on size of plots for each of these crops and corresponding yield could not be accessed at the time of assessment.

Figure 14: Farmers observing the furrows to be full

Allocating water to crops It must also be pointed that the absence of an irrigation schedule means irrigation is neither controlled nor measured. Using furrow system, a farmer just makes sure that his furrows are full of water to know they have enough water (Figure 14). This has been one of the reasons for conflicts as well as increased water losses.

Markets and Marketing While limited water resources has caused agriculture productivity to significantly reduce over the years, the farmers indicated that demand for their farm produce has always been increasing. Some of their produce has been sold locally within the community while some produce has been sold to retail shopping outlets within the nearby towns. It must be indicated that farmers bemoaned failure to meet demand for green vegetables especially during winter due to lack of water to increase production. This, they contend, has made it difficult for them to get contracts with companies that buy produce in bulk.

Challenges, Constraints and other issues

Water Shortage A number of challenges exist at this scheme. One of the prominent challenges is obviously the shortage of water. This suggests that there is an opportunity to introduce water saving technologies so that they can improve agricultural productivity with the little available water resources.

Lack of Irrigation Scheduling In addition, it was found that the farmers do not practice any irrigation scheduling to determine how much and when to irrigate their crops. This presents an opportunity to introduce capacity building for agriculture water management technologies such as water monitoring tools as well as simple irrigation scheduling practices.

Furrow Irrigation Use of furrow irrigation had been repeatedly pointed to as a challenge by the farmers especially to the amount of losses it renders in the midst of the water scarcity. Farmers do realise that using improved irrigation technologies such as drip irrigation system would be ideal for their scheme. They however also do recognise that they do not have the financial muscle to fund installation of this equipment.

Potential for Water Re-use Looking at the challenge of water, a discussion on the possibility of using grey water for irrigation was undertaken with the farmers. The farmers however indicated that they have huge reservations on using grey water as they are not sure of the quality of the produce. They indicated that they would require to be well oriented on the side effects of grey water on their health and that of the crops.

4 Approach for improving Agricultural Water Management on Selected Schemes

4.1 Overview of Soil Water Monitoring Tools

Soil water monitoring tools Three ways to measure soil water status are gravimetric soil water content (SWC), volumetric SWC and soil water potential (Charlesworth, 2005). *The gravimetric SWC* is described on weight basis (g of water per g of dry soil), the *volumetric SWC* is calculated by multiplying the gravimetric SWC by the soil bulk density (cm^3 of water per cm^3 of soil or mm^3 of water per cm^3 of soil). The soil water potential (soil water suction) is a measure of soil tension i.e. the energy (kilopascals, kPa) needed to extract the water that is held more tightly as the soil becomes drier (Charlesworth, 2005). Most soil water monitoring (SWM) tools use suction or volumetric water content indirect measurement systems to provide information related to the soil moisture status of the particular soil they are placed in (Charlesworth, 2005; Bittelli, 2011).

SWM tools for application Two SWM tools (Wetting Front Detector also known as FullStop™ and the Chameleon sensor) exist. Wetting Front Detector (WFD) and Chameleon sensor operates on the suction principle. They are simple, and affordable with substantial potential to improve famers' understanding on soil water and nutrient management.

Wetting Front Detector (WFD; Box 1) is useful in the management of nitrate and salt as well as improving irrigation water efficiency under different crops, soil types and irrigation methods in

Box 1: Wetting Front Detector

WFD is an irrigation scheduling and nutrient monitoring tool developed by Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land & Water. WFD is funnel-shaped and comprises of a filter and a mechanical float mechanism. It is usually used in pairs and are buried at prescribed depths in the root zone of plants. It is designed to allow the funnel to concentrate the downward movement of water so that saturation occurs at the base of the funnel producing free water. Free water during or shortly after irrigation is produced at the base of the funnel when the suction of the soil around the WFD is about 3 kPa. The free water produced from the unsaturated soil activates a mechanical float which in turn operates an indicator flag above the soil surface alerting the farmer that water has penetrated to or past the prescribed depth in the soil. The sample of soil water captured by the detector is used to measure the concentration of solutes (salt and nitrate) in the soil profile.

(Sources: Stirzaker & Hutchinson 1999; Stirzaker, 2003; Stirzaker, 2005; Stirzaker et al., 2005; Stirzaker, 2006; Stirzaker & Hutchinson et al., 2006).

Bundaberg, Canberra and Gosford, Australia (Stirzaker and Hutchinson, 1999). Similarly, additional case studies in Australia on the assessment of WFD as a practical means for scheduling irrigation and soil nutrient management have been reported (Stirzaker & Wilkie 2002; Stirzaker, 2003; Stirzaker & Thompson, 2004; Stirzaker & Hutchinson, 2006). Also reported in another study (Stirzaker, Sunassee and Wilkie, 2004) in Australia are field trials to compare WFD, tensiometer and time domain reflectometry (TDR) methods for monitoring water, nitrate and salt have been reported.

Chameleon Soil Water Sensor (Box 2) Unlike the WFD, there are no published reviewed articles on the use of Chameleon sensor for improving irrigation. Pilot tests of the chameleon sensors under small research and development activity, Australian Centre for International Agricultural Research (ACIAR) projects are ongoing in Mozambique, Tanzania, Malawi and Zimbabwe (ACIAR, 2017; Stirzaker, 2016).

Box 2: Chameleon Soil Water Sensor The Chameleon sensor was also developed by CSIRO Land & Water for determining soil water content to improve irrigation scheduling. The sensor is designed with the resistivity principles of the watermark sensor demarcating three water levels (wet soil, moist soil and dry soil). The Chameleon soil water sensor comprises of an array of 3 or 4 sensors. In a monitoring site, the sensors are buried in the soil at different depths, a portable handheld reader is connected to the buried sensors which gives an output via colour diode (blue, green and red) and a phone app where the visual output from the reader is entered and later time-stamped, geo-referenced and displayed for the user. The data is displayed as colour lights (blue, green or red meaning soil is wet, moist or dry respectively). The name 'Chameleon' was chosen because it changes colour to reflect its surroundings such that soil water conditions from the top of the soil to the root zone of the plants. This shows the farmer how well the irrigation refills the soil and how hard it is for the plants to absorb water from the soil.

(Sources: Stirzaker et al., 2014; Stirzaker, 2016).

Investigations into use of WFD and Chameleon in Africa are limited and are at preliminary stages While data are increasingly being collected on implementation of WFD and Chameleon in Africa, only six reports (Geremew et al, 2008; Stirzaker et al., 2010; Fessehazion et al., 2011; Adhanom, 2014; Stirzaker, 2016; Stirzaker et al., 2017) have focused on their application. Geremew et al (2008) observed that the use of feedback from WFDs to regulate irrigation amount recommended by Soil Water Balance (SWB) model calendar was not effective. Stirzaker et al (2010) reported that irrigators in South Africa see WFD as simple, intuitive and advantageous over their usual practice. Fessehazion et al's (2011) field experiments revealed that water management approaches using WFD can improve nitrogen and irrigation water use efficiency without compromising yield and forage quality of annual ryegrass. In the determination of the sensitivity of

WFD for managing irrigation water in the root zone, Adhanom (2014) found that length of WFD designs have significant effect on the sensitivity (a modified version of 90 centimetres was more sensitive). However, recent report (Stirzaker et al., 2017) showed that scheduling irrigation using WFD at 600 millimeter depth was not effective because of the inability of WFD to detect weak wetting fronts at this depth. Results from pilot studies in Tanzania, showed that Chameleon sensor was effective in irrigation scheduling as well as prevented leaching of nutrients and increased yield of tomatoes, onions and green maize (Stirzaker, 2016). Despite their important work, key gaps remain including:

1. Quantification of immediate impacts of tool introduction on crop production and irrigation water use efficiency with reference to smallholder or large scale commercial farmers
2. Identification of broader impacts of such tools on income and livelihoods on different scales (smallholder and large scale commercial farmers)
3. Examination of viability of such monitoring tools on schemes relying on treated wastewater
4. Identification of constraints to adoption of the monitoring tools.

4.2 Design of Field Trials and Experimental Plots

The study shall be designed to accommodate the differences in the local conditions in the 3 different schemes under investigation. It must be noted for instance that while farmers at Mothlake Irrigation Scheme work as a group, farmers at the Glen Valley Irrigation scheme operate on individual basis while that for the Mogobane is one farm managed by one individual. This highlights the need to adapt approaches to these different realities.

Considerations for site design

i) The study should consider using both rainfall and irrigation seasons to be able to provide useful insights valuable for both supplemental and full irrigation.
ii) Significant agricultural inputs for the plots such as seed, fertilizer and chemicals might be required for the Mothlake Scheme. Capacity appears relatively lower on this scheme.
iii) Sufficient capacity building to be done prior to the implementation of the trials to ensure that the farmers understand the use of WFD and Chameleon Sensor in enhancing the effective management of water application.

Objectives of the Field Trials

i) Evaluate impact associated with the use of WFD and Chameleon Sensor on agricultural water productivity
ii) Identify the constraints to adoption and the potential for outscaling of tools amongst smallholder farmers

Methodology for Field Trials

The following sections provides a detailed methodology for conducting the field trials and monitoring the impact of these technologies.

Objective No 1: Evaluate impact associated with the use of WFD and Chameleon Sensor on agricultural water productivity

In order to address this objective, the following methodology shall be utilised.

Selection of appropriate technological designs and models In order to provide a targeted approach and evaluate associated impact, the study team shall select appropriate model of the WFDs based on previous studies. This accounts for availability of variety of designs of WFDs such as Tube Detectors, Fullstop detectors and Hybrid Detectors.

Training of farmers in the operation and maintenance of the WFDs and Chameleon Sensors Upon selection of the appropriate models to be used, farmers will be trained on the use of WFD and Chameleon sensor. The capacity building will be targeted at farmers that will participate in the trials directly (for the cases of Glen Valley and Mothlake) and workers that will be directly involved in the trials at the Mogobane Irrigation scheme. The training shall aim at educating them on how to install, take readings and interpret the readings on the technologies as well as keeping records of their various routine activities on the trial plots. It shall also be important to train the farmers to be able to troubleshoot any minor problems encountered during the course of using the technologies.

Establishment of Trials sites and Plots A participatory action research approach will be followed. In the participatory action research, the approach is to have a demonstration plot of size 70 by 70 meters (4900 m^2) on farmer's field to create a learning activity for the farmers. Due to the institutional arrangement in these schemes, the trial sites and plots shall be designed to suit the individual conditions of the irrigation scheme. For instance, consideration shall be put on type of crops being grown by farmers in that particular season recognising that impact on productivity will be easy to identify if the same crop is trialled at the same time. This suggest that selection of farmers to participate in the trials at Mothlake and Glen Valley Schemes will depend on their ability to plant the same crop during that season.

Establishment of trials (installation of sensors on farmers' fields) will be based on arrangement with farmer(s) on the nearest cultivation time. At least two farmers' fields shall be used as trial plots at Glen Valley Irrigation scheme so that we can be able to learn their experience with the technology. For the Mothlake irrigation scheme, farmers own very small irrigation plots and do not have structured irrigation schedule. This suggests that the trials at this scheme should be tailor-made to suit the local conditions. This might mean establishing one demonstration plot where all farmers are responsible for managing the agronomic practices. For the Mogobane scheme, installation of the sensors in one demonstration field is sufficient. For the three seasons, it is suggested that a different crop be used in a season and a different group of farmers be used to generate a variety of experiences.

Data collection and monitoring Farmers will be visited monthly for effective feedback on practices and data collection. The following is the preliminary dataset that must be collected.

(a) Soil Profile

The soil data for all the irrigation demonstration plots shall be collected to determine the soil type, composition, soil field capacity, permanent wilting point and soil depth. This is particularly important as the response of the crops to soil water moisture and nutrients availability is dependent upon the type of soil and this has also the potential to affect the response of the sensors.

The soil samples collected at different depths in the demonstration plots shall be collected using a soil auger. The samples shall be taken to the lab for analysis for chemical and physical composition.

Soil nitrate and salinity will be monitored weekly from soil solution that will be collected from Wetting Front Detectors. Nitrate test strips and Pocket Electrical Conductivity (EC) meters will be used to measure nitrate and salinity respectively. Monthly average will be reported for each crop production cycle.

(b) Crop productivity

Crop production records at the end of each cropping cycle will be observed. The measurement for this will be crop yield per unit of land used for production (tons/ha).

(c) Water use efficiency or water productivity

Daily volume of irrigation water flowing onto farm for each crop (m^3) during crop production cycle will be recorded. Daily rainfall should also be recorded. Water productivity will be crop yield per quantity of water used for production (tons/m^3). However, measurement of volume of irrigation water depends on the peculiarity of site (source of water and irrigation system).

(d) Fertilizer used

Farmers will also be required to record any fertilisers that have been used on the demonstration plot and previous season crops planted. This would help to determine the quantity of nutrients available in the soil versus the baseline that shall be collected during the soil analysis.

(e) Change of Practice

The impact of changed practices will be evaluated. Farmers can link their visual inspection of the soil to the level where the sensor indicate that irrigation should commence. The degree to which indications from sensors do or do not match with their intuitive approach will be gauged.

Identifying a "control" area for comparison To provide an indication on the degree to which plots that make use water-sensing technologies elicit different impacts from those not making use of such technologies, a control area will be identified and monitored on each scheme. Selection of control area will be heavily dependent on the ability to monitor the set of key parameters just described. The control area is expected to be of equal or greater size than the area on which water-sensing technologies are tested.

Data Analysis and Reporting Following collection of relevant data, quantitative data will be analysed using simple descriptive statistical tools such as average, percentage, standard deviation, and frequency distribution of Statistical Package for Social Science (SPSS, Version-22, SPSS Inc., New York, NY, USA) software. Farmers' stories on modification of practice based on feedback from tools will be analysed using SenseMaker® Cognitive Edge software (http://cognitive-edge.com/sensemaker/). Data on physiological and morphological traits of interest of selected crops will be subjected to Analysis of Variance (ANOVA) using proc GLM of Statistical Analysis System (SAS) software.

Objective No 2: Identify the constraints to adoption and the potential for outscaling of tools amongst smallholder farmers

Data Collection Semi-structured questionnaires will be used to document farmers' stories and feedback on modification of practice based on feedback from the technologies. The analysis of data collected will be used to provide information on constraints to adoption and the potential for outscaling of the technologies. The information for this objective shall be collected at the end of two growing season. This means that two sets of data shall be collected and will therefore provide extensive and in-depth depiction of farmers' experiences.

In order to assess farmers' knowledge on water and nutrient management as well as modification of practice based on information from sensors, FGDs and or semi structured questionnaires will be conducted at the end of each crop production cycles. Farmers will be asked open ended questions such as (1) What are the lessons learnt? (2) What changed or what practice do you plan to change? (3) What are the unclear issues?

Further, the study will investigate various factors that might pose as constraints associated with the adoption of WFD and Chameleon. These could range from levels of difficulty to operate and maintain the technologies or lack of access to finances to buy the technologies. As such, the study shall investigate socioeconomic factors including;

- Access to finance for example credit facilities, subsidies or incentives
- Market infrastructure
- Educational level of farmers
- Access to agricultural information/extension services
- Farm infrastructure and
- Farm inputs

Data analysis Quantitative data generated will be analysed using simple descriptive statistical tools such as average, percentage, standard deviation, and frequency distribution of Statistical Package for Social Science (SPSS, Version-22, SPSS Inc., New York, NY, USA) software. Responses given by farmers to open-ended questions will be examined in a variety of ways that are often qualitative in nature, in order to elicit factors explaining use or disuse of new technologies and approaches. Such analysis will also focus on understanding the potential relevance of other, potentially overlooked factors in unlocking the potential of agriculture in the region.

5. References

ACIAR, 2017. Virtual Irrigation Academy (VIA) Project. Details available online: http://aciar.gov.au/aifsc/projects/virtual-irrigation-academy-improve-water-productivity-malawi-and-tanzania

Adhanom, G.T., 2014. *Design features determining the sensitivity of wetting front detectors for managing irrigation water in the root zone* (Doctoral dissertation, University of Pretoria).

Alemaw, B.F., Scott, K. and Sullivan, A., 2010. Water Availability and Access in the Limpopo Basin. Challenge Program on Water and Food (CPWF) Working Paper: Basin Focal Project Series, BFP-L01. Colombo, Sri Lanka: CGIAR CPWF.

Areola, A. A., Gwebu, T. D., & Sebego, R. J. (2014). A spatio-temporal analysis of peri-urbanisation in sub-Saharan Africa: a case study from Lobatse, Botswana. *African Geographical Review*, *33*(2), 174-201.

Bittelli, M., 2011. Measuring soil water content: A review. *HortTechnology*, *21*(3), pp.293-300.

Botswana College of Agriculture Consult (BCA Consult, 2012). Consultancy for the poverty and social impact analysis of the integrated support programme for arable agriculture development (ISPAAD) for the United Nations Development Programme Republic of Botswana. BCA Consult (Pty) Ltd. Pp.96. Retrieved from https://www.unpei.org/

The Botswana Gazette*. Kgosi Seboko conflicted in p10 million Mogobane Project*. 10 March 2016. http://www.thegazette.news/?p=13823e

Botswana Institute for Development Policy Analysis (BIDPA). 2001. National Master Plan for the Arable Agriculture and Dairy Development (NAMPAADD) Implementation. Guidelines. Retrieved from https://www.africaportal.org/dspace/articles/national- master-plan-arable-agriculture-and-dairy-development-nampaadd

Cavrić, B.I., 2004. Planners' roles and techniques in developing sustainable'eco-city': The case of Gaborone, Botswana. *Spatium*, 11:53-76.

Centre for Applied Research (CAR). 2013. Scoping report for the state of waste management in and around Gaborone. Report prepared for the Japanese Government by CAR. 53p.

Charlesworth, P., 2005. Soil water monitoring. Published by: Land & Water Australia on behalf of the National Program for Sustainable Irrigation.

Cunguara, B. and Darnhofer, I., 2011. Assessing the impact of improved agricultural technologies on household income in rural Mozambique. *Food Policy* 36(3): 378–390.

Department of Water Affairs and Ministry of Minerals, Energy & Water Resources (DWA & MMEWR, 2013). Botswana Integrated Water Resources Management and Water Efficiency Plan (L. Dikobe, Ed.) Gaborone, Botswana: Government of Botswana. Volume 1&2: Main Report and Appendices Pp. 153.

Ernst, D. and Ewert, K. (2011). Re-evaluation of the Platinum SDI: a critical commentary *Journal of Economic and Financial Sciences* 4(1):81-98

Fessehazion, M.K., Stirzaker, R.J., Annandale, J.G. and Everson, C.S., 2011. Improving nitrogen and irrigation water use efficiency through adaptive management: A case study using annual ryegrass. *Agriculture, ecosystems & environment*, *141*(3), pp.350-358.

Geremew, E.B., Steyn, J.M. and Annandale, J.G., 2008. Comparison between traditional and scientific irrigation scheduling practices for furrow irrigated potatoes (Solanum tuberosum L.) in Ethiopia. *South African Journal of Plant and Soil*, *25*(1), pp.42-48.

Government of Botswana (GoB, 2003). Lobatse Urban Development Plan 2 : 2003 – 2009. "Towards Realisation of Vision 2016: Sustainable and Diversified Development through Competitiveness in Global Markets." Lobatse Town Council- Lobatse Urban Development Committee Ministry Of Local Government. Pp.143. Retrieved from http://www.gov.bw/Global/MLG/UDPs/Lobatse_UDP.pdf

Government of Botswana (GoB. 2011). Wastewater reuse and water harvesting for irrigation study- request for technical assistance fund for middle income countries. Department of Agriculture and Agro-industry. Submitted to African Development Bank, pp.9

Government Communication and Information System (GCIS, 2016). South Africa Yearbook 2014/15. Pp.59. Retrieved from http://www.gcis.gov.za/

Hanjra, M.A., Ferede, T. and Gutta, D.G., 2009. Reducing poverty in sub-Saharan Africa through investments in water and other priorities. *Agricultural Water Management* 96, 1062–1070.

International Fund for Agricultural Development (IFAD), 2010. Republic of Botswana Agricultural Services Support Project (ASSP). Project Design Report Draft Final Design Stage. Eastern and Southern Africa Division Project Management Department, IFAD. Pp.22.

Juana, J.S. (2014). Aid and the environment: The case of Botswana. WIDER Working Paper, No. 2014/007. Pp.27. Retrieved from http://hdl.handle.net/10419/96296

Kemp-Benedict, E., Cook, S., Allen, S.L., Vosti, S., Lemoalle, J., Giordano, M., Ward, J. and Kaczan, D., 2011. Connections between poverty, water and agriculture: evidence from 10 river basins. *Water international*, 36(1), pp.125-140.

Kholoma, E. (2011). A Survey of Water Losses–The Case of the Ramotswa Village in Botswana. TRITA LWR Degree Project 11:37

Kleynhans, W. and Claassen, C. (2012). A shift-share analysis of job creation in the Platinum SDI during its first decade (1996-2006). *Journal of Economic and Financial Sciences* 5(2):591-606
Limpopo Basin Permanent Technical Committee (LBPTC). 2010. Joint Limpopo River Basin Study – Scoping Phase Final Report – Main Report January 2010. Prepared by BIGCON Consortium. Mozambique.

Limpopo Basin Focal Project (LBFP) 2010. Poverty in the Limpopo Basin. Report submitted to the Challenge Program on Water and Food, phase 1.

Ministry of Agriculture (MoA, 2006). Agricultural Support Schemes Guidelines. Ministry of Agriculture Botswana. Pp.29.

Ministry of Agriculture (MoA, 2009). National Master Plan for Agriculture and Dairy Development (NAMPAADD). Pp.5. Retrieved from http://www.moa.gov.bw/?nav=supportschemes

Masamba, W.R.L. (2009). Transboundary Diagnostic Analysis of the Botswana Portion of the Okavango River Basin. *Output 3: Irrigation development*. Harry Oppenheimer Okavango Research Centre. Pp.33.

Ministry of Agriculture (MoA, 2010). Livestock Management and Infrastructure Development (LIMID) Phase II Programme. Agricultural Support Programme Guidelines. Department of Animal Production- LIMID, Ministry of Agriculture Botswana. Pp.12. Retrieved from http://www.moa.gov.bw/downloads/final_limid.pdf

Ministry of Agriculture (MoA, 2013). Guidelines for Intergrated Support Programme for Arable Agriculture Development (ISPAAD). Ministry of Agriculture Botswana. Pp.22. Retrieved from http://www.moa.gov.bw/downloads/new_ISPAAD_guidelines.pdf

Magombeyi, M. S., Taigbenu, A. E. and Barron, J. (2015). Rural food insecurity and poverty mappings and their linkage with water resources in the Limpopo River Basin. *Physics and Chemistry of the Earth Parts A/B/C*. 1-14

Mitchell, J.M., 1976. An overview of climatic variability and its causal mechanisms. *Quaternary Research*, *6*(4), pp.481-493.

Mulligan, M., Fisher, M., Sharma, B., Xu, Z.X., Ringler, C., Mah_e, G., Jarvis, A., Ramírez, J.C., Clanet, J., Ogilvie, A., Ahmad, M. (2011). The nature and impact of climate change in the Challenge program on water and food (CPWF) basins. *Water Int.* 36, 96-124.

National Agricultural Master Plan for Arable Agriculture and Dairy Development (NAMPADD, 2000). Final Report, Volume 4. Climate, Soils and Water. TAHAL Consulting Engineers.

National Master Plan for the Arable Agriculture and Dairy Development (NAMPAADD) Implementation Guidelines. Retrieved from https://www.africaportal.org/dspace/articles/national-master-plan-arable-agriculture-and-dairy-development-nampaadd

National Treasury (2015). Chapter 9 - Agriculture and Land. Intergovernmental Fiscal Reviews (IGFR) - 2015 - Provincial Budgets and Expenditure Review: 2010/11 - 2016/17. Department of National Treasury, Republic of South Africa. Pp.147-162. Retrieved from http://www.treasury.gov.za/publications/igfr/2015/prov/

Ngaka Modiri Molema District Municipality (NMMDM, 2012-2016). Integrated Development Plan 2012-2016. Pp75. Retrieved from http://www.nmmdm.gov.za/

Ngaka Modiri Molema District Municipality (NMMDM, 2016). 1st DRAFT 2016/2017 Integrated Development Plan. Pp75. Retrieved from http://www.nmmdm.gov.za/

Ramotshere Moiloa Local Municipality (RMLM, 2014). Reviewed Integrated Development Plan IDP 2015 – 2016. Pp 174

Ranganai, R. T., Gotlop-Bogatsu, Y., Maphanyane, J., & Tladi, B. (2001). Hydrochemical and Geophysical Evaluation of Groundwater Pollution in the Ramotswa Wellfield, SE Botswana. *BIE2001 Technical Papers*, 193-200.

Rural, Environment and Agricultural Development, North West Provincial Government (READ NWPG, 2015). Strategic Plan 2015-2020. "Setsokotsane Approach for Radical Socio-Economic Transformation with Special focus on Villages, Townships and Small Dorpies (VTSD) Economies." Pp. 56. Department of Rural, Environment and Agricultural Development, North West Provincial Government, Republic of South Africa Retrieved from http://www.nwpg.gov.za/

Staudt, M. G. (2002). Production of Environmental Hydrogeology Maps Using GIS for the Ramotswa Project Area, South East District, Botswana. International Postgraduate Masters Course " *Tropical Hydrogeology*" Eberhard-Karls Universität Tübingen Institut für Geologie and Paläontologie Sigwartstr.10 D-72076 Tübingen, Germany. Pp. 77

South East District Development Council (2003), The South East District Development Plan Document: Towards Realization of Vision 2016, Sustainability and Diversified Development through competitiveness, Ministry of Local Government, Botswana, pp. 45 – 66

Staudt, M., & Vogel, H. (2004). Environmental hydrogeology of the dolomite aquifer in Ramotswa, Botswana. In *Water Resources of Arid Areas: Proceedings of the International Conference on Water Resources of Arid and Semi-Arid Regions of Africa, Gaborone, Botswana, 3-6 August 2004* (p. 479). Taylor & Francis**.**

SMEC and EHES, 2006. Review of the 1991 Botswana National Water Master Plan. Report prepared for Government of Botswana.

Statistics South Africa (2013). Census 2011 Agricultural households Key Highlights. Report No. 03-11-01 (2011).Pp. 24 Retrieved from www.statssa.gov.za

Statistics Botswana (2014). Statistics Botswana Annual Report 2013/14. Pp.58. Retrieved from http://www.cso.gov.bw/images/annual1314.pdf

Statistics Botswana, 2015. Annual Agricultural Survey Report 2013. Pp.172 Retrieved from http://www.cso.gov.bw/images/agricreport2013.pdf

Stirzaker, R.J., 2003. When to turn the water off: scheduling micro-irrigation with a wetting front detector. *Irrigation Science*, *22*(3-4), pp.177-185.

Stirzaker, R.J. and Hutchinson, P.A., 2006. Irrigation controlled by a wetting front detector: field evaluation under sprinkler irrigation. *Soil Research*, *43*(8), pp.935-943.

Stirzaker, R.J., Stevens, J.B., Annandale, J.G. and Steyn, J.M., 2010. Stages in the adoption of a wetting front detector. *Irrigation and drainage*, *59*(4), pp.367-376.

Stirzaker, R.J., Sunassee, S. and Wilkie, J., 2004, May. Monitoring water, nitrate and salt on-farm: a comparison of methods. In *Irrigation Australia 2004 conference* (pp. 11-13).

Stirzaker, R.J., Maeko, T.C., Annandale, J.G., Steyn, J.M., Adhanom, G.T. and Mpuisang, T., 2017. Scheduling irrigation from wetting front depth. *Agricultural Water Management*, *179*, pp.306-313.

Stirzaker, R. and Hutchinson, P., 1999. A new method for benchmarking salt and nitrate leaching. *National Program for Sustainable Irrigation final report*.

Stirzaker, R. and Thompson, T., 2004. FullStop at Angas Bremer: A report on the 2002-3 data to the Angas Bremer Water Management Committee.

Sullivan, A., and Sibanda, M.L. 2010. 'Vulnerable populations, unreliable water and low water productivity: a role for institutions in the Limpopo Basin'. *Water International* 35(5): 545 – 572.

United Nations, 2015. World Statistics Pocketbook 2015 edition. Department of Economic and Social Affairs Statistics Division United Nations, New York. Series V, No. 39. Retrieved from http://unstats.un.org/unsd/pocketbook/

United Nations Environment Programme. 2015. Good practices for regulating wastewater treatment: legislation, policies and standards. Retrieved from http://unep.org/gpa/documents/publications/GoodPracticesforRegulatingWastewater.pdf

van Koppen, B.; Nhamo, L.; Cai, X.; Gabriel, M. J.; Sekgala, M.; Shikwambana, S.; Tshikolomo, K.; Nevhutanda, S.; Matlala, B.; Manyama, D. 2017. Smallholder irrigation schemes in the Limpopo Province, South Africa. Colombo, Sri Lanka: International Water Management Institute (IWMI). 36p. (IWMI Working Paper 174). doi: 10.5337/2017.206

World Bank Group, 2015. Botswana Poverty Assessment. Report No. 88473-BW. Poverty Global Practice Africa Region. Pp226. Retrieved from http://www-wds.worldbank.org/

World Bank, 2007. World development report 2008: agriculture for development. Washington, DC: The World Bank.

Yaron, G., Moepeng, P., Mmopelwa, D., Mookodi L., and Lekobane, R. 2012. A Study of the Contribution of Sustainable Natural Resource Management to Economic Growth, Poverty Eradication and Achievement of NDP 10 Goals: *Case Studies*. Botswana Institute for Development Policy Analysis (BIDPA) in association with GY Associates Ltd submitted to Ministry of Finance and Development Planning, Gaborone, Botswana.16p.

Zimbabwe Vulnerability Assessment Committee (ZimVac). 2011. Rural Livelihoods Assessment July 2011, Report. Harare, Zimbabwe.

Annex 1: Agricultural statistics (2011) of Local Municipalities in Ngaka Modiri Molema District Municipality, North West Province, Republic of South Africa

Local Muncipality	**Code**	**Seat**	**Area (km²)**	**Pop. (2011)**	**Pop. density (per km²)**	**Household Involved in agricultural activities**	**Household not involved in agricultural activities**	**Number of agricultural households involved in specific activity**					
								Livestock production	*Poultry production*	*Vegetable production*	*Production of other crops*	*Fodder grazing*	*Other*
Ditsobotla	NW384	Lichtenburg	6,465	168,902	26.1	9,464	35,036	3,854	5,681	1,429	1,752	743	996
Mahikeng	NW383	Mahikeng	3,698	291,527	78.8	20,483	63,756	10,191	13,248	2,683	2,766	1,423	2,253
Ramotshere Moiloa	NW385	Zeerust	7,193	150,713	21.0	14,371	26,369	6,647	9,796	1,110	1,225	609	817
Ratlou	NW381	Setlagole	4,884	107,339	22.0	11.348	15,541	6,689	7,118	384	445	145	796
Tswaing	NW382	Delareyville	5,966	124,218	20.8	10,023	20,612	4,947	6,638	961	1,469	730	921
		Number of agricultural households by population group of household head					**Number of agricultural households by sex of household head**		**Number of agricultural households by education level of household head**				
		Black African	*Coloured*	*Indian or Asian*	*White*	*Other*	*Male*	*Female*	*No schooling*	*Grade 1 to grade 11/Std9*	*Grade 12/Std 10*	*Completed tertiary*	*Other*

Local Muncipality	Code	Seat	Area (km²)	Pop. (2011)	Pop. density (per km²)	Household Involved in agricultural activities	Household not involved in agricultural activities	Number of agricultural households involved in specific activity					
								Livestock production	*Poultry production*	*Vegetable production*	*Production of other crops*	*Fodder grazing*	*Other*
Ditsobotla	NW384	8,135	112	24	1,173	19	6,612	2,851	2,058	5,555	1,207	628	15
Mahikeng	NW383	19,988	129	48	302	16	11,985	8,498	3,838	12,331	2,661	1,602	51
Ramotshere Moiloa	NW385	13,644	53	44	611	17	7,550	6,821	4,991	7,083	1,466	787	44
Ratlou	NW381	11,010	88	7	229	14	5,734	5,614	3,913	6,445	696	282	12
Tswaing	NW382	8,628	106	5	1,269	15	6,623	3,400	3,007	5,229	1,138	635	14

Local Muncipality	Number of agricultural households by age group of household head							Number of agriculture households by income level of household head					
	Less than 15	*15-34*	*35-45*	*46-55*	*56-64*	*+65*		*No income*	*R1-R38 400*	*R38 401-R307 200*	*R307 201-R1 228 800*	*Above R1 228 800*	*Unspecified*
Ditsobotla	18	1,312	1,988	2,302	1,777	2,066		2,388	5,342	1,326	181	48	180
Mahikeng	55	2,973	4,225	4,914	3,700	4,615		6,385	10,717	2,835	289	54	204
Ramotshere Moiloa	57	1,474	2,346	2,930	3,000	4,562		4,577	8,150	1,308	103	14	217
Ratlou	54	1,416	1,884	2,428	2,160	3,407		4,281	6,356	480	60	11	159
Tswaing	35	1,395	1,908	2,465	1,869	2,350		2,724	5,745	1,061	236	69	187

Local Muncipalit y	Number of agricultural households by age group of household head							Number of agriculture households by income level of household head					
	Less than 15	*15-34*	*35-45*	*46-55*	*56-64*	*+65*		*No income*	*R1-R38 400*	*R38 401-R307 200*	*R307 201-R1 228 800*	*Above R1 228 800*	*Unspecifie d*
	Number of agriculture households by type of activity						**Number of agriculture households owning only livestock**						
	Animals only	*Crops only*	*Mixed farming*	*Other*			*Cattle only*	*Sheep only*	*Goats only*	*Pigs only*	*Poultry only*	*Animal combinatio n*	*Other livestock*
Ditsobotla	6,257	1,162	1,644	401			850	70	111	147	3,575	1,457	47
Mahikeng	15,034	1,476	3,204	768			1,925	155	581	123	7,314	4,876	60
Ramotshere Moiloa	11,892	714	1,484	281			1,912	74	439	40	6,307	3,078	42
Ratlou	9,818	140	1,001	389			1,345	164	481	104	3,941	3,717	66
Tswaing	7,116	573	1,960	373			741	125	121	134	3,707	2,246	43

Local Muncipalit y	Number of agricultural households in livestock production by sex of household head			Number of agricultural households in poultry production by sex of household head				Number of agricultural households in other agricultural activities by sex of household head					
	Female	*Male*	*Total*	*Female*	*Male*	*Total*		*Female*	*Male*	*Total*			
Ditsobotla	1,063	2,791	3,854	1,691	3,990	5,681		347	649	996			
Mahikeng	3,697	6,493	10,191	5,818	7,430	13,248		946	1,307	2,253			
Ramotshere Moiloa	2,619	4,028	6,647	5,068	4,729	9,796		342	474	817			
Ratlou	3,026	3,663	6,689	3,745	3,373	7,118		336	461	796			
Tswaing	1,461	3,486	4,947	2,354	4,284	6,638		321	600	921			
	Number of agricultural households in vegetable production by sex of household head			**Number of agricultural households in production of other crops by sex of household head**				**Number of agricultural households in the production of fodder /pasture/grass for animals by sex of household head**					
	Female	*Male*	*Total*	*Female*	*Male*	*Total*		*Female*	*Male*	*Total*			
Ditsobotla	467	962	1,429	557	1,194	1,752		218	525	743			
Mahikeng	1,062	1,621	2,683	1,205	1,562	2,766		608	815	1,423			
Ramotshere Moiloa	434	676	1,110	539	687	1,225		229	380	609			
Ratlou	152	232	384	169	277	445		51	94	145			
Tswaing	265	696	961	392	1,076	1,469		125	604	730			

Local Muncipality	Number of agricultural households by Access to water				Number of agricultural households by main source of water							
	Piped water inside the dwelling/yard	*Piped water outside the yard*	*No access to piped water*		*Regional/local water scheme (operated by a Water Service Authority or provider)*	*Borehole*	*Spring*	*Rain-water tank*	*Dam / pool / stagnant water*	*River/stream*	*Water tanker*	*Other*
Ditsobotla	5,834	2,256	1,374		3,321	4,543	104	29	107	29	781	549
Mahikeng	8,737	6,581	5,164		8,872	8,588	117	52	88	20	1,762	983
Ramotshere Moiloa	8,003	5,210	1,157		8,966	3,429	48	15	49	53	1,462	348
Ratlou	2,165	8,112	1,071		6,326	3,048	23	53	18	61	1,232	587
Tswaing	4,105	5,135	783		5,808	3,496	69	20	36	45	360	188
	Number of agricultural households by main type of toilet						**Number of agricultural households by type of energy, mainly use for lighting**					

	Flush toilet (connected to sewerage system)	*Chemical toilet*	*Pit latrine*	*Bucket latrine*	*Other*	*None*	*Electricity*	*Gas*	*Paraffin*	*Candles*	*Solar*	*None*
Ditsobotla	3,075	138	5,085	120	268	778	7,673	16	50	1,683	17	26
Mahikeng	3,534	100	15,825	31	208	785	17,178	29	256	2,897	69	54
Ramotshere Moiloa	2,114	61	11,521	31	191	453	12,494	12	73	1,720	39	32
Ratlou	434	205	9,451	31	276	950	10,088	10	45	1,155	22	27
Tswaing	2,554	52	6,320	38	369	689	8,245	15	71	1,635	19	38

(Author's computation, Source of data: Statistics South Africa- Retrieved from http://www.statssa.gov.za/)

Annex 2: Questionnaire for the Focus Group Discussions

1. Name of the scheme
2. Names of farmers participated in the discussion (to be attached as attendance register)
3. Composition of members in the scheme (by gender)
4. Please provide the history of your irrigation scheme
5. Describe the source and status of your water resource
6. Do you have enough water? Every year? All seasons? If there is a concern, what specific steps can be taken to improve water-availability? How do you cope with variation in rainfall/water availability? Are there any supplemental measures to the storage methods just listed (e.g., crop selection, cropping system in year)?
7. Do you store water or how do you ensure you have enough water? What are some of the positive impacts that you have seen? What are some of the barriers to more widespread use of such storage methods?
8. Describe the status and extent of your infrastructure
9. What are the needs of the farmers in the schemes in terms of managing water for irrigation?
10. What are the current practices in agricultural water management/use?
11. What challenges do farmers face during the agro-production activities?

12. What soil and water monitoring technologies are currently in use?
13. What are the advantages and disadvantages of these technologies?

14. What knowledge gaps exist in technologies used for agricultural water management?
15. What traditional or existing agriculture water management practices are done by the farmers in the selected irrigation schemes?
16. What are the cost implications of the current agriculture water management technologies or practices?
17. What are the perceptions of the farmers on the appropriateness of the agriculture management technologies they currently use?
18. What areas require improvement in the current technologies used for agriculture water management?
19. What knowledge exist on the new technologies earmarked for this project? Are there any perceptions about the efficiency and / or usability of these technologies?
20. Are there any constraints that should be expected while introducing the new technologies?
21. While doing irrigation, who is responsible within the household? Male or Females? Exclusively or mainly or both equally?
22. Do you belong to a WUA? If yes, how is it organised and what are the roles and responsibilities of the WUA? What benefits do you get from belonging to a WUA? If not, what form of organisation exist
23. How do you ensure institutional sustainability? Who will be responsible for recurring costs (e.g., operation and maintenance of equipment; maintenance and repair of infrastructure; replacement and additional equipment and infrastructure; etc.)?

24. Have you made investments in your farm, individually or collectively? hIf investments have improved agriculture productivity and water management, how secure are you that the State, the village, an individual, etc. will not take it away sometime in the future? Is lack of secure property rights a barrier to further investments?
25. Do you control access to the land? Put another way, are the investments on the land threatened by outside factors (e.g., free-roaming livestock, people harvesting tree crops without permission, etc.)?
26. Who sets rules for how the land and water infrastructure are managed (e.g., for bas fonds irrigation, rice, potatoes, and vegetables can be produced on same land—who makes rules about management of that land; in irrigation perimeters, water flows through primary, secondary and tertiary canals to individual fields—who sets rules for how water is distributed; around bore holes, pasture must be managed and water distributed—who makes and enforces rules; etc.?)
27. To what extent are women involved in decisions for land and water management? Explain.
28. How did you learn about the technologies/systems (farmer-to-farmer visits, neighbors, radio, etc.)?
29. Who provided for capital inputs (e.g., infrastructure for irrigation perimeters and retention dams; pumping equipment; lay-out for rainfall management structures; construction of rainfall management structures, etc.)?
30. How do you promote community ownership (buy-in)?

Annex 3: List of Participants in FGDs

13-11-2017 Motlhaka Farming coperative

Name	Signature
(1) Magaret Modise	Ms modise
(2) Aidh Motloko	Idah
(3) Kenole Lekalake	K. Lekalake
(4) Teko Megenlane	Telco
(5) Mosagale Olyile	Mogagale
6 Mooketsi Ntshwane	N. [illegible]
7. Mochisa Banyana	B. mochisa
8 Kgomo Kgomotso	K.y kgomo
9 Gae Tshepiso	[illegible]
10. Lethoko Keabetswe	[illegible]
11 Victor Tshetlhane	Victor..

WATER RESEARCH COMMISSION

GLEN VALLEY MEETING AT DPT OF AGRIC 8/12/17

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