PERFORMANCE ASSESSMENT FOR SUSTAINABLE IRRIGATION WATER MANAGEMENT

A case study of Lower Limpopo Irrigation System, Southern Mozambique

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By

Eduardo Marcos Cuamba

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master (Integrated Water Resource Management) of the University of Dar es Salaam

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the University of Dar es Salaam a dissertation entitled: ***Performance Assessment for Sustainable Irrigation Water Management, A Case Study of Lower Limpopo Irrigation System - Southern Mozambique,*** in Partial fulfillment of the requirements for the degree of Master of (Integrated Water resources Management) of the University of Dar es Salaam**.**

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DECLARATION

AND

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I, **Eduardo Marcos Cuamba**, declare that this dissertation is my own original work and that it has not been presented and will not be presented to any other University for a similar or any other degree award.

Signature______________________________

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DEDICATION

I dedicate this dissertation to my parents, Marcos Cuamba (in memory) and Esitela Matsinhe “Thanks for guiding me since my childhood and for your diligent support in my education”, to my lovely wife Olinda da Graça Cuamba, to my brethren Salomão, Daniel, Esperança, Tristeza and Anselmo and finally to my entire family for the given support.

ABBREVIATIONS

AGLW	Water and Land Development Division
AIDS	Acquired Immune Deficiency Syndrome
ARA-Sul	Administração Regional de Aguas-Sul
ARC	Agricultural Research Council
ARC	Agricultural Research Council
BM	Central Bank of Mozambique
BOD	Biochemical Oxygen Demand
CCT	Christian Council of Tanzania
COD	Chemical Oxygen Demand
CV	Coefficient of Variation
CWR	Crop Water requirement
DCG	Department for Communities and Government
DNA	Direção Nacional de Águas
EC	Electric conductivity
EP	Empresa Pública
ET	Crop Evapontraspiration
Eto	Reference Evapotranspiration
FAO	Food and Agriculture Organization
GRI	Gross Return on Investment
HIV	Human Immunodeficiency Virus
IFAD	International Fund For Agriculture development

IPPM	Integrated Production and Pest Management
IR	Irrigation Requirement
IWMI	International Water Management Institute
KMO	Kaiser-Meyer-Olkin
MCA	Multi-criteria Analysis
MS	Microsoft
MT	Metical (Mozambique currency)
NGOs	Non-Governmental Organization
NO3	Nitrate
O&M	Operation and Maintenance
OECD	Organization for Economic Cooperation and Development
PAP	Priority Action Programme
PCF	Principal Component factor
pH	Potential of Hydrogen
PNW	Present Net Worth
PVC	Polyvinyl Chloride
P_{world}	World Price
RBL	Regadio do Baixo Limpopo (Lower Limpopo Irrigation system)
RH	Relative Humidity
RIS	Relative Irrigation Supply
RWS	Relative Water Supply
SADAC	Southern African Development Community
SPSS	Statistical Package for the Social Sciences

SSA	Sub-Saharan Africa
SSF	Self-Sufficiency
Std. Deviation	Standard Deviation
SVGP	Standardized Gross Value of Production
TDS	Total Dissolved Solids
UDSM	University of Dar es Salaam
UNEP	United Nation Environmental Programme
USAID	United State Agency for International Development
USD	United State Dollar
USDA	United States Department of Agriculture
WB	World Banc
WDC	Water Delivery Capacity
WMO	World Meteorological Organization
WUE	Water-Use Efficiency

SYMBOLS

Symbols	Description	Units
Q	Discharge	m^3/s
V	Velocity	m/s
A	Area	m^2, ha
S	Slope	m/m
R	Hydraulic radius	m
N	Manning coefficient	-
EC	Electric Conductivity	S/m

ABSTRACT

In most of the irrigation systems in Mozambique, the low water use efficiency combined with the intensive use of agrochemical and unimproved technologies has been appointed as being a serious threat to the environment and waste the already scarce water resources . In Connection to this, a study was conducted to evaluate the performance of Lower Limpopo Irrigation System (RBL). Field observation and survey, personnel interview and literature review techniques were used for data collection. A set of comparative performance and environmental indicators developed by the International Water management institute (IWMI) were used to analyze the collected data. The study results indicate good performance of the system in terms of production per unit of land. However, the high Relative Irrigation Supply and Relative Water Supply ratio (1.93 to 2.75 and 3.5 to 5.4 respectively) show the existence of problems on irrigation water management, thereby suggesting the need for more work in order to improve the irrigation efficiency. The Gross Return on Investment varied from 1.1% to 20.9% indicating a very low capacity of the system to generate profit. The SSF value was between 6.7 % and 110 %. Values of Self-Sufficiency below 100 % indicate that the fees collected from irrigation are not capable of covering the operation and maintenance costs, being this one of the major concern for the sustainability of the system. The study concluded that the increase in yield per hectare comes at the cost of environment and miss use of irrigation water. Therefore adoption of water saving practices and environmentally friendly technologies are highly recommended to minimize the waste of water and environment degradation.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

In most countries of the Southern Africa Development Community (SADC), including Mozambique, the combined effect of population growth and climate change or climate variability contributes to the increasing pressure on the already threatened and scarce water resources. These factors limit the availability of water for food production and threaten food security in many developing countries (FAO, 2015).

A Study by Seckler *et al*. (1998), relate that most of the regions in developing countries have absolute water scarcity which affects one-third of their population. In Limpopo Basin, where the study area is located, the over-use of water for agriculture and mining upstream, is already causing a severe water shortage in the lower catchment (Mozambique), which can be dry up to eight months (Amaral *et al*, 2004). Being the largest water user, concerns about water scarcity have to pay more attention to this sector. In Mozambique, the agriculture sector accounts for nearly eighty-seven percents of total water use in the country (FAO, 2005). Studies by Perry (2007) and Kijne *et al*. (2003), refer that an improvement in irrigation efficiency and increase in agriculture water productivity are crucial in the mitigation of competition for water resources, environment protection and sustainable food provision.

According to Ganho (2012), the Lower Limpopo Irrigation System (RBL) is the second largest water consumer and source of diffuse pollutants in the basin due to the inadequate water management, exhaustive use of agrochemicals (fertilizers and pesticides) and livestock farming. Therefore, a coordinated effort is needed from different stakeholders in order to ensure a sustainable production and protect the threatened water resources.

With the view to minimize the water losses and increase productivity in irrigation systems, a performance assessment should be carried out to check the state of health of the systems and also the water use efficiency (Molden *et al*., 1998). Different approaches for irrigation performance assessment are available, but in this study, the comparative performance (external indicators) and environmental performance indicators were used.

1.2 Problem statement

The Limpopo River Basin, where the research was carried out, is considered to be one of the most vulnerable river basins in Africa, not only due to the particular climate conditions in the region but also due to the weak water management. Moreover, the Lower Limpopo Valley is presumably the environmentally more vulnerable section in all the extensive Limpopo river basin (UNEP/FAO/PAP, 1998). According to FAO (2004), Apart from drought, the concern on water scarcity and salinity in Limpopo basin is aggravated by misuse of water for irrigation (over-abstraction), lack of trained staff in water management and inadequate poor drainage systems. USAID (2015) and FAO (2004), reported that the increasing water abstraction for irrigation upstream the Limpopo River estuary is one of the main causes of increasing saltwater intrusion, degradation of water resources by returning polluted flow to the river and reduction of mangrove population.

Appointed as one of the major water use sector located in lower Limpopo valley, the performance of the Lower Limpopo Irrigation System (RBL) is negatively affected by poor practices and inefficiencies at the farm and post-harvest level. (USAID, 2014). Therefore, the low water use efficiency becomes a potential threat for environmental degradation and waste the valuable and scarce water resources.

Besides the above-stated problems, there is no much work done to evaluate the system performance in order to provide considerable information in selecting better performing practices under the current system performance. The research carried out by Julaia (2009), in Chokwe irrigation system was only focused on internal process indicators rather than external indicators.

Hence, this research will look at ways in which both the output from agriculture and water use efficiency can be increased through the introduction of more performance-oriented management practices. For such, a set of external comparative performance indicators and environmental performance indicators were used to evaluate the current operational state of the system and propose strategies for improvement.

1.3 Research objectives

1.3.1 Main Objective

The main objective of this research is to assess the performance of Lower Limpopo Irrigation System using external comparative performance indicators and environmental performance indicators.

1.3.2 Specific objectives of the study

1) To identify the main factors affecting productivity and sustainable water management in Lower Limpopo Irrigation system.
2) To estimate the overall performance of Lower Limpopo irrigation system.
3) To propose appropriate strategies to improve the performance of the irrigation system.

1.4 Research questions

The research seeks to give answers the following questions:

1) Which are the main limiting factors and how are they affecting the productivity and sustainability of the RBL irrigation system?
2) How the RBL irrigation system is performing in relation to water and land productivity, and water use efficiency?
3) Which measures can be adopted to adjust the indicators so that they can provide better results on the irrigation system operational performance?

1.5 Significance of the study

This study results if adhered to and implemented will be a significant endeavor in addressing the gap-in-knowledge on the optimum potential of the irrigation system and how it can perform well with the limited available land and water resources.

Likewise, the results will be beneficial to different stakeholders (policy maker, water managers, and farmers) by providing a better understanding of how the system is operating and help to analyze the problems, their causes and identify ways and means to achieve efficient and effective project management or scheme performance. Moreover, this study is useful as a future reference for researchers on the subject of irrigation performance and irrigation water use efficiency which is still scarce in the country in particular and in many developing countries in general. Furthermore, the output from this study will be useful for water management institutions and operators to ensure better irrigation services and sustainability in RBL irrigation system which could also be extended to other similar irrigation schemes in Mozambique.

1.6 Scope of the study

This study made a comparative performance evaluation of three irrigation blocks nested to Lower Limpopo Irrigation system. Relevant comparative (external) performance indicators were applied for comparison in terms of selected criteria. These include water productivity, land productivity, water supply, water delivery capacity and financial indicators. Moreover, for each irrigation block, factors affecting agriculture productivity and sustainable irrigation water management were assessed and analyzed using Principal Component Factor Approach.

Due to time and financial constraints, was not possible to collect data in all the irrigation blocks as well in all the secondary canal within the selected blocks, for this reason, the study was limited to three irrigation blocks. However, the selected sampling techniques used are representative and similar to the population of the scheme as a whole. Hence, the results from this study could be extended to other similar state-based managed systems in the basin in particular and in the country in general.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of Key Terms

The base crop is defined as the prime marketable crop under cultivation in the total irrigated area for the period in the analysis (Molden *et al*.,1998).

Farmers' Field School (FFS) is a learning process for groups of farmers in which they find out the ecological relationship between different factors affecting the health of their crop (pests, natural enemies and other), thus enabling them to make more efficient and healthier crop management decisions (FAO, 2002).

Indicators are the ways of measuring progress towards the achievement of the goal. They provide an objective basis to track the progress and assessment of final achievements. A good indicator should define the level of achievement, specifically: how much? how well? by when? (FAO, 2002).

Irrigated agriculture is defined as the practice of agriculture activity where artificial means are used to supply additional water to the field, encompassing the use of water control practices and infrastructures to remove the undesired water (FAO, 1999).

Irrigation efficiency is defined as the ratio (expressed as a percentage) of the average amount of water applied to the field used helpfully to the total average amount applied (USDA, 1997).

Irrigation is the use of artificial means to provide water to cultivated crops, in order to make possible the crop production in arid regions and to compensate the effect of water scarcity in semi-arid areas. The rainfall may be irregular throughout the year and uneven between years even in regions where the total seasonal rainfall is adequate (FAO, 1997).

Sustainable agriculture is defined as the one that meets the needs of present and future generations for its products and services while ensuring, environmental health, profitability and socio-economic equity (FAO, 2014).

Water productivity is defined as the ratio of the net benefits derived from crop, fishery, livestock, forestry, and mixed agricultural systems to the amount of water required to produce those benefits (Molden *et al*., 2010).

Water-use efficiency (WUE) is the ratio of biomass accumulation, expressed as the assimilation of carbon dioxide, total crop biomass, or crop grain yield, to water consumed, expressed as evapotranspiration, transpiration or total water input to the system (Sinclair *et al*., 1984).

2.2 Description of the study area

2.2.1 The Limpopo River Basin

The Limpopo River within Mozambique flows about 561 km until it drains into the Indian Ocean in Xai-Xai town (Louw and Gichuki, 2003). The average annual temperatures are about 24 °C and the maximum daily temperatures range from 30º-32 and 34 °C along the coastal zone and in the central area, respectively. The annual average relative humidity is about 65% in the central zone and 75% in the northern and southern areas (Mertens and Loureiro, 1974). The evaporation range from 800 mm to 2400 mm/year, being the average evaporation rate (1970 mm/year) higher than rainfall (IWMI/ARC, 2003).

Rainfall varies considerably throughout the basin, from 860 mm/year along the shoreline to below 30 mm per year in the arid area. The rainfall variability can be explained by the cycle occurrence of anticyclone conditions which cover the entire southern Africa (FAO, 2004). According to Amaral *et al* (2004), a major part of the annual rainfall (95%) in Mozambique is observed during October to March, in diversified secluded rain periods and insulated locations, describing the cyclic recurrent, irregular and unpredictable rainfall. The part of runoff that is produced inside the country is about 400 million cubic meters per year (Brito *et al.*, 2009).

2.2.2 The Lower Limpopo Irrigation System: geographical and historical context

The Lower Limpopo Irrigation System (RBL) is situated Xai-Xai district in about 5 km far from Xa-Xai city, in Limpopo river basin (Figure 3.1), close to the river outlet. The Limpopo river flow is characterized by a pronounced high seasonal and inter-annual fluctuation (Brito *et al.*, 2009). Moreover, due to relief condition of the floodplain, which normally does not exceed 100 m above sea level, the ecological condition of the floodplain is cyclically influenced by the occurrence of floods and dry spells caused by the discharges and water retention in dams located upstream the basin (Ganho, 2013).

The irrigation infrastructures suffer from cyclic deprivation due to the destruction caused by the recurrent occurrence of flood and huge assets are needed for their rehabilitation. the condition of irrigation infrastructures turns the practice of agricultural activity tricky and costly for the farmers. The history of agriculture in lower Limpopo region is categorized into four major phases, namely: Period of colonial capitalism(between 1950 to 1975), to planned economy (Socialist) from (1975 to 1983) and finally the shift to market economy (1983-2000) to the actual market economy from the year 2000 to the present which is dominated by rehabilitation funded infrastructure (Ganho, 2013).

From 1994 the system began to face problems related to irrigation infrastructure degradation which was exacerbated by the occurrence of flood in the year 2000 leading the system to collapse. Between 2003 and 2008, a total area of 4000 ha was renewed as a part of Massingir Dam rehabilitation project (Appendix 1). In 2010 the government decided to revitalize the Lower Limpopo Irrigation system by creating the Lower Limpopo Irrigation system company (RBL, Ep). The role of the created company was to ensure the management of the system and thereby, reactivate the irrigated agriculture in the region. When it was established, the RBL-EP had a jurisdiction of only 12 000 hectares of irrigated land (area with infrastructures), which were later extended in 2012 to an area of 70 hectares (RBL, 2015)

2.2.3 Drivers for basin degradation

IWMI/ARC (2003), refer that in whole Limpopo River Basin, the main factors leading to the continuous environment degradation include the misuse of water resources, contamination due encroachment by settlements, mining activities upstream and developments.

A study by DNA (1999) indicated that throughout the Limpopo Basin length, the major water resources concerns include: (i) increasing salinity; (ii) discharge of untreated wastes or partially treated waste water; (iii) dumping of untreated loads from upstream mining activities; (iv) reduction of river flows exacerbated by the increasing demands.

In Mozambique, the main sources of pollution include the practice of agricultural in Chokwe Irrigation System, which is characterized by the intensive use chemical products combined with poor and depredated drainage network. Other non-point sources of pollution, but not the least, are domestic effluent discharges in all the river extension, salt intrusion and waters mineralization as a result of decreased flows (IWMI/ARC, 2003).

2.2.4 Current situation of land and water resources for irrigation in Mozambique

Latest estimations of water consumption per sector in Mozambique indicate that irrigated agriculture is the major water consumer accounting for about 87% of the country total water consumption. (FAO, 2005). Likewise the practice of irrigation in Lower Limpopo Valley is appointed as the main threat to the environment as it cause water pollution and land degradation (Ganho, 2012).

Although rain-fed agriculture accounts for the majority of the cultivated land, irrigated agriculture, which currently occupies about 1% of the total cultivated area, constitutes a significant contribute to the national agricultural production. However, Irrigated agriculture is characterized by high water losses, low efficiencies, highly subsidized water rates, and low yields per unit of applied water (Marquês, 2006).

Therefore, any management practice leading to an improvement in water use efficiency, either by adopting water saving technologies or by increasing agriculture productivity for the same amount of water, is of vital importance to make the best use of limited and threatened water resources. These savings would also inevitably mean more water available to expand irrigated areas or to allocate to other sectors within the same river basin, while also ensuring environment protection (Marquês, 2006).

2.3 Main factor affecting productivity and sustainability water management

In Mozambique, the low agricultural productivity has been seen as a result of lack of appropriate technologies combined with deficient financial supports for agricultural activities. In addition, agricultural markets are commonly distant, unpredictable and not competitive for smallholder farmers (IFAD, 2014).The harmful effect of the current agricultural techniques to the environment include, soil deterioration, reduction and pollution of water sources, wasteful energy use, reduction of biodiversity, and degradation of non-agricultural habitat (FAO, 2004).

2.3.1 Personal characteristics of farmers

The characterization of farmers encompasses number variables that can have an influence in the day to day activities of farmers as well as in the agriculture productivity. The main variables are as per the following description.

Education and Knowledge: Research findings by a number of authors reported the vital role of education in agriculture productivity and generation of revenue. For example, a study by Bingen *et al*. (2003), refer that awareness and know how are fundamentals for farmers to accept new productions methods and techniques, obtain input, modify the methods they do their agricultural activities and have access to market. There is also a confidence that access to education can trigger an economic boost by strengthening the farmers productive potential as well as removing the traditional biases which can prevent the farmer to grow, such as gender biases. (Asfaw and Admassie, 2004)

Gender: can be defined as a set of established habits and relation between women and men in a particular society or place (Adeoti, *et al*., 2012). Camara *et al*., 2011), refer that woman farmers are the main accountable group for food production for the livelihood of most families in rural areas. Likewise, studies relate that women farmers are somehow more sensible and aware about the need for environment protection than men farmers (Burton, 2013).

Despite the recognized contribution of both men and women for food production, gender disparity in this sector was reported in a number of studies. As an example, Mohammed and Abdulquadri (2011), reported the tendency of particularizing some crops to be only cultivated by men and others by women. A research by Adeoti *et al*. (2012) carried out in Ghana concluded that vegetable production was mostly cultivated by men as it requires the use of more corporeal power.

Age, family size, and landholding size: The agricultural experience of the farmers is directly proportional to the maturity of the householder. This makes the production of various crops by the farmers extremely dependent on their prior expertise. (Adomi, *et al*., 2003). Thus, farmers with large experience are likely to improve the yield of their property. Nevertheless, because farmers with advanced age tend to have less corporeal power, the previous conclusion is not unlimited, given the fact that this trend tends to reduce the willingness to accept changes and approve new technology. (Burton, 2013).

2.3.2 Technological factors

This set of factors encompasses the use agrochemical products, new crop pattern, improved seeds, artificial water application technologies and soil conservation methods. The above-stated techniques and practices are meant to improve the water and land productivity.

Chemical fertilizer: Aune and Bationo (2008), refer that the application of fertilizers is the starting point to enhance productivity as if the soil quality and productivity are poor the adoption of other techniques and practices will not bring the desired results. A number of studies reported that in sub-Saharian Africa use of chemical fertilizers is negligible, being the application in this region estimated in 11 kg/ha against 130 kg/ha and 271 kg/ha applied in south Asia and East Asia, respectively (Janvry, 2010).

The least use of soil fertilization technologies in Sub-Saharan Africa relegates the region to the last position in the world. The application of fertilizer below the average is an apparent sign that improvement of agriculture productivity in Africa continue to be development defiance (Xu *et al*., 2009 and Crawford *et al*., 2003). The inadequate soil fertilization is appointed as the reason for the low productivity per unit land, which is considered to be less than the world standards (Morris *et al.*, 2007).

Irrigation: The positive effect that can be generated by the artificial supply of water to cultivated crops which in turn leads to rural poverty alleviation makes the practice of irrigation as one of the vital inputs of is one of the vital production factors in agriculture. Moreover, the use of irrigation can trigger an increase in the small-scale farmer productivity and create alternatives for their livelihood thereby, mitigating their dependability to the rainfall variability and extrinsic effect (Hussain and Hanjra, 2004).

However, due to the negative effects that the practice can cause to the environment such as land deterioration, contamination of water resources and interference on ecological functions, the practice of irrigation require special attention to avoid disturbances (Hussain and Hanjra, 2004).

2.3.3 Credit markets/agricultural loans

Credit in agriculture can be defined as the money lending for agricultural production, agro-processing and agribusiness, and the manufacture and supply of productions factors (Aggelopoulos *et al*., 2011). The possibility of small-scale farmers get a loan from formal financial institutions is very low since they almost never have suitable guarantee to banks. In many African countries the land tenure is State propriety and the farmers do not own title deeds for their farms but even where they do, the markets are not structured well enough so that their properties can be considered suitable collateral. (Kindness and Gordon, 2001). As an alternative, smallholder farmers get loans from micro-credit banks which normally do not request collateral. In this system of credit, the loan is for a group of borrower and collateral is substituted by the commitment the each group member to prevent one member from failure. to pay (Kindness and Gordon, 2001).

2.3.4 Environmental factors

There are many environmental factors influencing agricultural productivity and consequently the revenue of farmers. The environmental factors considered in this research are precipitation, soil erosion, land cover and soil characteristics. The expansion and increase of the area for crop production throughout the world is appointed as responsible for producing 25% and 30% of global greenhouse gas emissions, as well as influencing climate variability (Janvry, 2010). Kintomo *et al.* (2008), also reported that the decrease in agricultural productivity and environmental health are some somehow due to the intensification of agriculture activities and poor soil management practices.

2.4 Comparative performance Indicators

Performance assessment in irrigation and drainage refer to regular surveillance, recording, and analysis of activities associated to irrigation in order to guarantee continuous improvement. The final objective of performance assessment is to attain an effective and efficient utilization of resources by supplying appropriate information to all levels of the system management (Molden *et al*., 1998). The evaluation of an irrigation system is of capital importance as it allow the identification of sustainable management practices and methods that can be successfully fulfilled to enhance the irrigation efficiency (FAO, 1989).

The field level assessment of surface irrigation is a vital aspect of both the management and development of the scheme. The assessment at field level is essential to classify the parameters of the scheme in order of their weight, to discover its functionality deficiencies, and build up options for a better use of the scheme (FAO, 1989).

Selected indicator: The selected indicators has been developed and widely field-tested by the by the International Water Management Institute (IWMI). The comparative indicators were developed to demonstrate gross relationships and trends which are helpful in depicting the actual state of the system. For example where a certain scheme is performing very good, or where deep intervention is needed (Molden *et al*., 1998).

2.4.1 Indicators of Irrigated Agricultural Output

The agricultural output indicators establish relationship between agriculture output with unit land or unit water. Values of output per unit command area higher than output per unit irrigated area indicate that the irrigation intensity in the system is greater than one. Lower value of output per unit irrigation supply if compared to the value of output per unit water consumed indicate that part of water applied to the field is not productive. The indicators are as per the equations below (Molden *et al.*, 1998).

$$\text{Output per cropped Area } \left(\frac{\$}{ha}\right) = \frac{\text{Production}}{\text{Irr. Cropped Area } (A_{Cropped})} \ldots\ldots\ldots\ldots(2.1)$$

$$\text{Output per Unit command } \left(\frac{\$}{ha}\right) = \frac{\text{Production}}{\text{Command Area } (V_{div})} \ldots\ldots\ldots\ldots(2.2)$$

$$\text{Output per unit Irrigation supply } \left(\frac{\$}{m3}\right) = \frac{\text{Production}}{\text{Diverted Irrig. Supply}(V_{div})} \ldots\ldots\ldots\ldots(2.3)$$

$$\text{Output per unit water consumed } \frac{\$}{m_3} = \frac{\text{Production}}{\text{Volume of Water by ET}(V_{consumed})} \ldots\ldots\ldots(2.4)$$

where,

Production is the Output of the area under irrigation in terms of gross or net value of production measured at local or world prices (equation 2.5)**;**

Irrigated cropped area is the Sum of the areas under crops during the time period of analysis;

Command area is the designed or nominal area to be irrigated;

Diverted irrigation supply is the volume of water diverted to the command area**;** and

Volume of water consumed by ET is the Actual evapotranspiration of crops.

The SGVP is obtained from the computation of equivalent yield based on local prices of the crops under cultivation, compared to the local price of the main, locally produced and internationally traded base crop (Molden *et al*., 1998).

$$SGVP = \left(\sum_{Crops} A_i Y_i \frac{P_i}{P_b} \right) P_{world} \qquad \text{......} 2.5$$

Where,

SGVP is the standardized gross value of production;

Y_i is the yield of crop i;

P_i is the local price of crop i;

P_{world} is the monetary value of the base crop traded at world prices;

A_i is the area cropped with crop i, and

P_b is the local price of the base crop.

2.4.2 Water Supply Indicator

These indicators depict the state of water availability or shortage, and how tightly supply and demand are related. Values of Relative Irrigation Supply (RIS) higher than one indicate that excess irrigation water is being supplied and RIS values greater than RWS values is a sign that major amount of water supplied in the area is from irrigation. The indicators are as per the equations below (Molden *et al*., 1998):

$$\text{Relative irrigation supply} = \frac{\text{Irrigation supply}}{\text{Irrigation demand}} \qquad \text{......(2.6)}$$

$$\text{Relative Water Supply} = \frac{\text{Total water supply}}{\text{Crop demand}} \qquad \text{......(2.7)}$$

where,

Crop demand is the potential crop ET, or the ET under well-watered conditions;

Total water supply is the surface diversions plus rainfall; and

Irrigation supply is the surface diversions only.

2.4.3 Indicator of the irrigation infrastructure

The water delivery capacity (WDC) ratio illustrate if the system design is somehow a constraint to cope with the actual crop water demand at the pick period or not. To meet the crop demand at the pick period without an limitation, the value of WDC indicator mast be greater than one. Ratios of WDC very close to one are not recommended as they may indicate difficulties for the system to meet the crop water requirement at the pick period. The indicator for irrigation infrastructure is per the equation 2.8: (Molden *et al*., 1998).

$$\textbf{Water delivery capacity (\%)} = \frac{\text{Canal capacity to deliver water at system head}}{\text{Peak consuptive demand}} \quad (2.8)$$

where,

Capacity to deliver water at the system head is the present discharge capacity of the canal at the system head; and

Peak consumptive demand is the peak crop IR for a growing period expressed as a flow rate at the head of the irrigation system.

2.4.4 Financial indicator

The self-sufficiency indicator indicates whether the users are capable to manage the system by themselves the assistance from the government or not. The computation of this indicator provides the percentage of the revenue generated from irrigations that is applied in the operation and maintenance. Values of self-sufficiency equal or greater than 100% indicate that the farmers can operate the system without an external fund and values less than 100% may be an indication of sustainability concerns. The financial indicators are as per the equations 2.9 and 2.10 (Molden *et al*., 1998):

Financial self-sufficient = $\frac{\text{Revenue from irrigation}}{\text{Total O \& M expenditure}}$ ....(2.9)

Gross return on Investment (%) = $\frac{\text{Production}}{\text{Cost of irrigation infrastructure}}$ ....(2.10)

where**:**

Production is the Output from irrigation in terms of gross or net value measured at local or world prices;

Cost of irrigation infrastructure is the cost of the irrigation water delivery system referenced to the same period as the Standard Gross Value of Production**;**

Revenue from irrigation is the revenue generated from irrigation fees, or other locally generated income**;** and

Total O&M expenditures are the amount expended locally through O&M plus outside subsidies from the government.

2.4.5 Environmental performance indicators

This set of indicators meant to evaluate the effect of irrigated agriculture on land and water resources. These are as per the summary in Table2.1.

Table 2.1: Environmental indicators

Adapted from Malano and Burton, 2001

Indicator	Definition	Mozambique Standard
Physical	Salinity (electrical conductivity) of the irrigation supply and drainage water.	2.5 mS/cm
Biological	Biological load of the irrigation supply and drainage water expressed as Biochemical Oxygen Demand (BOD) at 20oC	< 5
Chemical	Chemical load of the irrigation supply and drainage water expressed as Chemical Oxygen Demand (COD)	≤ 150 mg/l
Physical	Total Dissolved solids (TDS)	≤ 2000 mg/l
Chemical	Amount of acids and alkalies discharged expressed as potencial of Hydrogen (pH)	6.5-8.5

2.4.6 Properties of performance indicators

An accurate performance indicator is composed by both an current value and an projected value that permit the evaluation of the degree of variation. Additional, it must include information that helps the manager to find out if the variation is tolerable or not. Below are some of the performance indicators properties recommended by Bos (1997):

Scientific basis: an indicator must be derived from an analytically and statistically experienced fundamental model of the section of the system it refer to.

Quantifiable: the required information to quantify the indicator should be readily accessible or reachable (quantifiable) with the available kwon-how. The assessment should be replicable.

Reference to a target value: Means that the significance and the suitability of the projected value and acceptance for the indicator can be settled. The settled values along with their degree of variation must be correlated to the existing technology and management practices (Bos *et al*., 1991).

Provide unbiased information: preferably, in the formulation of performance indicators a narrow ethical perspective should be avoid. Actually, this is no ease since even technical procedures have different ways of thinking.

Ease of use and cost effectiveness: mainly for regular management, performance indicators must be strictly achievable, and readily used by the organization personnel considering their motivation and level of knowledge. Moreover, the implication of adopting the use of indicators in respect to equipment, investment, and human resources commitment, mast fit within the organization’s assets.

2.4.7 Limitations of the Indicators

It is important to highlight that the calculation of indicators is generally influenced by a number of uncertainty derived from the broad use of secondary data, not collected by the researcher and from the considerable level of uncertainty in the computation of effective precipitation and crop water evapontraspiration, for which several methods exist (Dastane, 1974).

The uncertainty in the calculation of effective precipitation is also found on the estimation of actual crop evapotranspiration. According to Molden *et al*. (1998), the variation in water deliveries, soil characteristics, and farmer practices make the estimation of regional evapotranspiration quite difficulty. It is even more difficult to get a good estimation when crops are stressed or deficit irrigation is practiced.

Because of the above stated, two irrigation scheme can only confidently be considered different where the magnitude is considerable large. Where the difference between system performances for computed indicator is less than 20%, the difference in performance is considered to be negligible or insignificant.

2.4.8 Application of the indicators

The selected comparative indicators were experimented in eighteen irrigation systems located in eleven countries all over the world. These are Colombia, Egypt, Burkina Faso, India, Malaysia, Morocco, Niger, Mexico, Pakistan, Turkey and Sri Lanka. The most important characteristics of the systems used for the calculation of the indicators are as per the Table 2.2. These characteristics infer that the experiences were carried out in a number of agro-climatic conditions and systems with different water distribution patterns, crops and cultivation patterns, water resource accessibility, and different management methods. Table 2.3 depicts the computed indicators for eighteen (18) irrigation schemes throughout the world (Molden *et al*., 1998).

Table 2.2: Main characteristics of the observed irrigation schemes

Source: Molden *et al*., 1998

No.	Country	System name	Type of system	Command area (ha)	Cropping pattern	Climate	Cropping intensity	Annual rainfall (mm)	Annual evaporation (mm)	Type of manage-ment	Water availability
1 2 3	Burkina Faso	Gorgo Mogtedo Savili	Tank storage Village irrigation scheme Pumping scheme	50 93 42	Rice, potato, Tomato, bean	Sudano Sahelian Agroclimatic zone	0.93 2.00 0.94	400 to 1,200	2,600	Village cooperatives	Water-short systems
4 5 6	Colombia	Coella Saldana Samaca	Diversion Diversion Storage	25,600 13,975 3,000	Rice, maize, sorghum Fruit and vegetables Onion and potato	Temporate and tropical	1.01 1.61 1.60	1,000 to 1,500 700	1,800 1,100	Transferred to WUAs	Water-short Water-abundant Sufficient water
7	Egypt	Nile Delta	Storage	3,100,000	Wheat, maize, Rice, sorghum, Egyptian cloves, Cotton	Arid	2.00	10 to 500	–	Agency-managed	Sufficient surface water, groundwater, drainage water
8	India	Mahi Kadana	Storage-cum-groundwater (conjunctive use)	212,000	Rice, wheat, Tobacco, banana, Vegetables	Semiarid	1.20	823	1,700	Agency-managed	Abundant
9	Malaysia	Muda	Storage	96,000	Rice-rice	Humid	2.00	2,000	1,800	Agency-managed	High rainfall but insufficient stored surface water
10	Mexico	Alto Rio Lerma Cortazar Module Salavatierra Module	Storage system 1,714 deep wells (conjunctive use)	107,541 18,848 15,897	Wheat, sorghum, maize and bean. Underground water used for wheat, vegetables, alfalfa	Moderate Subhumid	0.66 0.70 0.46	700	–	Transferred to WUA	Surface Water-short project
11	Morocco	Triffa Scheme	Storage and pumping	36,060	Orchards, sugarbeet, Potato, wheat	Semiarid Mediterranean	1.00 150–450	Average 300	–	Agency-managed	Water-short
12 13 14	Niger	Saga Kourani Baria I Kourani Baria II	Pumping from river Pumping from river Pumping from river	407 425 268	Rice Rice Rice	Arid	1.85 1.76 1.69	300 to 550		Agency-managed	Water-sufficient
15	Pakistan	Chishtian sub-division	Storage-cum-groundwater	70,656	Cotton, rice	Arid	1.20	200 mm	Agency-	Water-short managed	
16 17	Sri Lanka	Nachchaduwa Rajangana	Storage Storage	2,539 5,909	Rice, chili, soybean, Vegetables, onion, Rice	Semiarid	2.00 2.00	981 500 to 1,800 Average 750	2,000 2,000	Joint management – do –	Water-short Water-abundant
18	Turkey	Seyhan	Storage	120,200	Maize, cotton, oranges, and many others	Mediterranean	0.86	620		Transferred	Water-abundant

Table 2.3: Computed performance indicators for 18 systems in 11 countries

Source: Molden *et al*., 1998

Country	System	Year	Output / unit cropped land ($/ha)	Output / unit command ($/ha)	Output / unit irrigation supply ($/$m^3$)	Output / unit water consumed ($/$m^3$)	Gross return on investment %	Financial self-sufficiency %	Relative water supply Ratio	Relative irrigation supply Ratio	Water-delivery capacity Ratio
Burkina Faso	Gorgo	1992/93	1,205	1,065	0.10	0.91	9	42	1.6	3.5	3.5
	Mogtedo	1992/93	1,204	2,499	0.09	0.14	21	79	1.4	2.7	2.1
	Savili	1992/93	3,085	2,652	0.37	0.80	33	–	2.5	2.6	2.9
	Gorgo	1994/95	771	679	0.08	0.12	6	35	1.9	2.7	3.5
	Mogtedo	1994/95	1,403	2,384	0.11	0.15	20	78	1.4	2.5	2.1
	Savili	1994/95	2,348	2,281	0.28	0.62	29	28	2.5	2.6	2.9
Colombia	Coella	1993	1,290	1,303	0.14	0.20	24	114	1.8	1.8	2.2
	Saldana	1993	1,125	1,811	0.12	0.17	33	127	2.2	2.9	3.2
	Samaca	1993	1,472	2,462	0.63	0.34	36	109	1.2	1.1	1.7
Egypt	Nile Delta	1993/94	1,510	2,594	0.12	0.11	26	–	1.6	1.6	1.3
India	Mahi Kadana	1991/92	605	515	0.04	0.03	30	–	3.9	3.0	2.9
	Mahi Kadana	1995/96	916	893	0.07	0.06	52	53	2.7	2.5	2.6
Malaysia	Muda	1994/95	1,021	2,041	0.38	0.10	59	–	0.8	0.4	–
Mexico	Alto Rio Lerma										
	Surface + Public wells	1994/95	2,227	1,464	0.18	0.24	28	80	2.2	3.3	5.1
	Private wells	1994/95	3,220	2,242	0.26	0.37	64	–	1.9	2.5	–
	Cortazar Module										
	Surface + Public wells	1994/95	2,615	1,827	0.22	0.25	33	133	2.1	2.3	1.2
	Private wells	1994/95	3,626	2,888	0.26	0.48	66	–	2.2	2.6	–
	Salvatierra Module										
	Surface + Public wells	1994/95	2,117	974	0.10	0.27	27	101	4.1	4.8	2.4
	Private wells	1994/95	1,863	703	0.14	0.23	75	–	2.3	4.5	–
Morocco	Triffa Scheme, Sec. 22	1994/95	1,087	1,358	0.27	0.34	–	47	1.3	1.1	–
Niger	Saga	1993/94	1,389	2,592	0.12	0.13	–	139	2.2	1.8	–
	Kourani Baria I	1994	827	1,460	0.05	0.17	–	–	2.9	2.4	–
	Kourani Baria II	1994	1,107	1,879	0.06	0.11	43	–	2.2	1.7	–
Pakistan	Chishtian sub-division	1993/94	384	477	0.04	0.05	–	40	1.3	1.2	0.8
Sri Lanka	Nachchaduwa	1994/95	826	1,544	0.04	0.08	34	–	2.0	2.2	–
	Rajangana	1994/95	967	1,934	0.06	0.11	43	–	–	–	3.3
Turkey	Seyhan	1996/97	2,167	2,526	0.21	0.19	108	88	2.07	2.15	2.62

2.5 CROPWAT model description

CROPWAT model is a software program for the computation of crop water demand and irrigation programming. Moreover, the software provide options for the design of diverse water supply scenarios and the computation of a number of water supply for several crop patterns (Allen *et al*., 1998).

Normally, the computation of crop CWR and irrigation schedules in CROPWAT is based on the required information prepared by the user which whether can be directly typed into the software or uploaded from other sources.

2.5.1 CROPWAT Program structure

The program is subdivided into in eight distinct modules, five of which are for data enter and three for computations. The entry to the modules is through menu in the tool bar or alternatively using the navigation bar at the left-hand side of the main view (Allen *et al*., 1998).

The data entry modules include climate/Eto, rain, crop type (dry crop or rice, Soil and Crop pattern. The computation modules are CWR, schedules and scheme, for the calculation of crop water requirement, irrigation schedule and scheme supply, respectively (Allen *et al*., 1998).

2.6 Potential environmental impact of irrigation development

The increase of food production by irrigation is considered as a threat to the environment because of its potential negative effect to the environment. FAO (1994), refer that the practice of irrigation can result in soil erosion; contamination of water sources through agrochemicals, deterioration of water quality, increase the concentration of nutrients in the water body which can lead to algal blooms, proliferation of aquatic weeds and eutrophication in waterways

A poor water management in irrigation systems may turn the water unhealthy for other users and affect aquatic ecosystems. Furthermore, the proliferation of aquatic weed in waterways can have negative effect in navigation and ecologic health consequences as it can abstract the water body surface (FAO, 1997).

Due to the huge amount of water that the large irrigation systems impound or divert from the river, they are considered likely to cause environmental instability, resulting from modifications in the limnology and hydrology of the river basins. The decrease of flow, can cause severe alterations in land cover pattern and ecology resulting in negative effects such as saltwater intrusion.

The water abstraction for irrigation reduces the amount of water downstream, preventing other users located downstream to have enough water to cover their needs. Moreover, the water over-abstraction takes out the water needed for the dilution of wastes downstream (FAO, 1997).

The practice of surface irrigation is frequently appointed as the one of source of Salinization and Waterlogging. The last, is mainly a result of poor drainage, water over-abstraction for irrigation and, to a minor degree, seepage from canals and ditches. Waterlogging concentrates salts in the plants' rooting zone by capillary rise from the lower soil profile. The accumulation of sodium in soil layers (Alkalization), is predominantly a harmful form of salinization which is no normally correct (FAO, 1997).

Salinity in irrigation systems mainly result from the application of irrigation water, watering of saline soils, and rising of saline water table combined with poor soil dreinage. If the water applied to the soil during the irrigation contain mineral salts, the salts are laid up into the root zone, since the amount taken up by plants in the process of evapotranspiration and removed at harvest is quite insignificant (FAO, 1997).

2.7 Strategies to improve the performance of the irrigation System

Despite their obvious contribution for food production to cope with the increasing world food demand as the result of rapid population growth, the practice of irrigation has been appointed as a potential threat to the environment due to their low use of inputs and improved technologies (Faurès *et al.*, 2007).

According to Joneydi (2012), in the strategies to reduce the pressure that irrigation system has been subjected, various innovative practices are available, which can be economically viable while time minimizing at the same the environmental burdens such as misuse of water resources, overuse of energy, waste production and land deterioration.

The suggested innovative practices include better use of the existing production systems, adoption of new other technologies, improve the farmers management expertise, modify the current crop patterns to lower the water supply and consumption, minimize the application of agrochemical products (Joneydi, 2012),
The efficiency use of irrigation water can potentially improve the economic feasibility of irrigated agriculture and ensure environment protection , without any need to increase water usage. For such, different types and field tested models for efficiency use of water are available, yet these are little used by farmers (Faurès *et al.*, 2007).

2.7.1 An overview of Multi-criteria Analysis (MCA) approach

The central role of MCA is to deal with the difficulties faced by the decision-makers in handling huge amounts of complex information in a consistent way. The MCA techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisal, or simply to distinguish acceptable from unacceptable possibilities (DCG, 2009).

2.7.1.1 Key features of MCA

Multi-criteria analysis establishes preferences between options by reference to an explicit set of objectives that the decision making body has identified, and for which it has established measurable criteria to assess the extent to which the objectives have been achieved. In simple circumstances, the process of identifying objectives and criteria may alone provide enough information for decision-makers (DCG, 2009).

One limitation of MCA is that it cannot show that an action adds more to welfare than it detracts. Unlike CBA, there is no explicit rationale or necessity for a Pareto Improvement rule that benefits should exceed costs. Thus in MCA, as is also the case with cost effectiveness analysis, the ‘best’ option can be inconsistent with improving welfare, so doing nothing could in principle be preferable (DCG, 2009).

2.7.2 Steps in Multi-criteria Analysis (DCG, 2009)

1. Establish the decision context. What are the aims of the MCA, and who are the decision makers and other key players?
2. Identify the options.
3. Identify the objectives and criteria that reflect the value associated with the consequences of each option.
4. Describe the expected performance of each option against the criteria. (If the analysis is to include steps 5 and 6, also ‘score’ the options, i.e. assess the value associated with the consequences of each option.)
5. ‘Weighting’. Assign weights for each of the criteria to reflect their relative importance to the decision.
6. Combine the weights and scores for each of the options to derive and overall value.
7. Examine the results.
8. Conduct a sensitivity analysis of the results to changes in scores or weights

CHAPTER THREE

METHODOLOGY OF THE STUDY

3.1 General information

To attain the proposed objectives, this research involved the performance assessment of the main limiting output and input factors in evaluating whether the irrigation projects are performing in a sustainable manner or not, in light to recommend sustainable strategies and practices to improve the management of the system.

Due to the very large area (70,000 ha) of the system, time limitation and resources constraints, the interview, field survey, and observations were carried out in three selected irrigations blocks nested to Lower Limpopo irrigation system. The criteria for selection was based on the current existing irrigation method, the level of technology (agricultural and irrigation), secondary data availability and the presence of crops under cultivation during the research period.

The interview focused on the relevant data for the calculation of the proposed indicators, such as agricultural production, environment sustainability, land size, crop intensity and level of satisfaction with the water supply services.

3.2 Description of the Study Area

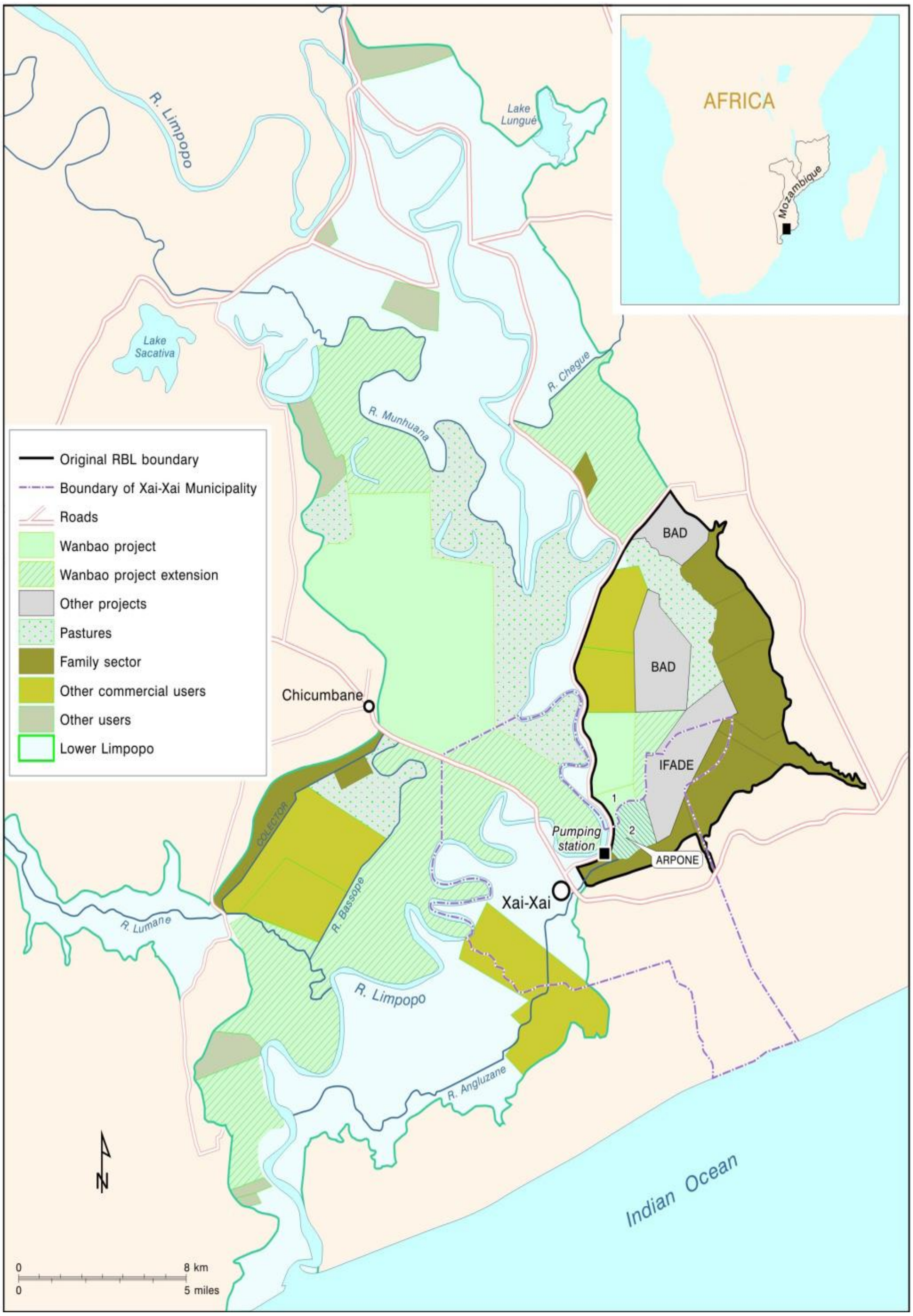
RBL was selected as the study area based on the proximity to an accessible road during the rainy season, availability of secondary. Moreover, the RBL is very vulnerable to land degradation provoked by low soil infiltration rate and to water resource pollution due to salt intrusion through Limpopo river and agriculture nutrients.

3.2.1 Location

The Lower Limpopo Irrigation system is located in Xai-Xai district, in the southern Mozambique at about 5 km far from Xai-Xai city. Its area is very close to the Limpopo river mouth and extends along the alluvial plain of the Limpopo Basin in the Lower Limpopo region (Ganho, 2013). It is bordered to the west and east by a sandy plateau (ridge), to the north by the road linking the headquarters of the Chissano administrative post to Chibuto town, and to the South by the sandy plateau at the mouth of the Limpopo River to the Indian Ocean (Figure 3.1).

3.2.2 Climate

According to Reddy (1986), the climate of the study area is sub-humid, characterized by large variations in rainfall throughout the year and between years, therefore with a rain-fed agriculture low to moderate risk. The average annual rainfall is around 1000 mm, occurring mainly from November to March and the average annual reference evapotranspiration (Eto) varies between 1200 and 1500 mm. The average temperatures range from 18.4 °C to 26.4 °C and monthly average relative humidity (RH) varies between 61% and 69%.



Adapted from Ganho, 2013

Figure 3.1: Map of Lower Limpopo Irrigation System

3.2.3 Soil

The terrain topography is flat with a very low gradient (almost nil), resulting in a very slow runoff (locally flooded during the rainy season and partially flooded in wet years), and the presence of very fine texture, very low permeability and groundwater table near to the surface. The soil profile is generally very dark color, from dark gray to black, which is due to the special composition of humus (Marquês *et al*., 2006).

3.2.4 Land occupation

The land occupation in the irrigation system is according to three different farming sectors, namely:

(i) Household sector: occupies an infrastructured area of 6000 hectares located at the interface between the upland zone and the lower zone. This area is potentially suitable for the production of vegetables and corn, exploring areas ranging from 0.5 to 5 ha, developing subsistence agriculture with poor link with the market;

(ii) Emerging sector: currently occupies an infrastructured area of 540 ha, with potential for the production of cereals and vegetables, exploring areas ranging from 4-48 ha per household and developing market-oriented agriculture and;

(iii) Commercial sector: occupying an infrastructured area of 9750 hectares located in the interior areas of irrigated land, directed to the production of cereals, with land size ranging between 450-8000 ha, developing a specialized agriculture with strong links with the financial market and guaranteed access to credit.

3.3 Data collection

The collection of data was done in collaboration with the Lower Limpopo Irrigation System Management Company from January to March 2016. During the reconnaissance survey, the RBL professional staffs, department of agricultural and meteorological offices and respondents were asked about the general state of the irrigation system. From the analysis of the information obtained from preliminary survey, three irrigation blocks were selected for observations.

The criteria for selection were the availability of organizational setup, the level of technology, farmer categories, proximity to the weather station and the data availability. The collected data encompasses primary data at field level and secondary sources, using the following data collection methods: Reconnaissance visits, semi-structured interviews, direct observation, literature review, field survey and laboratory analysis. In each selected block for observation, three plots corresponding water users were chosen from the top; middle and tail in the main canal.

3.4 Methodology based on Objectives

3.4.1 Identification of the main factors affecting productivity and sustainable water management in Lower Limpopo Irrigation system

To achieve the above objective, the methodology used involved a combination of descriptive and quantitative. For data collection, a semi-structured interview and periodic field observations were carried out to survey and examine the distribution network condition, the water applications methods, agricultural practices, water sources, labor availability and practices associated with water management technologies. The interview was split into different categories of interest, namely: Agronomic, socio-economic characteristics and sustainable agriculture production.

A total of 251 respondents out of 379 were interviewed. The sample size was calculated using equation 3.1 below (Cochran, 1977), and all the farmers were randomized in Microsoft Excel (random function), to select the plots to be observed.

$$n = \frac{z^2(pq)}{e^2} \quad \text{...(3.1)}$$

Where:

n = the size sample

z= standard error related with the chosen level of confidence (1.96)

p = estimated percentage in the population

q= 100-p

e= admissible sample error (5%)

The data entry was done in MS Excel and SPSS windows, version 16. For data analysis, the descriptive and analytical statistics were used. The descriptive statistic function in MS Excel was used for the calculation of frequency, percent, standard deviation, mean, the coefficient of variation and variance. Factor analysis approach preceded by Kaiser-Meyer-Olkin and Bartlett tests was used for the identification of factors affecting sustainable productivity and water management in the system.

3.4.2 Estimation of the overall Lower Limpopo irrigation performance

To achieve the above objective, five groups of relevant comparative performance indicators (equations 2.1 to 2.10) were used to evaluate and compare the performance Lower Limpopo Irrigation System. These are water supply, agricultural output, financial and Environmental indicators. The required data for the calculation of the selected comparative performance indicators include:

a) The canal capacity to deliver water at head: Was calculated using Hcanales for windows software, version 2.1. The input data were obtained by field survey measuring the canal profile using optical topographic level, canal cross section survey using measuring tape and literature review. These include canal slope, water depth, canal roughness and canal cross section area. The calculation of canal capacity in Hcanales is based on the Manning equation, as presented below (equation 3.2).

$$Q = (1/n)AR^{2/3}S^{1/2} \quad (3.2)$$

where,

Q = flow (m^3/s)

n = Manning coefficient

R = hydraulic radius (m)

S = channel slope (m/m)

A = Wetted are (m^2)

b) The volume of water delivered: The total volume of water delivered was measured using the current meter (Appendix B). The flows in the main canal were measured two times (at the morning and afternoon) per each observation day for the determination of the average daily discharges. The mean velocity in a vertical was measured by the one-point method (WMO, 1994), placing the current meter at 0.6 of the depth below the water surface.

The velocity for each measurement was obtained from the current meter table by crossing the revolution from the current meter with the constant in the table. The revolution per second was computed by dividing the total number of revolution per total recorded time. The discharges per each measurement event were computed using the velocity Area method (equation 3.3) and the total amount of water diverted in each irrigation event (day) were computed by multiplying the discharges by the total recorded irrigation time (equation 3.4).

$$Q = V*A_w \qquad (3.3)$$

$V_{total} = Q*t_{total}$ ....(3.4)

Where:

Q = discharge (m^3/s)

V = mean velocity

A_w = Wetted area

V_{Total} = Total volume of water diverted in each complete irrigation event

T_{Total} = Total time recorded

For measurement of flow in pipes and discharge from pumps (total amount placed in the conveyance), the ultrasonic Flexim Fluxus F601 flow meter was used. The input data were the pipe diameter, pipe production material (e.g. PVC, galvanized steel, cast iron) and pipe thickness (appendix 2). The total amount of water diverted in each irrigation event (day) were computed by multiplying the flow per unit time by the total recorded irrigation time.

c) The cost of irrigation Infrastructures: The initial investment costs were collected from the irrigation system design documents made available by RBL Management Company. From these data, the present year construction costs were calculated using the equation 3.5 below. The interest rate was obtained from the Central Bank of Mozambique (BM, 2016) and final value was obtained by the computation of the average of the interest rate from January, 01st to April, 01st, 2016, corresponding the period of data collection.

$$\text{Present Net Worth (PNW)} = (\text{Initial cost / ha})*(1+ r)^{n} \qquad (3.5)$$

Where:

r is the interest rate, which is taken from the design document and, n is the years from construction time.

d) Operation and maintenance cost: At MozIndia irrigation block, the cost was obtained from the farm manager. Since it was not possible to get the operation and maintenance costs at Wambao and Ponela blocks due to complexity for calculation since the major part of the costs are paid by the Government and Chinese partner, the costs of other irrigation schemes presenting similar infrastructures and structural condition were taken (Molden *et al.*, 1998). Therefore, considering the costs proposed by FAO (2005) for surface irrigation in Mozambique, the maintenance cost was found to be approximately US$500/ha per year and the expense for rehabilitation between US$500 and 1,500/ha, depending on the condition of the system (the average value of US$1000 was taken).

Moreover, it was found from the farmers records that the amount of money normally charged by the management company to cover the costs of operation and maintenance of the main canals was 3000.00 MT, corresponding to approximately US$66.7 per ha/year.

e) Crop water requirement: The net CWR and IR were calculated for each irrigation block using data collected in 2014/2015 cropping season. The CROPWAT Computer based program version 8, were used to compute the water requirement for rice in all the growing stages based on Penman-Monteith equation and dependable rain (FAO/AGLW formula) for the estimation of effective rainfall. The input data were the soil type, sowing date, rainfall and temperature data and crop pattern. The meteorological data were collected from the National Meteorology Institute.

d) Water diverted to the field: To compute the total amount diverted, the volume of water upstream and downstream of the selected off take was measured using current. The discharge was computed by calculating the difference between the upstream and downstream the off-take and the total volume diverted per each irrigation event were computed multiplying the discharge by the total recorded time.

e) Secondary data: The collected data include total yields, local prices and the world price of main crops per season, crop patterns, production cost, revenue generated, crop type and meteorological data. The above-stated data were obtained from field survey and literature review provided by different Government Institutions. The climatic data of the nearby weather stations of each irrigation block were obtained from the National Meteorology Institute and the Irrigation System design documents were collected from the respective Irrigation System Management company.

e) Laboratory analyses: The Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), sodium, chlorides and nitrates (NO3) were determined at the National Laboratory of Water and Hygiene. A total of six water samples, being two per month, were collected for analysis at the pumping stations and drainage system of each irrigation block at 0.6 depths below the water surface (Shaw, 1994). The other water quality parameters such as pH, Conductivity, Total dissolved solids and salinity were analyzed in-situ using portable instruments once per week and three times per day.

The samples were collected in 500 ml glass container for microbial analysis and in 1500 mm plastic bottle for physical parameters analysis and transported in controlled temperature in a cool box to the laboratory within 24 hours.

f) Standard Value of Production (SGVP): Was calculated using equation 2.5. The rice was taken as the base crop and the world price was obtained from the World Bank Commodity Price Outlook (WB, 2016).

3.5 Data analysis techniques and interpretation

The data analysis and interpretation were mainly concentrated on the calculation of the selected indicators. The results of each calculated category of indicators for all the blocks were plotted in MS Excel charts, and comparison was done between results from different irrigation blocks and within the blocks. Furthermore, all the results from the indicator calculation were then compared with the standard threshold to determine whether the system is performing well or not, as per the threshold presented in Table 3.1.

Table 3.1: Indicative Performance threshold

Indicator	Good	References
Relative Water Supply	≥1 [-]	Molden at al., 1998
Relative Irrigation Supply	1 [-]	Molden at al., 2008
Water Delivery Capacity	>1 [-]	Molden at al., 1998
Gross Return in Investment	>50%	Molden at al., 1998
Output per unit cropped area	4,445 USD/ha	USAID, 2014
Output per unit command area	> 4,445 USD/ha	USAID, 2014
Output per unit irrigation supply	0.6-0.1.6 USD/m3	Molden at al., 1998
Output per unit water consumed	0.6-0.1.6 USD/m^3	Molden at al., 2008
Biochemical Oxygen Demand (BOD)	≤ 5 mg/l < at 20^{o}C	Law n^{o} 20/97, October, 1st
Chemical Oxygen Demand (COD)	≤ 150 mg/l	Law n^{o} 20/97, October, 1st
Total Dissolved salts (TDS)	≤ 2000 ml/l	Law n^{o} 20/97, October, 1st

3.6 Appropriate strategies to improve the irrigation system performance

The results from factor analysis and the evaluation of performance indicator were analyzed and then used to develop sustainable strategies to improve the management of the scheme. All the parameters considered to be the cause of low system performance or potential threat to the environment were adjusted and different strategies and measures were suggested and ranked using multi-criteria analysis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Identification of the main factors affecting productivity and sustainable water management in Lower Limpopo Irrigation system

Agricultural productivity can be influenced by a number of factors which can influence it to enhance or decline hence, it is important to note that productivity and sustainability are not an absolute measure, but rather a measure of the ratio between inputs and agricultural outputs (Oluwatayo *et al*., 2008).

4.1.1 Personal characteristics of the farmers

Personal characteristics of the farmers consist of selected seven variables that can affect sustainable agricultural production in an irrigation scheme. The selected variables and their details are as per Table 4.1.

Table 4.1: Distribution of respondents according to personal characteristics

Characteristic		Frequency of respondents	Percentage
Age	20 – 35	75	29.9
	35-50	164	65.3
	Above 50	12	4.8
Gender	Male	111	44.2
	Female	140	55.8
Marital Status	Single	20	8.0
	Married	130	51.8
	Divorsed	37	14.7
	Widow	64	25.5
Household Size	Below 3	30	12.0
	2 – 4	45	17.9
	5 – 10	110	43.8
	Above 10	60	23.9
Total Annual Income in USD per household	Below 1000	29	11.6
	1000-5000	173	68.9
	Above 5000	49	19.5
Educational Level	No formal Education	44	17.5
	Primary Education	152	60.6
	Secondary Education	39	15.5
	University Education	16	6.4
Farm Size	0 – 1.5	151	60.2
	1.6 – 5	87	34.7
	Above 5	13	5.2

Based on the findings from the interview (summarized in Table 4.1), the average farmers age was 38 years, being the majority within the age range of 35-50 years. The greater part of the respondents (51.8 %) were married, 25.5 % widower and the least were the divorced representing 14.7% and the single with 8%. The previous results infer that most farmers in the irrigation system are younger and female and the married respondents were more involved in agricultural production than the single one. Each of the small-scale farmers (familiar sector) performing 60.2 % had an average of 1 ha of irrigated area and 46.3 percent of people has between 1-5 hectare of land and about 34.7 % (emerging sector farmers) devote an average of four hectare, this infers that majority (60.2%) of the farmer were mainly involved in subsistence agriculture.

According to Adomi, *et al*. (2003), the age and the experience of the household head is of capital importance for the improvement of their holdings productivity and sustainability as it helps the farmer to build up knowledge of farm practices in cultivating crops and occurrence of natural phenomena from previous cultivations experience.

Also, the gender disparity (55.8 % female against 44.2 % male) and the existence of household headed by widow women (25.5%) can be a constraint for the practice of sustainable agriculture in the irrigation system, since the gender preconception toward the right to get land, finance, and education for men tend to reduce the performance of female households heads in agriculture activities if compared to male household heads (Endale, 2011).

The high percentage of household with 5-10 persons which is 43.8% of the total number of respondents if compared with the result of the total annual income per household which shows that 69.8 % of the household have a total annual income in the bracket of 1000-5000 USD per household, imply that the annual revenue of the farmers was relatively low and quite insufficient to cover household needs and running costs of the irrigation system.

4.1.2 Factors affecting sustainable irrigation system productivity and water management

Agricultural productivity can be defined as the proportion of the total agricultural income to the total agricultural inputs used in farm cultivation (Oluwatayo *et al*., 2008). Historically irrigation has been seen as one of the major factors for increasing crop productivity, but such depends on various other factors that can cause it to increase or decrease, hence the importance of analyzing the limiting factors in RBL irrigation system, as described hereafter.

The Table 4.2, shows the identified variables affecting optimal productivity and irrigation water management in Lower Limpopo Irrigation system from the interviewed farmer's perspective and perception. According to the results displayed in the table 4.2, the inadequate agriculture input (Mean = 4.7, CV = 0.1), poor access to improved production technology (mean= 4.2; CV = 0.2), yield potentiality (Mean= 4.1; CV = 0.2) and high mechanization cost (Mean = 4.1; CV= 0.19) are the four most important factors affecting sustainable productivity and water management in Lower Limpopo Irrigation System. In fact, the use of traditional seed (unimproved seed), weak use of fertilizer and poor irrigation water management had been appointed by Marquês (2006), as the major factors constraining productivity in irrigation systems operated by small-scale farmers in Mozambique. Significant number of small-scale farmer in the Ponela irrigation block reported that some farmers are still using rice seed variety with maximum potential yield of 4 tons/ha, prone to pest and disease and long growing period which is very low if compared with that supplied by Chineses and Mozindia which can achieve a yield of about 12 tons/ha.

The last two values in the Table shows that in farmers' perspective the climate change and variability (Mean = 1.7; CV = 0.27) and flood and drought (Mean = 1.9; CV = 0.43) has the least effect on optimal productivity and sustainable irrigation water management. Indeed, the data from different respondents in all the selected irrigation blocks does not show significant differences between the yield per hectare obtained per male household heads in compared with that obtained per female household head.

The other variable in the Table 4.2 such as, access to inefficient marketing (Mean = 3.6; CV= 0.28), inadequate agricultural credit (mean = 3.5; CV = 0.24) and input availability (Mean = 3.4; CV = 0.25) are other variable that were considered by the respondents as they can affect considerably the sustainable productivity and irrigation water management. The other variables, not least, are shown in Table 4.2.

Table 4.2: Factors limiting optimal productivity and water management

Variable	Mean	Std. Deviation	Coef. of Variation
Inadequate agriculture input	4.7	0.463	0.10
Poor access to improved production technology	4.2	0.829	0.20
Yield potentiality	4.1	0.820	0.20
High mechanization cost	4.1	0.798	0.19
Inefficient marketing	3.6	0.998	0.28
Inadequate agricultural credit	3.5	0.846	0.24
Input availability	3.4	0.865	0.25
High cost of agriculture infrastructures	3.3	1.040	0.32
Poor quality of irrigation infrastructures	3.2	1.244	0.39
Poor implementation of policies	3.2	1.025	0.32
Poor participation of farmer in water management	3.2	0.775	0.25
Absence of water meter and penalties for water overuse	3.1	0.745	0.24
Crop pattern	3.1	1.223	0.40
Poor access to extension agents	3.1	1.058	0.35
Seed availability and quality;	3.0	1.115	0.37
HIV	2.9	0.709	0.25
Level of education	2.8	0.873	0.31
Land tenure	2.8	0.569	0.20
Droughts and floods	2.8	0.705	0.25
Climate change and variability	2.7	1.303	0.49
Water availability	2.6	0.890	0.34
Gender	2.5	1.227	0.49
Soil erosion and deterioration	2.1	0.845	0.41
Climate change and variability	1.9	0.810	0.43
Droughts and floods	1.7	0.468	0.27

Note: very slightly or not at al = 1 Little= 2 Moderately = 3 quite a bit = 4 Extremily = 5

4.1.3 Factor analysis results

The main objective of performing the factor analysis was to come out with a reduced set of factors that describe most of the dissimilarity that is observed in the selected large set of manifest variables. For this regard, a total of twenty-five (25) variables (Table 4.2) were selected and weighted by the farmer according to their perception on how each of them can affect the sustainable productivity and water management.

The prior step to factor analysis was the calculation of Kaiser-Meyer-Olklin (KMO) coefficient to examine the sampling adequacy, whether the partial relationship among items are small and Bartlett's test of sphericity to verify if the correlation matrix is an identity matrix. According to Kalantari, (2008) if KMO value is greater than 0.5 it can safely be used in factor analysis and the Bartlett Test of Sphericity (BTS) must be statistically significant ($p < 0.05$). In the present study, based on the result displayed in Table 4.3, the KMO coefficient is equal to 0.603 and Bartlett's test is significant at 99% level (Sig= 000) hence, good figures to proceed with the analysis.

Table 4.3: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.603
Bartlett's Test of Sphericity	Approx. Chi-Square	835
	df	325
	Sig.	0.000

After checking the suitability of the database for factor analysis, the factors were extracted using Principal Component Factor (PCF) method and all the extracted factor were then rotated using Orthogonal Varimax method to achieve significant factors. Following the rule of eigenvalue (Kaiser criterion) only factors with eigenvalues value greater than one were extracted, since all those with eigenvalue less than one contribute very little to explain the variance in the original variables. The extracted factors are presented in Table 4.4. These extracted nine factors determine 70.37 % of total variance regarding optimal productivity and sustainable water management in the overall irrigation system. In summary, these nine factors can validate 70.37% of the factors limiting the productivity and sustainable irrigation water management in the system. The number of factors was determined based on the acceptable minimum accumulated percentage of 60% proposed by Hair *et al*. (2006).

Table 4.4: Extracted factors with eigenvalues greater than one

Factor number	Name of factor	Total eigenvalue	% of Variance	Cumulative %
1	Technological and Knowledge factor	3.84	16.69	16.69
2	Economic factors	2.75	11.94	28.63
3	Institutional and legal factors	1.70	7.41	36.03
4	Crop Factors	1.66	7.23	43.26
5	Social factors	1.46	6.35	49.61
6	Hydological factors	1.27	5.54	55.15
7	Environmental factors	1.24	5.38	60.53
8	Gender factor	1.20	5.20	65.73
9	Soil factor	1.07	4.64	70.37

Table 4.5 shows the rotated loading factors status after removing all the variable with loading factors less than 0.5 since low values of commonality among a group of variables is an indication that they are not linearly correlated and therefore should not be included in the factor analysis (Schawb, 2007).

Table 4.5: Variable related to each extracted factor with loading factor

Principal Factor name	Variable	Factor Loading
Tehcnological and Knowlogde factors	Poor access to extension agents	0.656
	Access to improved production technology	0.647
	Inadequate agriculture input	0.717
	High mechanization cost	0.811
Econonic Factors	Inefficient marketing	0.691
	Inadequate agricultural credit	0.844
	Input availability	0.669
	High cost of agriculture infrastructures	0.713
Institutional and legal factors	Poor quality of irrigation infrastructures	0.668
	Poor implementation of policies	0.782
	management	0.599
	water overuse	0.624
Crop Factors	Inadequade Crop pattern	0.735
	Yield potentiality	0.807
	Seed availability and quality;	0.882
Social Factors	HIV	0.692
	Level of education	0.560
	Land tenure	0.668
Hydrological factors	Droughts and floods	0.638
Environmental factors	Climate change and variability	0.684
	Water availability	0.633
Gender Factors	Gender	0.636
Soil Factors	Soil erosion and deterioration	0.826

As seen from the Table 4.5, in each extracted PCF, other variable exist with loading factor greater than 0.5. So, since the aim of carrying out the PCF was to access the factors explaining better the variance, the variables which their variance cannot be explained by the main factor were removed in order to increase the amount of total variance, based on Kalantari (2008) principle. Thus, in the extracted factors described hereafter, the undesirable variables have been removed and variable with loading equal to 0.30 and above were used to name the group of factors, as per the result from the Varimax rotated factor matrix. The results of factor analysis suggested nine factors with a significant effect on productivity and sustainable irrigation water management in the system, specifically:

Technological and knowledge factors: This set of factors alone explains 16.69 % of the total variance. In other words, poor technology and farmers' knowledge can cause a decrease of 16.69 % of the productivity and water use efficiency. Poor access to extension services, deficient access to improved production technology, inadequate agriculture input are the other critical variables among technological and knowledge factor.

The impact caused by different technologies adopted in the three observed irrigations blocks on the increase of productivity per unit land was quite apparent. The examples are the clear differences of low rice productivity of about 4 tons / ha achieved by the farmer using conventional production technology if compared with the average of 7-9 t / ha achieved by the farmer who adopted Chinese technology and about 12 tons / ha for farmers who adopted the Indian technology. According to a study by USAID (2014), the low agricultural productivity in Mozambique is derived from of a absence of improved technologies, use of unimproved seed, and use of traditional cultivation practices.

Despite the unquestionable increase in the productivity per unit land, based on the real situation observed on the ground during the research, the small-holder farmer are not really learning enough in such way that they can implement the technology by themselves in upcoming growing season once almost all the technical activities are being implemented by Chineses and RBL staff in form of service provider. As an example, in Wambao block almost 90% of the farmers were not able to tell the cost and quantity of seed used and the cost of any activity ongoing in their own plot even how much they pay for water services. Moreover, there is deficient communication between the Chinese technical team that is transferring the technologies and the farmer because of the language barrier in between them.

Economic factors: These factors determine 11.94 % of the total variance. The most outstanding variables of this group are inefficient marketing, inadequate agricultural credit, high labor cost an input availability. The inefficient marking combined with inadequate agricultural credit were the main issues raised by the farmer in this group of factors. Farmers reported that the nearest available large market for vegetable sale is located in Maputo province, which is about 240 km far from the production area. This condition was raised as a constraint since is time-consuming and expensive for small farmers.

Aune and Batiano (2008), stated that a poor development of agricultural markets can create disproportionality between the input and output prices of agricultural products which in turn affect the income farmers. Pratap *et al*. (2008), refer that special attention is need when it comes to horticultural crops, since because of their perishable nature; farmers sell them immediately after harvesting to avoid postharvest losses. Therefore, that until the production reaches the final consumer passes through different intermediaries, resulting in high marketing costs which in turn reduce the profit margins of the small farmers.

With respect to agricultural credit, the farmers reported that they are only benefiting by micro-credit from the Government and rarely receive funding from the commercial banks since they normally do not have the collateral required as the land cannot be used as collateral. According to National land law, "the land is the property of the State and cannot be sold or otherwise alienated, mortgaged or encumbered" (Law nº 19/97, Art. 3). The previous finding is supported by Marquês (2006) in his previous study in Mozambique, where he found that the absence of land property rights limits the access of small farmer to credit from commercial banks.

Legal and Institutional factors: It determines 7.41 % of the total variance. In another sense, by minimizing the effect of these factors we can achieve 7.41 % of the objectives of increasing productivity and sustainable irrigation water management. Other variables associated with this factor which can affect productivity and efficient irrigation water use are the Poor quality of irrigation infrastructures, poor implementation of policies, the weak participation of farmers in water management, the absence of water meters and penalties for water overuse. The study results indicate that the reduced numbers and low qualifications of staff combined with the low availability of transportation facilities remain a serious constraint for the irrigation system management company. This scenario is exacerbated by the limited ability of the management company, to attract and retain qualified extension staff, since the government salary is significantly low if compared with that offered by other non-Government agencies.

Crop Factors: These factors explain 7.23 % of the total variance. Inadequate crop pattern, low yield potentiality and seed availability and quality, are other factors in this group. In his research, Alemu *et al*. (2008), affirmed that improved seeds can trigger a significant increase in agricultural productivity if other inputs are maintained under optimal condition. In Lower Limpopo Irrigation System, the impact generated by the use of improved rice seed is apparent. The farmers reported that the increase of their productivity from an average of 4 tons/ha using traditional seed three years ago, to an average of 7.5 tons/ha in 2014/2015 season when high yield seed was introduced by Chineses farmers.

Social factors: These factors explain 6.35 % of the total variance. The other important variables associated with this group are HIV/AIDS, the level of education and land tenure. The prevalence of the HIV virus in Mozambique is reported by USAID (2014) as one of the causes for low agriculture productivity as it attacks the most productive people in the household and lead to the increase in their expense due to medical costs and other cares.

Although the research results reveals absence of significant difference in the output per hectare between the educated and non-educated farmers, the difference on know-how between the two classes, was cleanly noted during the interview. The farmers holding formal education were able to interpret and explain the different phenomena affecting their productivity more fluently than those with none formal education. USAID (2014), considered the education as of capital importance in the agrarian community as it can help the farmers to understand easily the need for adoption of new technologies and increase the willing to learn new practices.

The other four extracted factor can be seen in details in Table 4.5 and all together determine a total of 20.76 % of the total variance. These include: Hydrological factors (5.54 %), environmental factors (5.38 %), gender factor (5.20 %) and soil factor (4.64 %). The study results show that the majority of female-headed households have a land size in the bracket of 0.5-1.5 hectares and has low self-sufficiency if compared with the land size of male headed households which have an average of four hectares. Therefore, female-headed households cultivate much reduced areas and have more difficulties to shift to new productive practices and technologies because they normally have limited labor and financial resources.

The above results are supported by other studies carried out by Collier (2003), which reported that in Mozambique the rural women is the most deprived group in terms of economic opportunities and their farming is characterized by low productivity. Likewise, it was observed that although the research results reported apparent gender equity in term of land tenure, it was notorious that the division of labor between the sexes is still being influenced by the local culture, being the men employed off-farm leaving the day to day farm activities to women.

4.2 Estimation of the overall Lower Limpopo irrigation system performance

4.2.1 Overview

For the fulfillment of this objective, the Ponela, Wambao and MozIndia Blocks were selected as they present differences on technology used, irrigation method and water sources. The type of crop grown (rice) during the study period was the same in all the three selected blocks and was taken as the base crop. .

The collected and processed core data in which the calculations of all the comparative indicators were based are as per the summary in Table 4.6 and 4.7.

Table 4.6: Parameters for calculation of individual project performance indicators

Irrigation Block	Planting date	Crop demand (m^3/ha)	Irrigation Demand (m^3/ha)	Eff. Rain (m^3/ha)	Annual Water delivered	Total Water supply (m^3/ha)
(1)	(2)	(3)	(4)	(5)	(6)	7 = (5+6)
Wambao	Jan, 04	6775	12068	3186	26542	29728
Ponela	Dec, 15	7729	12539	3091	19377	22468
MozIndia	Dec, 20	7303	12408	3347	17460	20807

Table 4.7: SVGP calculation for all the selected irrigation blocks (year 2014/2015)

Irrigation Block	Irrigated cropped area (ha)	Irrigated command area (ha)	Yield (t/ha)	Yield (t)	P_{World} (USD/ton)	SGVP (USD/year)
(1)	(2)	(3)	(4)	5= (2x4)	(6)	(5X6)
Wambao	3300	8300	7.5	24750	370.48	9,169,380.00
Ponela	28	360	4.0	112	370.48	41,493.76
MozIndia	25	60	9.0	225	370.48	83,358.00

Note: P_{world} is the World price obtained from World Bank, 2016 for the base crop (Rice)

4.2.1 Water Supply Indicators

This category of indicators describes the individual system with respect to the ratio between water supply and demand. The results provide the condition of water abundance or scarcity in the area and establish the relationship between supply and demand (Molden *et al*., 1998). The indicators are as per the Figure 4.1.

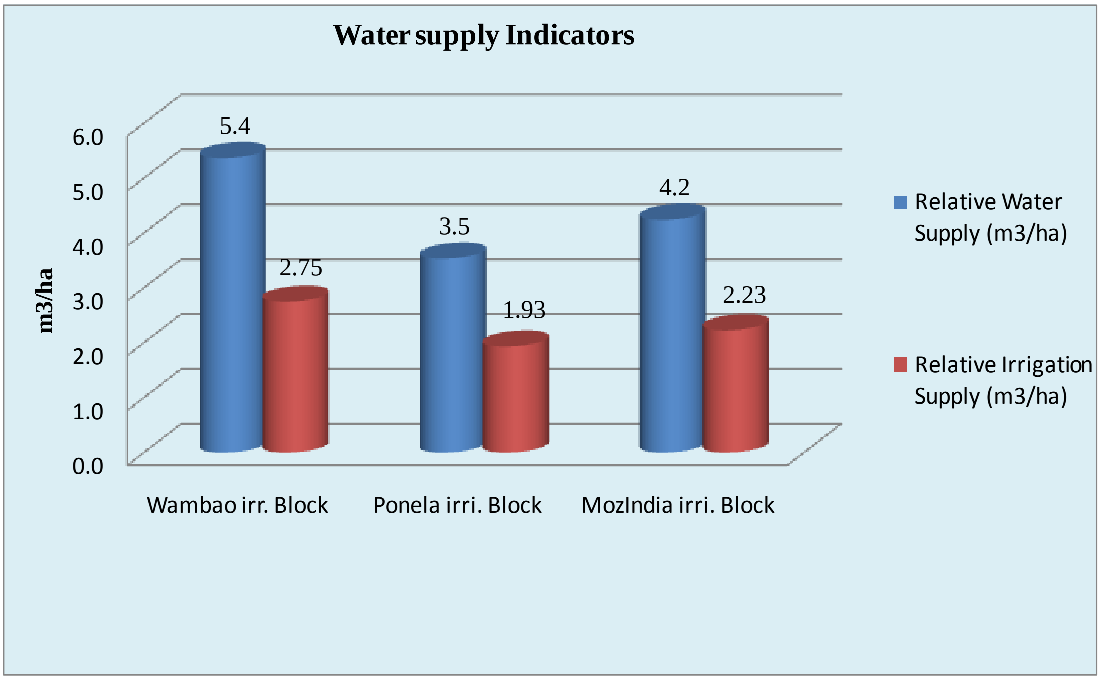


Figure 4.1: Water supply indicators

The results in Figure 4.1 show that the values of the water supply indicators (RWS and RIS) in all the blocks are higher than one, this indicates the abundance of water in the system during the study period. Molden *et al*. (1998), recommend values of RIS close to one rather than values higher or lower than one. Hence, high values of RIS in all the observed blocks indicate that excess irrigation water was being supplied.

Likewise, the results indicate that RWS values are greater than RIS which is an indication that there was a substantial contribution of rainfall to the water supply for agriculture in the area. It is important to note that the irrigation efficiency in all the blocks is very low, meaning that more than irrigation demand is being supplied. The RIS values vary from 1.93 to 2.75 which gives an indication of irrigation efficiency in the bracket of 36% at Wambao irrigation block to 52% at Ponela irrigation block. The low irrigation efficiency at Wambao Irrigation Block may be due to two main reasons: (1) all the canals (main and secondary) are not lined and some of the secondary canals are not well maintained as the maintenance activities are of sole responsibility of the farmers and, (2) there is no strict control of water leak from the flooded plots to the drainage ditch by the farmers.

Contrary, the irrigation efficiency in Ponela irrigation Block is reasonable and the main reason is the fact that all the distribution system is piped, minimizing in that way the water losses during the transportation. Likewise, the low irrigation efficiency may also be attributed to the fact that almost all the observed irrigation block are lacking discharge control structures leading to a weak capacity of farmers to have adequate control on efficient water application. The results found are similar with those found by Marquês (2006) in which he reported an irrigation efficiency of 40 to 50 % for small scale irrigation system in Mozambique.

4.2.3 Canal Delivery Capacity indicator

The water delivery capacity ration explains whether the conveyance system is somehow a limitation to cope with the crop water demand at the pick period. Values of WDC above one indicate that channel capacity is capable to meet the water demand at the pick period. A ratio of WDC very close is sign that the canal may not deliver enough water at the pick period to satisfy the short-tem demand.(Molden *et al*., 1998). The indicator for irrigation infrastructure is per the Figure 4.2.

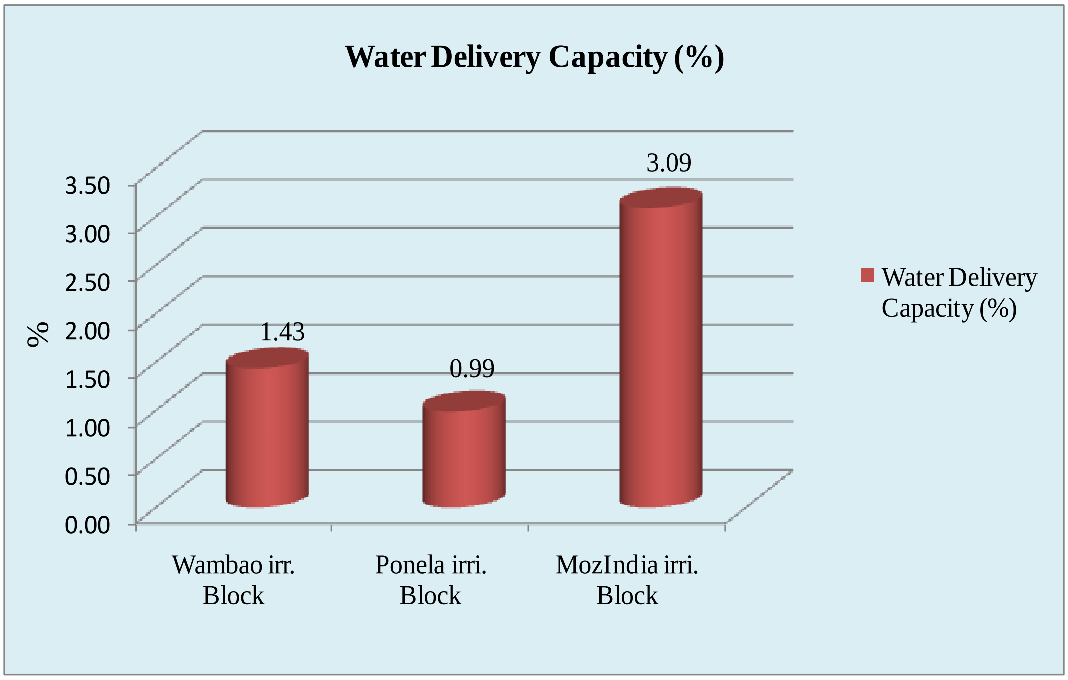


Figure 4.2: Water Delivery Capacity indicator

The values of WDC in Figure 4.2, show that at Wambao and MozIndia irrigation blocks the conveyance has enough capacity to deliver the necessary peak water demand (WDC > 1), this mean that the canals carrying capacity in this two irrigation blocks are not constrain. But in the Ponela block, the WDC value is less than one inferring that the canal capacity may be a constraint at peak crop demand time as the canal capacity to deliver water would be below the crop requirements.

4.2.4 Financial Indicators

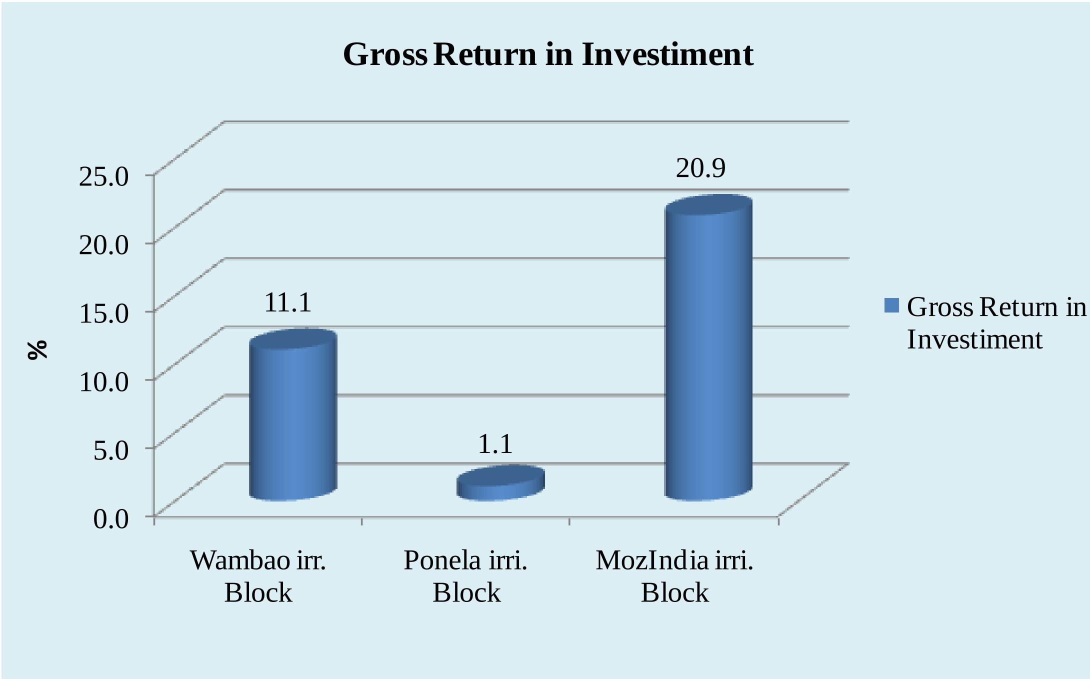


Figure 4.3: Gross Return in investment

Figure 4.3; show that in term of gross return on investment all the three observed blocks are no performing well. The higher value was observed at Mozindia irrigation Block, followed by Wambao block and the least in Ponela Block. The low GRI rate observed is mainly associated with the fact that more than 60% of the area were not under cultivation in all irrigation block during the season 2014/15 taken as the base year. The very low rate of return in investment at Ponela block is may be due to the high cost of infrastructures and lower agricultural productivity.

The reported GRI rates, infer that in the line that the rice is being produced at Ponela irrigation block is not profitable and may not cover the investment costs on infrastructures within the useful life of the system.

The results found in this study are similar with those reported by Molden *et al*. (1998), where the GRI of rice-based irrigation systems in Burkina Faso were low, ranging from 6% to 30%.

Self-sufficiency Indicator (SSF)

The financial self-sufficiency indicator is the measure of how much the farmer can pay for themselves the cost of irrigation operation and maintenance without an external help, whether from the government or non-Government partner.

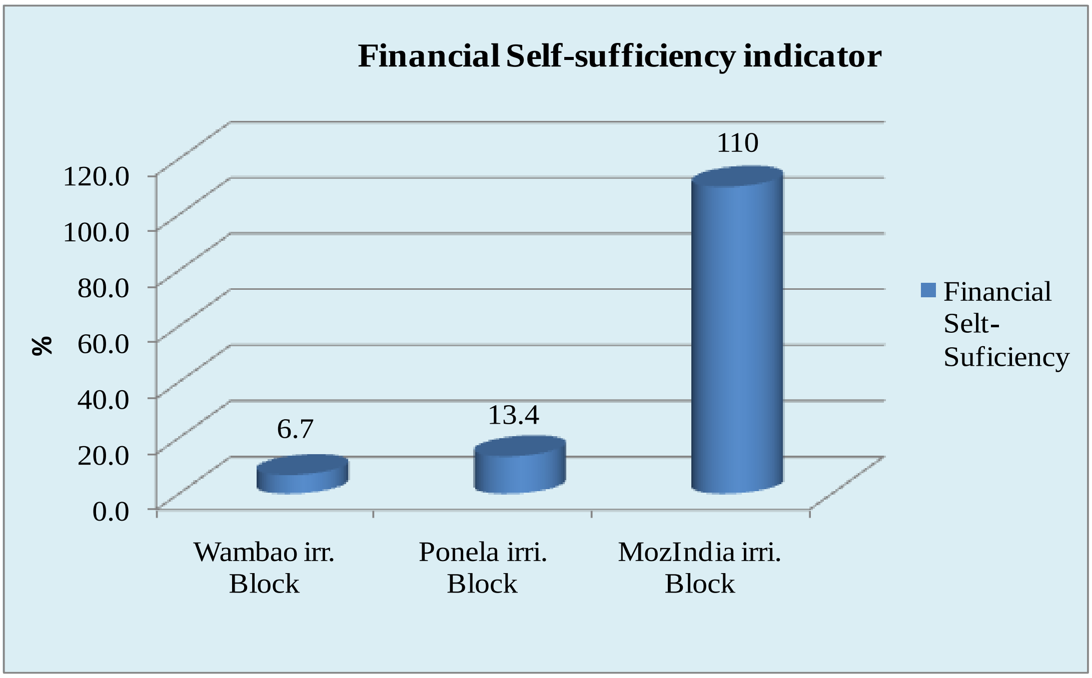


Figure 4.4: Self-Sufficiency indicator

As depicted in Figure 4.4, the financial self-sufficiency value was between 6.7 % and 110 %. The lowest SSF was observed at Wambao, followed by Ponela and the highest was observed at MozIndia irrigation block. Values of SSF below 100 % at Wambao and Ponela irrigation blocks indicate that the fees collected from irrigation are not capable of covering the operation maintenance costs. According to Molden (2010), the lack of capacity to cope with running expenses is one of the major concerns for the sustainability of many irrigation systems in Africa.

Indeed, it was observed in the two irrigation blocks with low SSF values that the irrigation system operation and maintenance costs are highly subsided by the Government and partners and the farmers are only paying for water supply services a symbolic value of 3000 Mt, approximately 67 USD/ha per season. This scenario becomes even more dramatic if considering the fact that the water rates are not paid depending on consumption, but rather per unit land, exacerbating the low farmer's willingness to pay for the improvement of water application efficiency and adoption of water saving technologies.

4.2.5 Land Productivity indicators

There are two selected indicators in this category. The first indicator the output per cropped area explain the response of the area under cultivation on producing the gross return and the second, the output unit command area, specify the average return of each designed command area.

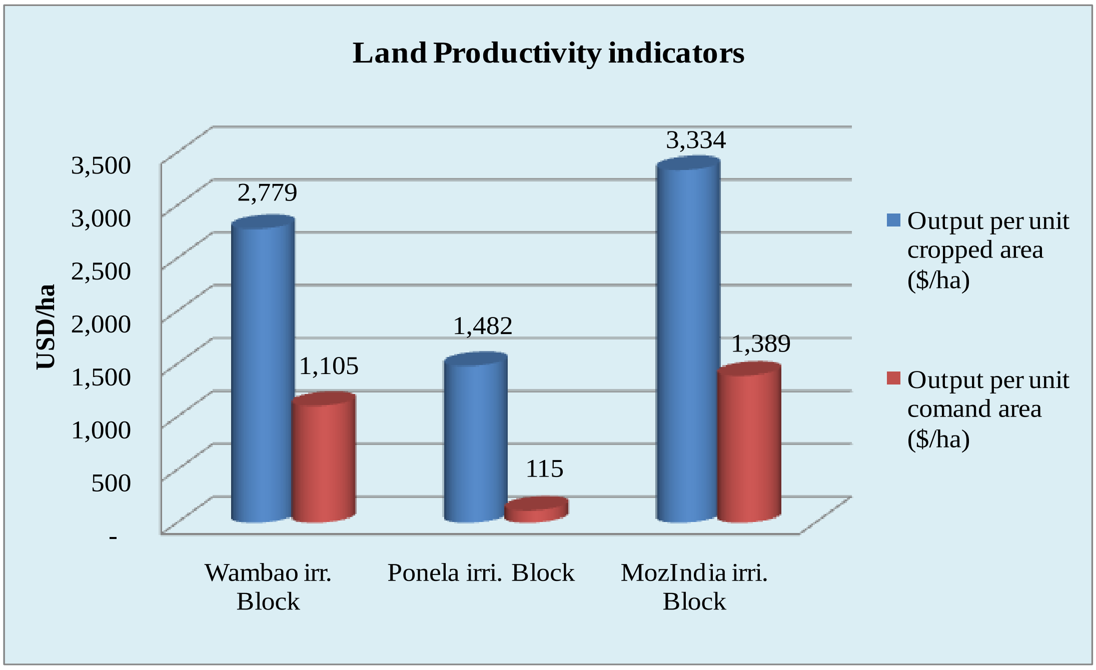


Figure 4.5: Land productivity indicators

As per the Figure 4.5, the MozIndia Irrigation Block has the highest output per unit command (1,389.00 USD/ha) area followed by Wambao irrigation Block (1,105.00 USD/ha) and the lowest was recorded in Ponela irrigation Block (115.00 USD/ha). Likewise, the graph shows that all the irrigation block has significantly higher output per unit cropped area than the output per command area, which is an indication of cropping intensity less than one in all the blocks.

In fact, it was observed during the data collection that the area with infrastructure under cultivation in 2014/2015 season was only 40 % at Wambao block, 7.8 % at Ponela block and 19 % in MozIndia. The farmers reported that are not cultivating all their area because of financial constraints to pay for the land preparation and acquisition of agricultural inputs. The farmers also appointed the cyclic occurrence of floods caused by climate variability as one of the causes for the very low cropping intensity. If comparing the 6.8 tons/ha average productivity of the overall Lower Limpopo irrigation system with the 2.5 to 4 ton/ha national average for paddy rice (USAID, 2014), it can be stated that irrigation system is performing well in term of land productivity.

4.2.6 Water Productivity Indicators

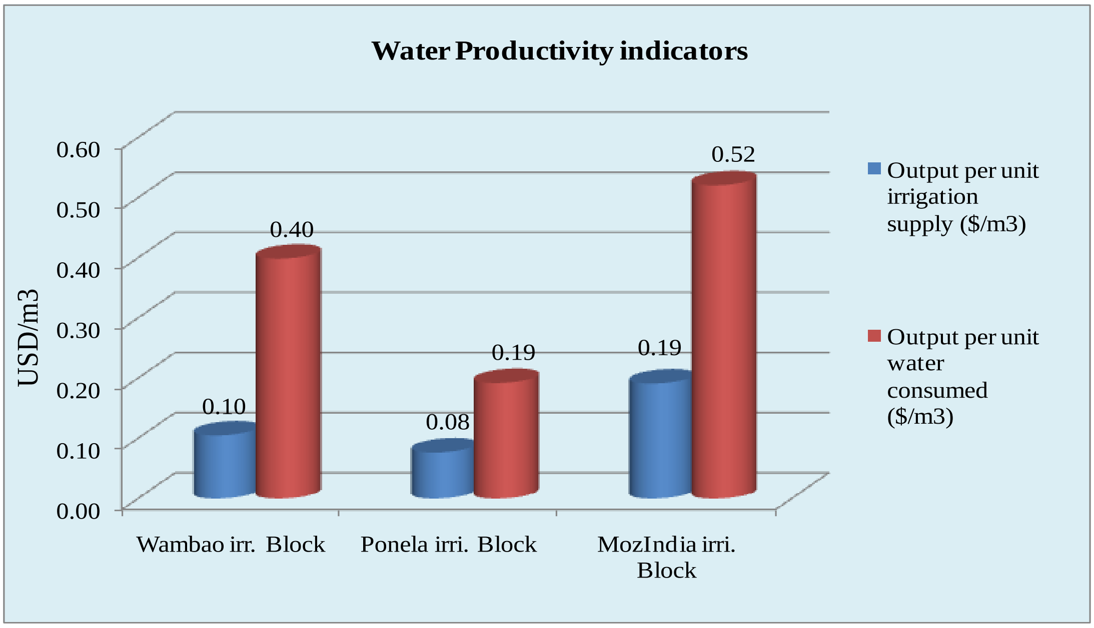


Figure 4.6: Water Productivity Indicators

From the Figure 4.6, MozIndia Irrigation block has higher values of output per unit water consumed (0.52 USD/ha) than Wambao (0.4) and Ponela (0.19) irrigation blocks. This means that each unit of water applied in the field generated more yields at MozIndia irrigation Block followed by Wambao and the least was Ponela irrigation block. In other words, at MozIndia irrigation block the water was used more efficiently from the economic point of view than in other two irrigation blocks. Also, it is shown in the same graph that, in all the irrigation Blocks, the output per water consumed is higher than output per irrigation supply. According to Molden *et al*. (1998), this is an indication that significant part of the water applied through irrigation was unproductive.

The differences in water productivity among the observed blocks should be explained by the level of technology used in each block, which differs from one to another and influences the water use by the crop. Taking as an example, at Wambao block, the farmers are benefiting from a technology transfer package, which include cautious soil leveling, use wet soil tillage technologies; use of improved seed and high-yield varieties, and use of pre-germination technology which contribute to improve the crop efficiency on water use while the farmers from Ponela Block are still producing in unleveled soil, use of dry tillage and use of traditional seed.

4.2.7 Environmental Performance

The water quality parameter for the determination of loadings entering each irrigation block were measured at the pumps delivery of each irrigation block and for the load from the irrigated area to the drainage system, the water quality parameters were measured at the point where the irrigation water leaves the drainage system, immediately before entering into the river. The results of water quality are as per the Table 4.7.

4.2.7.1 Irrigation Water Quality

The observation of water quality was considered to be of capital importance as is proved that all the available irrigation water contain dissolved chemical substances that may reduce the crop productivity and decline soil fertility (FAO, 1994). According to the results in table 4.8 aforesaid, the quality of the water may be a threat to land degradation and water body pollution if restrictive measures are not observed considering the fact that the observed values are above the minimal recommended for an unrestricted use of irrigation water.

Based on the potential irrigation problems and crop tolerance to salt, FAO (1994) recommend the following values for unrestricted use of water for irrigation: Chlorides (< 192 mg/l), Electric Conductivity (< 700 µS/cm) and Total Dissolved Solids (<450 mg/l) therefore, the recommended values are lower than those observed in the field.

Table 4.8: Results of Water quality parameters

Observed Parameter	**Unity**	**Irrigation block**						
		Wambao		**Ponela**		**Mozindia**		**Receiving Medium (Max. Limit)**
		Intake	**Outlet**	**Intake**	**Outlet**	**Intake**	**Outlet**	**Standard**
pH	_	7.29	6.95	6.69	7.2	6.94	7.15	6.5-8.5
Conductivity	µs/cm	1984	9000	976	3274	1025	3285	2500
COD	mg/l O_2	18	6.5	8.2	26	9.3	27	150
BOD	mg/l O_2	14	5	6	20	8	22	5
Chloride	mg/l Cl	361.59	3332.3	191.43	219.79	239.3	274.74	336
TDS	ml/l	1587.2	7200	780.8	2619.2	820	2628	2000

4.2.7.2 Irrigation impact on the Environment

The evaluation of the possible irrigation impact on the environment is indispensable because the practice of irrigation activities normally represent a modification of the natural state of the environment, by diverting water from a source, addition of water to areas where there was not any before, transfer and dispose of water. The condition of the water being released to the environment from the irrigated areas and the respective maximum recommended value are as per the Figure 4.7.

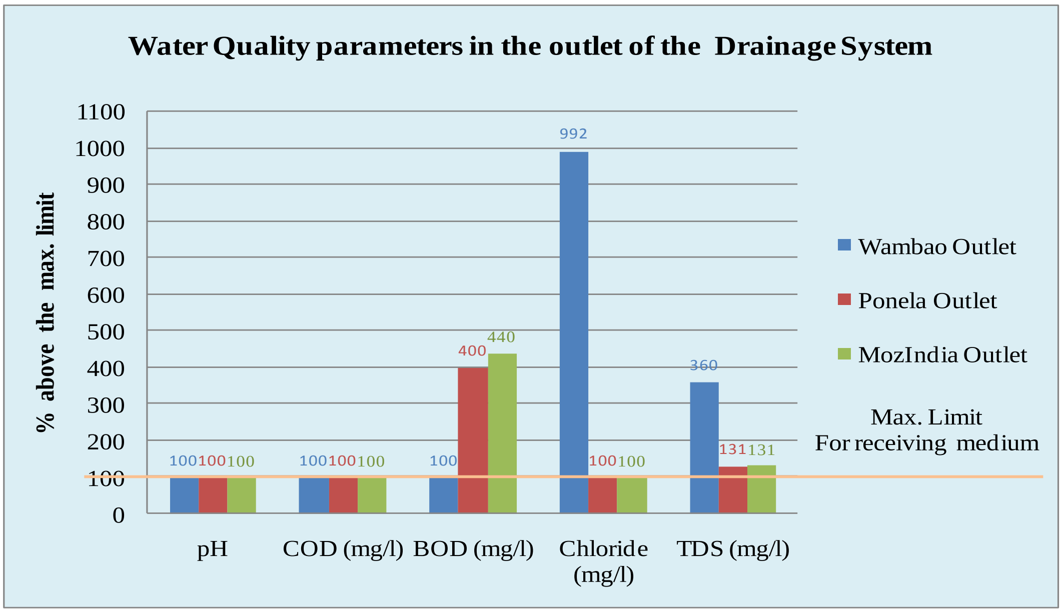


Figure 4.7: Water quality in the drainage system outlet

The Figure. 4.7, show that for all the irrigation blocks the water discharged into the river contain values of TDS above the maximum limit recommended for effluent discharge to the receiving medium in Mozambique. The results in Table 4.7, show negative differences between the concentration of TDS in the water from the source and the water from the drainage system, mainly in Wambao irrigation block.

According to FAO (1994), the increase of salts concentration in the drainage water is an indication that there is another source of salts apart the irrigation water. The high concentration of suspended solids in the drainage if compared with the water at the intake point, may be originated from the (1) accumulated salts in the root zone due to increased rates of leakage and poor drainage or (2) from water table rise caused by excess irrigation and poor water management in the system. The discharge to the river of untreated water with high concentration of salts may be a serious threat to biodiversity as it can cause pollution to the previously fresh water, reduce biota habitat (both land and water) and reduce the agricultural productivity.

As shown in Figure 4.7, the concentration of Biological Oxygen Demand is out of the recommended standard values for effluent discharge to the receiving medium in Mozambique, both at the intake from the river as well at the outlet in the drainage system. FAO (1994) state that the discharge of effluent with high BOD into the fresh water body may be harmful to the environment by affecting negatively the aquatic life as it can accelerate bacterial growth and reduce the oxygen levels to the extent that it may diminish to levels that are lethal for most aquatic organisms.

According to UNEP/FAO/PAP (1988), the not well-planned intensification of irrigation activities in lower Limpopo valley is a threat to water quality as it reduces considerably the amount of water released in Massingir dam, for “pushing” saline water back to the ocean, thereby allowing the salt water to flow into the river. The same source indicates that the salt intrusion in the Limpopo river mouth is one of the main causes of salinization, which in dry years can affect area located up to 80 km from the river outlet and cause the water to be unfit for irrigation (FAO, 2004).

4.2.8 Determination of overall system performance

After calculation and analysis of the various indicators individually, the indicators were combined to derive one composite indicator for each category of performance indicators, namely; one indicator for land productivity, one for water productivity, one for water supply, one for finance and one environmental indicator. By so doing, the various indicators were combined and weighted, considering each indicator to be of equal importance.

For the assignment of value to each set of indicators, the indicator below or above the threshold method was used to calculate the distance from the computed value to the threshold or optimal value (OECD, 2008). An indicator that was significantly equal or significantly above the threshold was considered to have a positive or negative influence on the composite depending on the nature of indicator.

After weighing the value for each indicator were normalized and calculated the overall performance indicate. The indicators with positive effect were maximized and those with negative effect minimized. The overall system performance was then obtained by the computation of the average of weighted values from each irrigation block. The results are as per the in Table 4.9.

Table 4.9: Overall system Performance Index

Irrigation Block	Weight per Indicator category						Performance Index
	Environment	Land productivity	Water productivity	Water suply	WDC	GRI	
Wambao	0.1117	0.0663	0.0600	0.0606	0.1667	0.0238	**0.49**
Ponela	0.1300	0.0130	0.0267	0.0863	0.1650	0.0039	**0.42**
MozIndia	0.1300	0.0694	0.0783	0.0748	0.1667	0.0413	**0.56**
Overall System Performance							**0.49**

According to result in Table 4.9, the overall system performance is not satisfactory having performance index below 49%. The Gross Return in Investment and Land productivity are the indicators with least values. As explained previously, the low values of this two indicators can be justified by the existence of an otiose area in all the irrigation blocks.

4.3 Strategies to improve Irrigation System performance.

The adoption of the following proposed strategies will contribute to the reduction of the poor state of irrigation water management, improve agricultural productivity (in relation water and land) and minimize the hazard impact of irrigation to the environment. The strategies were developed from the Multi-criteria analysis (MCA) for the improvement of Lower Limpopo irrigation system performance and were ranked as follows:

4.3.1 Legal and Institutional aspects

The main institutional limitation in improving agriculture productivity among the farmers is related to the fact that the water rates in almost all the irrigation blocks are based on the cultivated area rather than on the volumetric consumption. For example, the water rate in Wambao irrigation block is charged at MT3000/ha (≈67 USD/ha) per annum. Furthermore, the farmer using water carelessly are not faced with an additional cost, since the water use rights in the system are not clearly established. Therefore, the proposed strategy meant to build up motivation among water users managing badly the irrigation water through the implementation of volumetric water rights and penalties with the proportional tax for each excessive unit of water diverted from the canal.

Other measures identified for this category include reduction of irrigation subsidies and introduction of water saving pricing and establishment of water user associations to improve the participation of farmers in water management activities.

4.3.2 Economic aspects

During the data collection it was reported that the smallholder farmers are extremely financially constrained. The restriction to credit access generally lead to the reduction or totally not use of inputs such as chemical fertilizers, high-yielding seed, and mechanization what in turn lead to low agricultural productivity?

Although there are a considerable number of farmers benefiting from a technology transfer program with financing package included, at Wambao and Ponela irrigation blocks, a huge part of the targeted farmer still continue showing weak self-sufficiency with a little or total inability for self-financing if the funding package ends. Thus, the proposed strategy to revert the above-stated scenario is based on the reduction of farmer dependency on Government donation or credit for their sufficiency. This will be achieved through the introduction of self-sufficient household graduation program which must include prior training package on business management and improved crop production technologies.

This means those farmers that are benefiting from credit or donation from the Government have to be intensively trained in such way that after a given period of time they become self-sufficient and stop receiving funding or credit from the government. A household may be considered self-sufficient if the beneficiary is able to cover all the production costs after adopting a new improved crop production technology and fulfill its food needs for 12 months in the absence of funding or credit from the Government.

4.3.3 Technologic and agronomics aspects

Having in mind that the different agricultural practices and technologies adopted in the observed blocks such as full dependency on chemical fertilizer and pesticides are being harmful to the environment, the strategy proposed hereafter aim to ensure optimum production in an economical and sustainable sense. Thus, to ensure an sustainable increase in land and water productivity, the adoption of Integrated production and Pest Management (IPPM) concept has been seen as the most viable strategy.

The strategy must be implemented through farmer field School learning process having as the target the creation of capacity in farmer so that they can reduce their dependence on agrochemicals, reduce the costs of production and increase productivity, stabilize their yields, safeguard their health and Protect the environment.

4.3.4 Managerial aspects

This strategy mainly aims to enhance water productivity by increasing the water application efficiency. As observed on the field the actual practice consist on flooding the field maintaining a water layer ranging from 5-20 cm height, which leads to very high water abstraction, low irrigation efficiency, and land degradation through salt accumulation in the crop root zone. Thus, the proposed strategy consists on the reduction of the current water layer of about 5±20 cm to the condition of soil saturation or at least to 2.5 cm depth. A study by Johnson (1965), show results of experiments in which plants subjected to a water depth of 2.5 cm produced 5% more than those whose layer height was greater than 10 cm and states that the deep water inhibits tillering.

Other proposed measure include better irrigation scheduling based on actual crop water requirement, oriented water saving tillage, new technologies of soil preparation and continued on-farm training using Farmer Field School approach.

4.3.5 Socio-cultural aspects

As seen in the factor analysis, one of the main constraints for water productivity improvement by the smallholder farmers which are simultaneously poor, are the lack of knowledge and ability to adopt the technologies needed. The Poor knowledge about new irrigation technologies, exacerbated by limited know how about markets, deficient marketing strategies, cultural barrier and reduced labor due to HIV/AIDS, prevent the small scale farmer from adopting high productivity irrigation technologies.

So, being the socio-cultural acceptance the most important pre-requisite for new technologies adoption, these socio-cultural barriers preventing farmers from adopting water saving technologies must be removed from the mind of farmers through the introducing literacy programs, recycling of drainage and tail water, continuous training and advocacy.

4.3.6 Cross-cutting issues

The strategy in this session will address issues related to gender, HIV/AIDS, lack information and environmental conditions which were considered complex and challenging the ability certain population subgroups to address with the presence of threats to their well-being. The most highlighted factors by the farmers during the research was related do gender and HIV issues. Thus, to enhance the agriculture productivity and sustainable water management the effort must be on building the capacity of farmers, improving the ability of women to negotiate the access to land, credit, improved inputs, extension services and her participation in decision-making processes. Likewise, to motivate women participation in profitable productive sectors and decision-making process, there is a need of lifting social barriers and remove social and cultural biases that limit the women participation in wide range of social and economic roles.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Performance assessment and description of three different irrigation blocks nested to Lower Limpopo irrigation system were carried out based on comparative performance indicators and environmental performance indicators. The agricultural productivity was characterized by being variable from one block to another due to several factors that influence crop production in each irrigation block. Thus, the evaluation and comparison of the selected blocks helped to perceive the weaknesses and strengths of these irrigation blocks in term of agricultural productivity and water management. The following are the main conclusions from the study:

- Due to their economic and social dependence, the peasant woman is relegated to further vulnerability and its position in the decision-making process is reduced. Therefore, they have low capacity to negotiate aspects of access to extension services and technologies, land tenure, production of cash crops, credit and markets.

- From farmers' perspective, the main factors affecting productivity can be grouped into nine categories. These include technological and knowledge factors, economic factors, Institutional and legal factors, crop factors, social factors, Hydrological factors, environmental, gender and soil factors.

- MozIndia irrigation block is the most productive block, depicting high value of SGVP, being the reason the use of improved input combined with good irrigation water management. The productivity at Ponela irrigation block is lowest (1,482.00 USD/ha) as compared to MozIndia (3,334.00 USD/ha) and Wambao (2,779.00 USD/ha) irrigation blocks. The low productivity at Ponela is due to using of traditional production methods, low use of input and use of low yield seed.

- The highest gross return on investment rate was observed at MozIndia irrigation block followed by Wambao and the least was at Ponela Irrigation block. The very low GRI rate at Ponela block is due to the observed low productivity per unit area which was 4.5 tons/ha against 9 tons/ha at MozIndia block and 7.5 tons/ha at Wambao irrigation block.

- It has been noticed during the study that the yield increases per hectare come at the cost of environmental and miss use of irrigation water. The yield increase is mainly obtained by intensive use of heavy machinery for land preparation, use of inorganic fertilizers and pesticides and misuse of irrigation water, practices which are already threatening the environment health.

- The high Relative Irrigation Supply ratio indicates that the irrigation efficiency in all the irrigation blocks is in the bracket of 30 to 52 %, which coincides with those obtained from the secondary data. The highest value was observed at Ponela block and the lowest at Wambao irrigation block. The

Relative Water supply (RWS) values are greater than one indicating that there the supply was generous if compared to the demand throughout the seasons.

5.2 Recommendations

- The current productivity per unit area is good if compared to a national average for the base crop (rice) however, the sustainability is threatened unless institutional strategies are put in practice to motivate farmer for an adoption of water saving practices. Thus, is recommended to the system management company to find out mechanism to ensure the sustainability. of the irrigation system.

- To motivate farmer to adopt water saving practices, the water pricing and fees should be based on the total volume of water consumed per each farmer. For such, the preliminary work should be the construction of hydraulic discharge metering structures in the entire irrigation block.

- The overall irrigation efficiency is considerable low (approx. 44 %) due to huge losses in the conveyance system, and poor water management by the farmers. Therefore, it is very recommended to lined all the conveyance system or construct them by concrete and the introduction of water saving oriented practices.

- To minimize the effect of cross-cutting issues, a participatory program for capacity building and training in agriculture, agro-processing, and entrepreneurship for the youth, which should account for the differentiated needs of young girls and boys must be designed. The program must clearly develop strategies to motivate women participation and remove gender bias and socio-cultural barriers with relation to women and those affected by HIV/AIDS.

- The system management company (RBL, EP), must design strategies to avoid direct discharge of polluted water from irrigation into the river. Constructed wetland may be the most economic and environmentally viable alternative.

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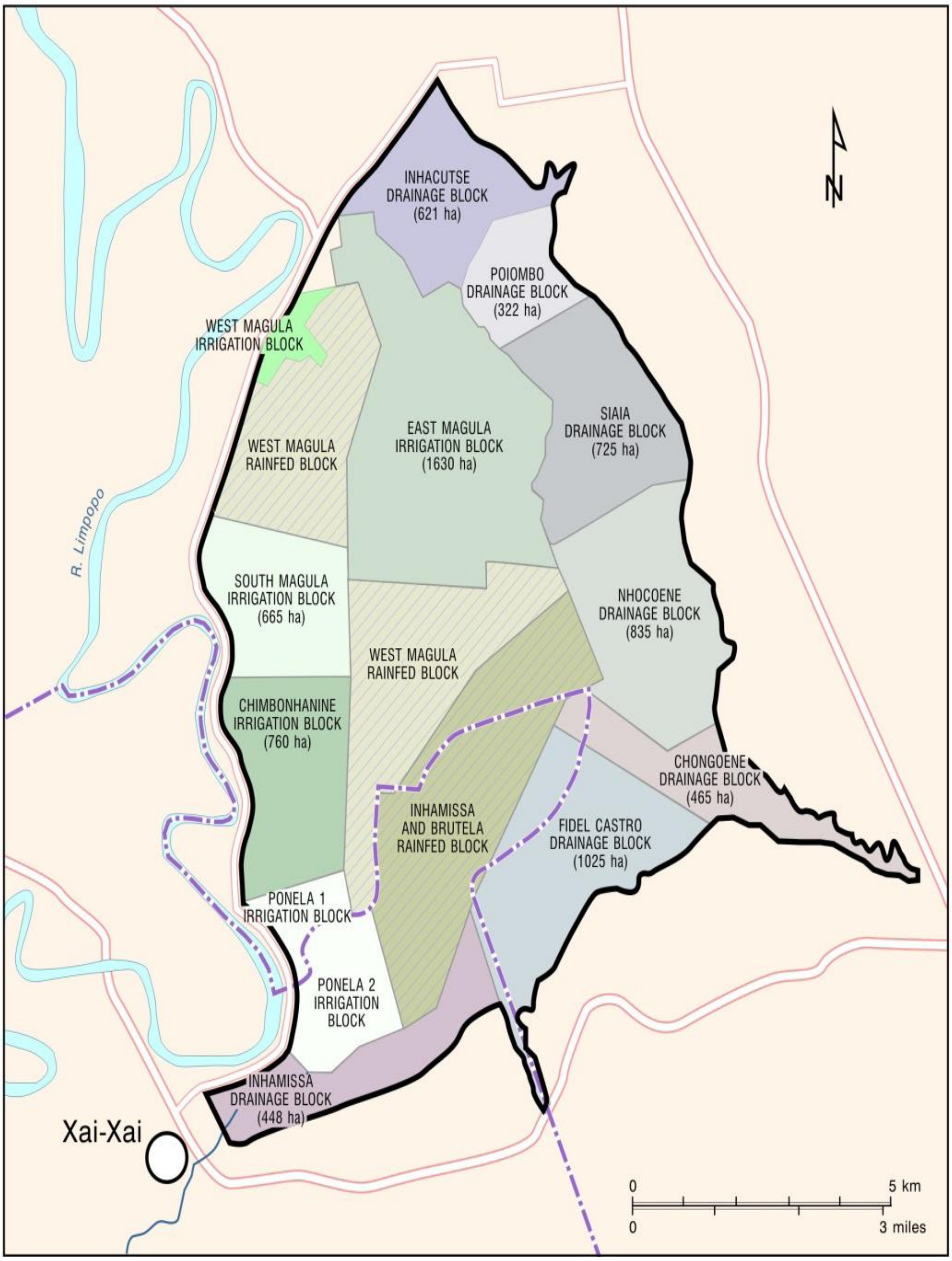
APPENDICES

APPENDIX A

Map of Lower Limpopo irrigation scheme (RBL)



Source: Adapted from maps provided by RBL-EP

APPENDIX B

Field survey measurements

Flow measurement in pipes using ultrasonic flow meter

Use of topographic level for open canal measuring

In situ water quality measurement

Flow measurement in open canals using current meter