COMPARATIVE PERFORMANCE EVALUATION OF PUBLIC RICE IRRIGATION SCHEMES IN WESTERN KENYA USING BENCHMARKING PROCESS

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Comparative Performance Evaluation of Public Rice Irrigation Schemes in Western Kenya Using Benchmarking Process

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DECLARATION

This thesis is my original work and has not been presented for any degree at any other University:

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DEDICATION

This work is dedicated to my husband Edwin Mbiti, my children Elliana Mumbe and Ryan Muuo.

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LIST OF ABBREVIATIONS/ ACRONYMS

AIS	Ahero irrigation scheme
AHP	Analytical hierarchical process
BIS	Bunyala irrigation scheme
BMPs	Best Management Practices
FAO	Food and Agricultural Organization
ICID	International Commission on Irrigation and Drainage
IPTRID	International Program for Technology and Research in Irrigation and Drainage
IWMI	International water management institute
KNBS	Kenya National Bureau of Statistics
NIB	National Irrigation Board
PCA	Principal Component Analysis
SRI	System of Rice Intensification
WKIS	West Kano Irrigation Scheme
WUA	Water users association

ABSTRACT

The inefficient water use, varying and low productivity in Kenya public irrigation schemes is a major concern. It is therefore necessary to periodically monitor and evaluate the performance of public irrigation schemes. This informed this study where a comparative performance analysis using benchmarking process was carried for Ahero, West Kano and Bunyala irrigation schemes in Western Kenya. The study aimed at evaluating performance of Western Kenya rice irrigation schemes using benchmarking indicators and principal component analysis; determining factors influencing performance and formulating best management practices needed to improve performance. The performance of the irrigation schemes was measured using thirteen standard performance indicators for the period between 2012 and 2016.The indicators were weighted using principal component analysis and combined to form a single performance score using linear aggregation method. Factor analysis method was used to group and quantify the level of influence of various factors on productivity of irrigation schemes. Finally best management practices of irrigation schemes were developed. Analytical hierarchical approach method was used to rank the selected best management practices according to the level of importance attached by farmers. Data was collected using field surveys, observation, interviews, focus group discussion and literature review. The irrigation schemes were found to be performing sub-optimally relative to similar irrigation schemes in the world. The relative irrigation supply ratio ranged between 0.68 - 3.38 while and relative water supply ratio varied between 1.44 -2.44. Ratios above 1.0

indicate water wastage. Water fee collection performance was between 45% and 97% indicating lack of full compliance in all schemes. Land productivity ranged from 3.06 tonnes/ha to 6.6 tonnes/ha which was relatively good compared to average global yield of 3.8 tonnes/ha. The average overall performance relative to threshold values in Ahero, West Kano and Bunyala irrigation schemes was 48%, 49% and 56% respectively. Bunyala irrigation scheme was identified as the best performing scheme while Ahero irrigation scheme was the poorest performing irrigation scheme. Technological and knowledge factors were found to have the highest influence of 24.57 % on performance of irrigation scheme. Farmer capacity building was identified as the most important strategy needed to improve productivity in western Kenya rice irrigation schemes. The study concluded that the performance of the three rice irrigation schemes is poor and unsustainable. The study recommends capacity building of farmers, mechanization of farming operations and system of rice intensification to be implemented to increase productivity. This study provides useful information to policy and decision makers on areas of weakness that require policy interventions.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Rice (*Oryza sativa L.*) is the second main cereal crop grown in the world. Rice is a staple food to more than half the world's population (Siwar, Diana Mohd Idris, Yasar, & Morshed, 2014). Globally, 150 million ha is under rice farming producing approximately 500 million metric tonnes of milled rice per year (Evans, Florence, & Eucabeth, 2018). Rice farming is the main source of employment and supports livelihoods of about one fifth of worlds' population (Siwar et al., 2014) . Currently, rice is grown in more than a hundred countries in the world with China and India accounting for 50 % of total production. About 90% of rice is produced and consumed in Asia (Muthayya, Sugimoto, Montgomery, & Maberly, 2014). The other major non-Asian rice producing countries are the United States, Brazil, Madagascar, Egypt, and Nigeria, which collectively contribute 5% of the total rice grown globally (Muthayya et al., 2014). Rice accounts for 29% of total grain produced in the world (Evans et al., 2018). Therefore, rice production is critical in addressing food security.

In Africa, rice is grown in over 75% of the countries and is source of food and livelihood to about 800 million people (Evans et al., 2018) . The demand for rice in Sub-Saharan Africa(SSA) has been growing steadily and has doubled since 1970 (Muthayya et al., 2014). Rice demand in this region is expected to keep on increasing due to population growth (4% per annum), increasing income levels and preference of rice over the other foods due to urbanisation (Muthayya et al., 2014). According to Amos & Ouma (2014), the demand for rice in Africa is more than production and nearly 40% of rice consumed in Africa is imported. Rice production is faced with various challenges such as degradation of water and soil resources, declining productivity, decrease in efficiency of agrochemical use, adverse changes in climate, land fragmentation, shortage in labour and energy (Siwar et al., 2014).

In Kenya, Rice is the third most important cereal crop grown after maize and wheat (Gitonga, 2017). 95 % of rice in Kenya is grown in irrigated paddy fields while the remaining 5% is grown in rain-fed farms (Siwar et al., 2014). Rain-fed rice is mainly grown in Kwale, Kilifi and Tana River counties in coast region and Bunyala and Teso areas in western Kenya (Amos & Ouma, 2014) . Rice is mainly grown in government established irrigation schemes managed by National Irrigation Board (NIB) which are Ahero, Bunyala and West Kano irrigation schemes located in Western Kenya and Mwea irrigation scheme in Central Kenya. The NIB-managed irrigation schemes occupy 78% of total land area under rice farming in Kenya (Evans et al., 2018). Based on Kenya National Bureau of Statistics (KNBS) report in Table 1.1, total paddy rice output in 2017 was 81,198 metric tonnes (Kenya National Bureau of Statistics, 2018). Rice production declined by 20.0 % from 101,510 tonnes to 81.2 thousand tonnes in 2017 (KNBS, 2018). Mwea irrigation scheme in central Kenya accounts for 75% of production, 67 % of irrigated area and 85 % of gross value of output produced between 2012 and 2017 (KNBS, 2018).

Table 1.1: Rice production in Kenya

Paddy production	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017
Mwea (tonnes)	64,672	70,416	91,624	78,760	59,291
Ahero (tonnes)	8,326	7,405	7,942	6,494	7,752
West Kano (tonnes)	5,165	4,345	2,039	4,364	4,083
Bunyala (tonnes)	4,278	4,289	4,600	4,522	3,632
South West Kano (tonnes)	8,262	9,574	10,268	7,100	6,440
Total Paddy Production (Tonnes)	90,703	96,029	116,473	101,510	81,198
Area (Ha)	18,600	19,411	13,998	14,586	21,949
Average yield (Tonnes/Ha)	4.9	4.9	8.3	7.0	3.7
Gross Value (Ksh. Million)	4,347	4,536	6,717	5,673	4,395

Source: Kenya National Bureau of statistics (2018)

Rice consumption has been growing much more rapidly than production at an annual rate of 12 % since 1960 (Tanui, 2017). Rice production in Kenya is below demand and the gap is filled through imports. Currently, 54,000 metric tonnes of milled rice are produced in Kenya which is below demand of 693,000 metric tonnes (KNBS, 2018). Furthermore, rice consumption is expected to increase due to rising population, changing eating habits and urbanization (Gitonga, 2017). Increasing rice production would therefore reduce import bill.

Amos & Ouma (2014) reported that rice farming in Kenya faces various challenges such as; destruction of crops by pests such as quelea birds and rodents like rats which; weeds such as string and false finger millet; erratic rains that affect production of rain-fed rice; drought; flooding common in West Kano irrigation scheme that destroy the ridges and rice fields; high prices of inputs and high electricity cost for pumping water in most of the schemes leading to reduced profit margin; degradation of land and reduction in soil nutrients due to soil erosion and continuous cultivation lowering rice production; poor access to credit by farmers in most of NIB scheme; informal subdivision of land units and renting of land by official tenant farmers in the NIB schemes which increased dependants and demand for water; poor access to extension services by farmers in NIB schemes associated with changes in institutions offering the services; diseases such as rice blast, bacterial blight, rice rust, sheath rot which reduce the quality and quantity of rice yields per unit area.

Ministry of Agriculture (2008) identified lack of land ownership, labour scarcity due to urban migration, high prevalence of water borne diseases and HIV/AIDS, unfavourable informal cross-border trade with Uganda and Tanzania, liberalization of the rice irrigation schemes leading to poor management practices due to limited Public-Private partnerships, high cost of production, poor infrastructure, poor access to credit, poor market organization and low technical skills/knowledge on rice production as the main challenges facing rice farming production in Kenya .The challenges listed constraint rice production in Kenya especially among small-scale farmers in NIB-managed irrigation schemes. Interventions aimed at overcoming these challenges could greatly boost production of rice.

Paddy rice farming in Ahero, West Kano, Bunyala and Mwea irrigation schemes is done using conventional method of continuous flooding. This system of rice farming utilises a lot of water and production is highly reduced during drought (Evans et al., 2018).Therefore there is need to utilise water efficiently by improving productivity to produce more crops for every drop of water supplied. Efficient utilisation of water, land and other resources increases productivity and promotes sustainable development in irrigated agriculture. Improving efficiency of water utilisation contributes to improved equity in water distribution and reduction in the difference in crop water requirement and actual water use (Balderama, Bareng, & Alejo, 2014).

Public irrigation schemes in Kenya are characterized by inefficient water use, varying and low productivity (Karina & Mwaniki, 2011). In addition, the schemes are further known for poor performance which hinders their expansion (Ngigi, 2002). Despite channelling heavy investments in these irrigation schemes their operation efficiency and effectiveness have not improved (Ngenoh, Kirui, Mutai, Maina, & Koech, 2015). This calls for deeper understanding of causes of low productivity in order to suggest remedies needed to improve performance. Increased productivity can be achieved by evaluating performance of the existing public with the aim of improving their performance. The performance of irrigation schemes can be evaluated using evaluation tools and techniques such as rapid appraisal procedure (RAP), fuzzy set theory, analytical hierarchy process (AHP), Remote sensing and Geographic information systems (GIS), and Benchmarking.

Benchmarking is a comparative performance evaluation tool. It involves comparison of irrigation schemes with the aim of identifying the best practices in each of scheme (Córcoles, de Juan, Ortega, Tarjuelo, & Moreno, 2012). The main objective of benchmarking is to improve performance of an organisation. Low Productivity has been reported in public irrigation schemes (Karina & Mwaniki, 2011) and there is need to improve their performance. Benchmarking technique is the most suitable performance evaluation tool because it provides insight on areas of weakness that require improvement. Improvement of performance is therefore possible once the areas of weakness have been identified.

Benchmarking was developed by International Programme for Technology and Research in Irrigation and Drainage (IPTRID) as a management tool for improving productivity and efficiency in irrigation and drainage sector (Malano et al., 2004). Benchmarking is a process of analysing and improving performance of an organisation through comparison either internally with desirable set standards or externally against similar organisations (Malano, Burton, & Makin, 2001). Benchmarking involves measuring an organization's activities, inputs and outputs against those of key competitor's to establish action needed to improve performance (Knox et al., 2013) . The best performer among the organizations is identified and becomes the benchmark against which similar organisation will improve own performance. IPTRID, FAO, World Bank, IWMI and ICID have laid emphasis on measuring performance in irrigation and drainage sector as a way of achieving sustainable development in agriculture.

The drivers to improving performance of an irrigation system include; increasing competition for limited water resources, increased demand for food, need for improved efficiency of water use, high water prices and pressure to achieve high productivity at less cost (Malano et al., 2001). In benchmarking, performance is measured using performance indicators. Comparison of performance indicators does not provide a clear picture of the overall performance of an irrigation scheme relative to the others. Therefore, multivariate data analysis tools such as data envelope analysis (DEA), analytical hierarchal approach (AHP), cluster analysis and Principal component analysis (PCA) have been used together with performance indicators to evaluate performance of irrigation schemes.

Principal component analysis is a multivariate data analysis tool used in weighting indicators based on underlying statistical data structure (OECD, 2008). Using PCA, Collinear indicators are grouped together to form a composite indicator that captures most of the information common to the indicators. PCA reveals how different variables change relative to each other and how the variables are associated. In this study, PCA was used to combine individual indicators to form a single performance score. The performance score gives a measure of the level of performance of an individual irrigation scheme relative to the others. Benchmarking performance of irrigation schemes provides information on areas of weakness that requires improvement.

1.2 Statement of the Problem

Public irrigation schemes in Kenya are characterized by inefficient water use, varying and low productivity (Karina & Mwaniki, 2011). It is therefore imperative to discover the causes of low productivity by conducting a systematic evaluation of performance using such tools like the benchmarking process and consequently suggest remedies needed to improve performance. The performance of the irrigation schemes has only been described using yields and this is not sufficient to describe the overall performance of the irrigation scheme. Benchmarking irrigation schemes enables identification of performance gap between current and better achievable standard and making changes to achieve higher performance standards. Benchmarking performance of three public rice irrigation schemes in western Kenya was done to determine how well the schemes are performing in terms of service delivery and resource utilisation.

1.3 Objectives

1.3.1 Main Objective

The main objective of this study was to quantify and benchmark performance of public rice irrigation schemes in Western Kenya.

1.3.2 Specific Objectives

The specific objectives are to:

i. Evaluate performance of selected Western Kenya public rice irrigation schemes using benchmarking indicators and Principal Component Analysis.
ii. Determine factors influencing performance of public rice irrigation schemes in Western Kenya.

iii. Derive best management practices for public rice irrigation schemes in Kenya.

1.4 Research Questions

i. How are public rice irrigation schemes in Western Kenya performing?
ii. Which are the main factors influencing performance of public rice irrigation schemes in Western Kenya?
iii. What are the best ways of improving of public rice irrigation schemes in Western Kenya?

1.5 Justification

Irrigated agriculture being the main consumptive water user is under pressure to produce more food for every “drop” of water (Bos, Burton, & Molden, 2005) . Therefore, many irrigation systems have to look for ways of improving performance. Public irrigation schemes in Kenya are facing problems of inefficient water use, varying and low productivity. In addition, heavy investments are channelled into these irrigation schemes but their productivity is below the expectation (Ngenoh et al., 2015). There is therefore need to improve productivity and increase efficiency of utilisation of water and other resources. One way of improving performance of irrigation institutions is through benchmarking irrigation and drainage projects. This prompted evaluation of performance of public rice irrigation schemes in Western Kenya using benchmarking process.

Irrigation schemes that are mainly growing rice were selected for this study because rice production in Kenya is below demand and there is need to increase productivity. Furthermore, 78% of area under rice farming in Kenya (Evans et al., 2018) is under NIB-managed irrigation schemes. To allow for comparison, benchmarking is applicable to similar irrigation schemes in terms of management, irrigation system, climate (Malano et al., 2001). Western Kenya public rice irrigation schemes use basin irrigation systems, abstract water by pumping and are located within the same climatic region. Benchmarking performance of western Kenya rice irrigation schemes will enable identification of areas of weakness that require improvement to realise higher performance standards. The study provides information that could be used in improving design, upgrading, monitoring and evaluation of public rice irrigation schemes in Western Kenya.

1.6 Scope

The study was carried out in West Kano, Bunyala and Ahero irrigation schemes, which are pumped irrigation schemes, under the management of National Irrigation Board (NIB). The study was confined to rice farming which is the main crop in the three irrigation schemes. Although other crops are grown, they were excluded from this study because there is no existing documentation of their production data. Evaluation of performance of the irrigation schemes was based on two domains: service delivery and productive efficiency. Service delivery domain contains two areas of service provision: (a) water supply efficiency - the adequacy of managing water delivery to meet water demand; and (b) financial performance - the efficiency of using resources to offer irrigation service. (c) Productive efficiency – which gives a measure of the efficiency of using water resources in irrigation to produce food and fibre. Thirteen (13) external performance indicators over a five year period (2012-2017) were used in the evaluation.

1.7 Limitation of the study

Lack and inconsistency of time series data on operation of irrigation schemes limited the number of performance indicators that could be computed. Only 13 indicators out of the 27 IPTRID recommended indicators (Malano et al., 2001) were used for performance evaluation. Due to inconsistent and lack of time-series secondary data the indicators which could be computed with the available data were 13. Due to limited research period and funds, it was only possible to evaluate performance of irrigation schemes using external indicators. The internal indicators (process indicators) were therefore excluded from this study. Furthermore, internal indicators are suitable for use in internal analysis of scheme performance relative to set management targets rather than in cross-comparison.

CHAPTER TWO

LITERATURE REVIEW

2.1 Irrigation systems in Kenya

Irrigated agriculture occupies 4 per cent of the 2.9 million ha area under agriculture in Kenya (Government of Kenya, 2013). It contributes 3 per cent of the Kenya's gross domestic product (GDP) and 18 per cent of the total value of all agricultural produce (GoK, 2013).The main irrigated crops in Kenya are rice, wheat, maize, vegetables, coffee, fruits, sugarcane, cotton and horticulture (Ngenoh et al., 2015). Kenya's irrigation systems can be broadly categorized into smallholder schemes, large-scale private/commercial irrigation schemes and public schemes (Ngigi, 2002). Large scale commercial farms developed by individual farmers or companies occupy 40 per cent of total irrigated land which is approximately 75,840 ha. The schemes grow high-value crops, especially horticulture using modern technology mainly for export market, some of the commercial irrigation schemes are located in central region, Naivasha, Athi river area, and Nanyuki (Ngigi, 2002). Kakuzi, Delamere and Del Monte are some of the large commercial farms practising successful irrigation projects.

Small holder irrigation schemes account for 42 per cent of the total irrigated area (Ngigi, 2002). The schemes are owned and managed by either individual farmers or a group of water users. There are a total of 3000 existing smallholder irrigation schemes occupying a total of 51,903 ha of land area (GoK, 2013). They supply the urban centres with the bulk of horticultural products. Marketing problems, poor mobilization and participation, inadequate access to credit facilities are some of the challenges limiting performance of smallholder irrigation schemes.

Public irrigation schemes account for 18 per cent of total area under irrigation in Kenya (Ngigi, 2002). The schemes are centrally managed by government mainly through National Irrigation Board (NIB), a government body mandated with management, development and coordination of national irrigation schemes. The main public irrigation schemes managed by NIB are; Mwea, Ahero, Hola, Perkera, West Kano, Bunyala and Bura (MoW&I, 2017). Most of these public schemes are traditional rice growers although maize has been introduced in Hola, Perkerra and Bura irrigation schemes. The details of the existing NIB- managed public irrigation schemes are presented in Table 2.1.

Table 2.1: Existing Public Irrigation Schemes

Scheme	County	Irrigation area (acres)	Water abstraction method	Water conveyance method	Irrigation method	Main crop
Mwea	Kirinyaga	26,000	Gravity	earth canal	Basin	rice
Hola/ Tana	Tana river	4,700	Pumped	earth canal	Furrow	maize
Bura	Tana river	3,500	Pumped	earth canals	siphons	maize
Ahero	Kisumu	2586.5	Pumped	earth canals	Basin	rice
West Kano	Kisumu	2,250	Pumped	earth canals	Basin	rice
Bunyala	Busia/ Siaya	1,734	Pumped	earth canals	Basin	rice
Perkerra	Baringo	2,500	Gravity	earth canal	Furrow	maize

Source : Ministry of Water and Irrigation, (2017)

2.2 Performance of irrigation schemes

Performance of an irrigation scheme is the measure of the degree to which it achieves target objectives (Malano et al., 2004). Evaluation of performance of an irrigation system gives an indication of how far the goals and objectives set during project formulation have been achieved. It points out the relation between the actual results and expected results (Rani et al., 2011). Evaluation of performance of irrigation schemes has been undertaken using various tools and techniques which are: direct measurement using indicators, Fuzzy set theory, Analysis hierarchy process (AHP) and Remote sensing and Geographic information systems (GIS) Techniques.

2.2.1 Direct measurement using indicators

Evaluation of performance of irrigation schemes is done using performance indicators. A performance indicator is a description of actual achievement in relation to one of the objective of irrigation system (Ayana & Awulachew, 2007). Indicators of performance of irrigation schemes can be categorised into internal and external performance indicator. Internal indicators relates actual performance to specific management targets set that correspond to goals of the system targets such as duration, timing, water flow rates, cropping patterns, irrigated area (Molden, Sakthivadivel, Perry, De Fraiture, & Kloezen, 1998). The indicators look into operations, hardware of the system, institutional and management set up, water distribution and delivery (Burt, 2001). External (comparative) indicators are used for cross-comparison of systems in terms of outputs and impacts (Molden et al., 1998). External indicators are ratios used to compare outputs with inputs of a system without considering internal processes.

Benchmarking is based on external indicators. Rapid appraisal procedure (RAP) combines both internal and external indicators. It is used for appraising irrigation projects and allows identification of actions and steps for designing modernization plan. “RAP has been used as a foundation for benchmarking” (Renault, Facon, & Wahaj, 2007). Direct measurement methods are simple, quick and focus on direct measurement of variables. The disadvantages of this method is that it is subjective, requires time to collect data for evaluation and there is uncertainty in collection of data (Elshaikh, Jiao, & Yang, 2018).

2.2.2 Fuzzy set theory

Fuzzy theory was developed by Zadeh (1965) to deal with situations where information is incomplete, not precise or is fuzzy . Fuzzy theory is used in cases of uncertainty and irrigation management is one of such cases (Elshaikh et al., 2018). This method is based on concept of probability or possibility. The degree of membership of an element is assigned a range from 0 to 1 (Zadeh, 1965). Evaluation is done based on either qualitative or quantitative scale but quantitative expression is most preferred. The choice of fuzzy linguistic expression depends on the problem being considered (Elshaikh et al., 2018). Fuzzy set method is programmable and flexible. The disadvantage of this method is that it requires technical skills and focuses on only one problem (Elshaikh et al., 2018).

Kumari & Mujumdar (2016) used fuzzy-set method to evaluate the success or failure state of an of an irrigation reservoir system based on evaporation deficit of the crops. Montazar, Gheidari, & Snyder (2013) developed fuzzy- based analytical hierarchy methodology to evaluate performance of irrigation projects in Sefidrood area and Qazvin irrigation project in Iran based on managerial, technical, social, environmental, and economic aspects. Ghosh, Singh, & Kundu (2005) used fuzzy set theory to evaluate performance of Mahanadi Delta Irrigation Project in the State of Orissa, India based on service utility assessment from farmers’ perspective. The linguistic responses of farmers on utility of irrigation service provided were evaluated using fuzzy theory.

2.2.3 Analysis hierarchy process (AHP)

Evaluation is broken into main factors which are then arranged into hierarchy (Saaty, 1990). AHP is used in evaluation of irrigation systems because it provides deep analysis of the systems (Elshaikh et al., 2018) . This method is based on experts' subjective decisions. It can be used to turn qualitative indicators to quantitative ones. AHP has been applied in evaluation of performance of irrigation projects. Okada, Styles, & Grismer (2008) developed AHP model using rapid appraisal internal indicators to evaluate performance of 16 irrigation projects. The effect of improving management, water delivery and hardware on performance of irrigation project was evaluated using AHP model developed (Okada et al., 2008). Tran, Malano, & Thompson (2003) applied AHP together with maximum utility to evaluate priorities of asset renewal in La Khe irrigation scheme in North Vietnam. This method is flexible, programmable and can be applied to complex problems. However it is subjective and requires technical skills to use it (Elshaikh et al., 2018).

2.2.4 Remote sensing (RS) and Geographic information systems (GIS) Techniques

The real time performance of an irrigation system is determined using satellite images combined with maps of the irrigation systems (Elshaikh et al., 2018). Remote sensing at various scales can be used to assess crop growth and yields (Siwar et al., 2014). Satellite imagery in-conjuction with surface models can be used to determine actual evapotranspiration (ET). Using satellite measurement, spatial distribution of crop yield is determined using light use efficiency concept (Bastiaanssen & Steduto, 2017). Remote sensing is a useful tool for monitoring crop productivity and water use efficiency

(Elshaikh et al., 2018). The advantage of remote sensing method is that it is objective, enables coverage of a wide area, allows time repetition, applicable in areas with data scarcity and is powerful tool in measurement of evapotranspiration (ET). The disadvantages of remote sensing are; it requires high technical skills, it cannot be used when there are clouds, high resolution images are expensive, low resolution images have high errors (Elshaikh et al., 2018).

Bastiaanssen & Steduto (2017) applied remote sensing to determine water productivity of various crops at regional and global scale. Ray, Dadhwal, & Navalgund (2002) used remote sensing to evaluate performance of Mahi Right Bank Canal in Gujarat, India. Adequacy (AI), water use efficiency (WUE), and equity (EI) performance indices were computed using crop vegetation spectral index profiles, crop inventory and crop evapotranspiration generated using remote sensing. Iqbal & Mastorakis (2005) used remote sensing and GIS to evaluate performance of irrigation systems in the cotton-wheat zone of Pakistan. Near Infrared and Thermal IR spectral bands were used to detect cropping pattern and areas affected with salt.

Evaluation of performance of irrigation schemes in Kenya has been undertaken using various evaluation tools. Maillu (2016) evaluated the performance of Mwea irrigation scheme in the period 1997-2014 using external indicators. The performance of Mwea irrigation scheme was found to be below the designed capacity. The low productivity was related to poor cropping pattern and poor farm management (Maillu, 2016). Kang'au, Home, & Gathenya (2011) evaluated performance of small holder pumped irrigation schemes in Kenya based on fuel consumption rate, pump efficiency and pipe head losses. Use of performance indicators in evaluating performance of irrigation schemes is still limited in Kenya.

2.3 Benchmarking in Irrigation and Drainage Sector

Benchmarking is defined as " systematic process for securing continual improvement through comparison with relevant and achievable internal or external norms and standards" (Malano et al., 2001). It involves measuring an organisation's activities, inputs and outputs against those of key competitor's to establish action needed to improve performance (Knox et al., 2013). Benchmarking is an external (comparative) performance assessment which allows comparison of irrigation systems using external performance indicators. Benchmarking is carried out in six stages: identification and planning; data collection; analysis; integration; action; and monitoring and evaluation (Malano & Burton, 2004; Kulkarni, 2004). Prior to undertaking benchmarking process, irrigation schemes are categorized to ensure they are comparable. The targets change over time and are continuously updated to maintain best practices (Malano et al., 2001). Benchmarking in irrigation schemes is a data intensive activity and requires daily data collection. Benchmarking performance of irrigation and drainage projects is based on twenty seven (27) standard performance indicators proposed by IPTRID presented in Table 2.2 (Malano & Burton, 2004).

Table 2.2: Proposed key performance indicators.

Domain	Performance indicator	Data required
	Total annual volume of irrigation water delivery (m^3/year)	Total daily measured water delivery to water users.
	Annual irrigation water delivery per unit command area (m^3/ha)	Total daily measured water inflow to the irrigation system. Total command area serviced by the system.
	Annual irrigation water delivery per unit irrigated area (m^3/ha)	Total daily measured water inflow to the irrigation system. Total annual irrigated crop area.
	Main system water delivery efficiency	Total daily measured water delivery to water users. Total daily measured water inflow to the irrigation system.
Service delivery performance	Annual relative water supply	Total daily measured water inflow to the irrigation system. Total daily measured rainfall over irrigated area. Total daily/periodic volume of crop water demand,

		including percolation losses for rice crops.
	Annual relative irrigation supply	Total daily measured water inflow to the irrigation system. Total daily/periodic volume of irrigation water demand (crop water demand excluding effective rainfall), including percolation losses for rice.
	Water delivery capacity	Current main canal capacity. Peak month irrigation water demand.
	Security of entitlement supply	System water entitlement. 10 years minimum water availability flow pattern.
Financial performance	Cost recovery ratio	Total revenues collected from water users. Total management, operation and maintenance (MOM) cost.
	Maintenance cost to revenue ratio	Total maintenance expenditure. Total revenue collected from water users.
	Total MOM cost per unit area (US$/ha)	Total management, operation and maintenance expenditure. Total command area serviced by the system.
	Total cost per person employed on water delivery	Total cost of MOM personnel. Total number of MOM personnel employed.

	(US$/person)	
	Revenue collection performance	Total revenues collected from water users. Total service revenue due.
	Staffing numbers per unit area (persons/ha)	Total number of MOM personnel employed. Total command area serviced by system.
	Average revenue per cubic meter of irrigation water supplied (US$/m^3)	Total revenues collected from water users. Total daily measured water delivery to water users.
	Total gross annual agricultural production (tones)	Total tonnage produced under each crop.
	Total annual value of agricultural production (US$)	Total annual tonnage of each crop. Crop market price
	Output per unit serviced area (US$/ha)	Total annual tonnage of each crop. Crop market price Total command area serviced by system.
Agricultural Productive efficiency	Output per unit irrigated area	Total annual tonnage of each crop. Crop market price.

	(US$/ha)	Total annual irrigated crop area.
	Output per unit irrigation supply (US$/$m^3$)	Total annual tonnage of each crop. Crop market price. Total daily measured water inflow to the irrigation system.
	Output per unit water consumed (US$/$m^3$)	Total annual tonnage of each crop. Crop market price. Total volume of water consumed by the crops (ET_c).
	Water quality: Salinity (mmhos/cm)	Total daily measured water inflow to the irrigation system. Electrical conductivity of periodically collected drainage water samples. Total daily measured drainage water outflow from the irrigation system.
Environmental performance	Water quality: Biological (mg/litre)	Biological load of periodically collected irrigation water samples. Total daily measured water inflow to the irrigation system. Biological load of periodically collected drainage water samples.

	Total daily measured drainage water outflow from the irrigation system.
	Chemical load of periodically collected irrigation water samples. Total daily measured water inflow to the irrigation system. Chemical load of periodically collected drainage water samples.
Water quality: Chemical (mg/litre)	Total daily measured drainage water outflow from the irrigation system.
Average depth to water table (m)	Periodic depth measurement to water table.
Change in water table depth over time (m)	Periodic depth measurement to water table over 5 year period.
Salt balance (tones)	Periodic measurement of salt content of irrigation water. Periodic measurement of salt content of drainage water.

Several performance indicators have been developed by various countries to suit their irrigation systems. There is no limitation to the number of indicators to use. The choice of indicators to use depends on the nature of irrigation system being evaluated, drivers of benchmarking and availability of data (Kamwamba-Mtethiwa, Weatherhead, & Knox, 2016;Malano et al., 2001). The main drivers to improve performance of public irrigation schemes in western Kenya is the need to produce more food to meet the country' rice demand and reduce rice imports, efficient use of water resources and growing pressure to increase cost saving since huge investments have been channelled into these schemes (Ministry of Agriculture, 2008) . This informed use of indicators under service delivery, financial and agricultural productivity efficiency while indicators under environmental performance were left out. Due to missing data such as measured water delivery to water users, total management, operation and maintenance (MOM) cost, 10 year minimum water availability flow pattern, cost of MOM personnel, the 21 indicators under service delivery, financial and agricultural productivity categories could not be computed. Therefore it was only possible to compute 13 indicators. Several studies have been undertaken on benchmarking performance of irrigation systems.

Since its inception in 2001, benchmarking has proven to be a useful tool in evaluation and improving performance of irrigation schemes. Countries such as Australia, China, India have developed their own performance indicators that are suitable to their irrigation systems (Cornish, 2005). Indian National Committee on Irrigation & Drainage (INCID) has developed 20 performance indicators for benchmarking irrigation systems in India (Indian National Committee on Irrigation and Drainage, 2002). 12 performance indicators were applied in Benchmarking irrigation systems in Maharashtra in 2003-2004 (Government of Maharashtra, 2005). So far 69,13, 11, 21 and 4 performance indicators have been developed for benchmarking performance in Australia, China, Maharashtra, Mexico and Sri Lanka respectively (Cornish, 2005). Molden et al. (1998) used 9 indicators to compare performance of 18 irrigation systems across the world. Several studies have been undertaken on benchmarking performance of irrigation systems.

Phadnis & Kulsreshtha (2011) benchmarked performance of Samrat Ashok Sagar irrigation project in India by using 8 indicators. The project was found to be suffering from low canal water carrying capacity. The water carrying capacity of right bank canal and left bank canal was 56.49% and 77.35% respectively. Balderama et al. (2014) assessed performance of Divisoria, Garab, Lucban SWIPs and NIA-MARIIS Irrigation systems in Cagayan River Basin, Philippines using 7 indicators. MARIIS, Garab, Lucban, and Divisoria SWIPs registered an overall system performance efficiency of 59%, 47% 55%, and 36% respectively. The input-use efficiency in small scale irrigation schemes was found to be more variable. The above studies have been based on use of indicators alone to evaluate performance of the irrigation schemes. This alone cannot sufficiently describe the overall performance of an irrigation scheme. This limitation has been overcome by combining performance indicators with multi-criteria data analysis tools as is the case in this study. Studies (Borgia et al., 2013; Ntantos & Karpouzos, 2010; Phadnis & Kulshrestha, 2013; Rodrı´guez-Dı´azz, Camacho-Poyato a, Lo ´pez-Luque, & Pe ´rez-Urrestarazu , 2008) have used data envelope analysis (DEA), analytical hierarchical process (AHP), Principal component analysis (PCA), cluster analysis and balanced score-card to evaluate performance of irrigation schemes.

Borgia et al. (2013) combined cluster and data envelop analysis to establish benchmarks for land productivity and performance of small and large irrigation schemes along the Senegal Valley in Mauritania. Using Data envelope analysis (Borgia et al., 2013) the irrigation schemes were grouped into; consuming and productive (cluster 3), precarious (cluster 1), and productive and economic (cluster 2) using hierarchical cluster aggregation. Only four schemes were found to be efficient with an average relatively high land productivity of 4.75 tonnes/ha, low energy cost of 59 €/ha. Ntantos & Karpouzos (2010) also applied data envelope analysis (DEA) method together with IWMI performance indicators to rank and compare performance of irrigation systems in Thessaloniki Plain, Greece. The highest efficiency values (0.9-1) were achieved in pressurised networks or localised techniques Irrigation systems. Irrigation systems with pipeline networks had very low technical efficiency. Rodrı´guez-Dı´azz et al. (2008)used benchmarking together with multivariate data analysis tools (cluster analysis and principal component analysis) to evaluate the efficiency of nine irrigation districts in Andalusia, Spain.

Phadnis & Kulshrestha (2013) applied scorecard-based framework to measure irrigation service performance of Samrat Ashok Sagar major irrigation project, using key selected indicators developed by Indian National Committee for Irrigation and Drainage. Phadnis & Kulshrestha (2013) weighted the performance indicators using devised score method based on stage Delphi-study. The financial, technical and agricultural performance of Samrat Ashok Sagar major irrigation project was found to be 77 %, 81.2 % and of 89.3% respectively (Phadnis & Kulshrestha, 2013) . Balanced score card method is subjective since it is based on individual expert opinion and is subject to biasness. This weakness has been overcome by using objective multi-criteria data analysis tools (OECD, 2008). To overcome subjectivity in weighting indicators, Cuamba (2016) assigned equal weights to performance indicators to measure the overall performance of Lower Limpopo Irrigation System, Southern Mozambique. The overall performance of Lower Limpopo Irrigation System scheme was found to be 49% (Cuamba, 2016). This study combined principal component analysis and benchmarking performance indicators to measure the overall performance of irrigation scheme.

2.3.1 Principal component analysis

Principal component analysis is a statistical multivariate technique that is used to transform a number of correlated observed variables into a smaller number of linearly uncorrelated variables referred to as Principal Components (Jamilah et al., 2012). The first principal component accounts for the highest variation in data while the subsequent principal components have the highest possible variable. The number of observed variables "k" are reduced into few principal components "k" which accounts for the maximum variance such that "p" < "k". PCA assigns weights to variables based on eigenvalues and eigenvectors (OECD, 2008). This method is objective and relies on the underlying data structure to generate non-subjective weights which are less biased. The weight assigned to an indicator corresponds to the level of variation caused by the indicator. Multicollinearity and presence of outliers can be detected using this method (Rodrı´guez-Dı´azz et al., 2008).

PCA is suitable for analysis variables with unequal scale of measurement. PCA simplifies analysis of multidimensional phenomenon by reducing the number of correlated variables (Rodrı´guez-Dı´azz et al., 2008). Use of PCA in evaluation of performance of irrigation schemes is still limited. PCA and performance indicators was used by Rodrı´guez-Dı´azz et al. (2008) in measuring performance of irrigation schemes in Andalusia district, Spain through computation of quality index (QI). Zema, Nicotra, Tamburino, & Zimbone (2015) used PCA to identify areas of weakness in seven Water Users' Association (WUA) in Calabra, Southern Italy. The Ionio Catanzarese (ICZ) WUA was ranked as the best performing with a quality index of 4470, while the Basso Ionio Reggino (BIRC) was found to be the least performing with a quality index of 1410. BIRC was found to have a weakness in both system operation performance and financial management. Lowering water prices was found to be the solution to improving performance of BRIC WUA's in Calabra, Southern Italy (Zema et al., 2015).

2.4 Factors Influencing Performance of Irrigation Schemes

Productivity in agriculture is influenced by inputs used such as fertilizers, water, labour, machinery, seed and size of land. These inputs are broadly categorised into capital, land and labour. Several studies have been carried to explain the factors influencing productivity of irrigation schemes (Samian, Mahdei, Saadi, & Movahedi, 2015;Ngenoh et al., 2015; Mugera, 2015; Rehman, Chandio, Hussain, & Jingdong, 2017). The factors are linked to the inputs applied in agriculture. Identification of factors influencing performance of irrigation schemes is driven by the need to come up with best strategy to improve performance (Dlamini, 2013). The various factors that have been found to affect performance are discussed in the following sections.

2.4.1 Farmer personal characteristics

Personal characteristics of the farmers affect their ability to undertake day to day farming activities and irrigation scheduling (Cuamba, 2016). Aspects of concern are age, gender, level of education, household size, marital status, farm size, farmer income and land holding size. The level of education influences the farmer's ability to use appropriate farming methods and adopt new technologies introduced. Education enables an individual to act beyond traditions and habits. It therefore has a positive impact to farmer's ability to undertake farming practices. However, when individuals achieve very high education levels, they tend to shun from indulging in agricultural activities (Kiseto, 2014).

Age is an indicator of an individual's ability to own and control resources such as labour, land and cash (Kiseto, 2014). In agriculture, it affects the farmer's knowledge and expertise on farming since experience is gained over the years. Size of household has an impact on the availability of labour at farm and scheme level. The size of farm has an influence on the farmers' ability to access credit facilities (Ngenoh et al., 2015; Mugera, 2015). Gender is considered as an important variable in irrigation. Although women make up the majority of population in an irrigation scheme, they are often left out in the decision making stages (Van Koppen, 2002). Gender in agriculture has been reported to determine ability to access resources such as water and land (Obiero, 2010).

2.4.2 Water management and legal factors

These are all practices undertaken in water diversion from source to farms, irrigation scheduling, maintenance of water distribution and field infrastructure for the benefit of water users (Bouman et al., 2007). The factors under this category relate to maintenance of the infrastructure, policy implementation, management of system by the providers and water users, water quality and quantity. Water management, implementation of policies, poor quality of irrigation infrastructure and weak farmer participation were found to have 7.41 % limitation on productivity and sustainable water management (Cuamba, 2016).

2.4.3 Farming inputs

Irrigated agriculture is a highly specialised enterprise that requires timely application of inputs and in required quantities in order to optimize yields (FAO, 2002). The consumable agricultural inputs such as seeds, fertilizers, agrochemicals and machinery are provided in public irrigation schemes. Rehman et al. (2017) reported use of fertilizers, improved seed and credit availability to have a positive and significant influence on agricultural gross domestic product (AGDP).

2.4.4 Economic factors

Cuamba (2016) considered variables under this category to be access to credit facilities, marketing, cost of agricultural inputs and labour. Use of fertilizers greatly increases yields and income in agriculture since it is considered as the main input. Credit is vital in rural agriculture commercialization and modernization (Rehman et al., 2017). Economic factors such as inadequate agricultural credit, inefficient marketing, and high cost of labour and availability of inputs were found to have 11.94 per cent effect on productivity in Lower Limpopo irrigation scheme, Mozambique (Cuamba, 2016). Access to credit facilities is still a major challenge in Kenya. High risks of agribusiness and issues of land ownership are the main factors limiting use of land as security to access banking credit facilities (GoK, 2015). Farmers in Western Kenya Rice Irrigation Schemes have access to credit through a revolving fund scheme. However, the revolving fund schemes have been experiencing systemic challenges that are mainly associated with poor governance leading to under performance of the credit schemes.

2.4.5 Access to irrigation extension services

Irrigation extension services entail research and knowledge transfer on water delivery, land, and agronomy management. Knowledge in preparation of land, crop establishment, application of water, weed and pest control, harvesting and post harvesting is required for success in irrigation activities (Mugera, 2015) . Mugera (2015) reported that inadequate access to extension services by farmers contributed to low crop production in Hola irrigation scheme, Kenya. This was evidenced by only 11 per cent farmers trained on land preparation, 34 % farmers trained on establishment of maize seed, 27 % on management of maize seed and 20 % on handling of maize seed during harvesting and post-harvest. The main research station at Ahero is a shadow of former self and therefore, unable to offer effective extension/research services.

2.4.6 Availability of labour

Irrigated crop farming is a labour demanding enterprise all year round compared to rain fed agriculture (Mugera, 2015). Therefore availability of labour plays a crucial role in the crop production in irrigated agriculture. Availability, cost and reliability of labour has been found to have a direct and positive impact to financial and agricultural performance of small scale sugar cane farmers in Swaziland (Dlamini, 2013). Young and energetic people who could be a good source of labour shy away from farming. This has limited access to labour in the rice fields because the young people are not interested in farming activities. Rice farming in Western Kenya irrigation schemes is manual and is highly affected by availability of labour. Shifting from manual to mechanised rice farming could help solve the problem of inadequacy in labour.

Several studies (Mugera, 2015; Ngenoh et al. 2015; Rehman et al. 2017; Miruri & Wanjohi, 2017) have identified the factors influencing crop productivity in irrigation schemes. However, the quantitative effect of the various factors on the overall performance of the irrigation schemes has not been investigated. In this study, factors influencing performance of irrigation schemes were categorised into; technological and knowledge factors, Institutional and legal factors, economic factors and crop factors.

2.5 Best management practices

Best management practices in agriculture are procedures and actions that focus on water conservation and reduction in the potential negative impacts of agriculture to the environment. Use of BMPs in agriculture has demonstrated an increase in yield, decrease in amount of resources used and reduction in the amount of pollutants released to the environment (Waskom, 1994). The effectiveness of BMPs relies on careful selection on BMPs that suit a certain irrigation system (Gomo, Senzanje, Mudhara, & Dhavu, 2014). Various best management practices in agriculture have been developed over time. These include the following (WMAF 1997;TSSWCB 2005;ICID 1996):

i. Irrigation Scheduling
ii. Volumetric irrigation water measurement
iii. On-farm Irrigation Audit
iv. Land Levelling
v. Conservation tillage and crop residue management
vi. Contour farming
vii. Contour farming
viii. Bruch control/ management
ix. Lining irrigation ditches
x. Use pipelines instead of ditches
xi. Centre-pivot sprinkler irrigation system
xii. Drip irrigation system
xiii. Linear move sprinkler irrigation system

The choice of BMPs applicable to an irrigation system can be done using multi-criteria decision making (MCDM) tools (Hernandez & Uddameri, 2010). MCDM tools are applied in complex decision making where there are multiple conflicting alternatives. The various MCDM methods are based on decision matrix which enables evaluation and ranking of the various available alternatives (Gomo et al., 2014). The selection of MCDM method depends on the objective of the decision maker. MCDM methods that have been applied in engineering are hierarchical approach (Gomo et al., 2014); and Multi-attribute Decision Making Process and Atanassov-Intuitionistic Fuzzy Sets (Hernandez &

Uddameri, 2010) . Analytical hierarchical process (AHP) is the most commonly used MCMD method in agricultural systems.

2.5.1 Analytical hierarchical process (AHP)

Analytic Hierarchy Process involves selection of an alternative based on the level of relative importance to the other alternatives. An hierarchical structure is used to rank alternatives of preference and priority (Aldababseh, Temimi, Maghelal, Branch, & Wulfmeyer, 2018) . Complex aggregation of alternatives is based on linear model. Eigenvectors are used in ranking alternatives (Gomo et al., 2014). Gómez-Limón & Riesgo (2008) used AHP in constructing composite indicator to measure sustainability of agriculture. Aldababseh et al. (2018) applied AHP method to determine suitability of land for growing various types of crops in Emirate of Abu Dhabi, UAE. Montazar & Snyder (2012) used AHP to determine optimal cropping pattern in Koohdasht Irrigation District under water scarcity.

2.6 Research gap

Studies (Kang'au, Home, & Gathenya, 2011; Ngenoh et al., 2015; Maillu, 2016) have evaluated performance of various irrigation schemes in Kenya based on fuel consumption, pump efficiency, pipe head losses, pipe head losses, economic determinants of performance, external indicators. Comparative performance evaluation has not been undertaken on public irrigation in Kenya. Furthermore, combination of various performance categories such as financial, water delivery, water and land productivity, and environmental performance into a single performance score has not been undertaken in Kenya. Therefore, to address this knowledge gap, the performance of public rice irrigation schemes in western Kenya was evaluated using benchmarking tool.

2.7 Conceptual framework

The variables being studied relate as shown in Figure 2.1. The level of performance of an irrigation scheme depends on the scores of various performance indicators. The economic, crop, technological and knowledge and institutional factors influence the level of performance that a scheme can achieve. The choice of best management practices needed to improve performance depends on factors influencing performance.

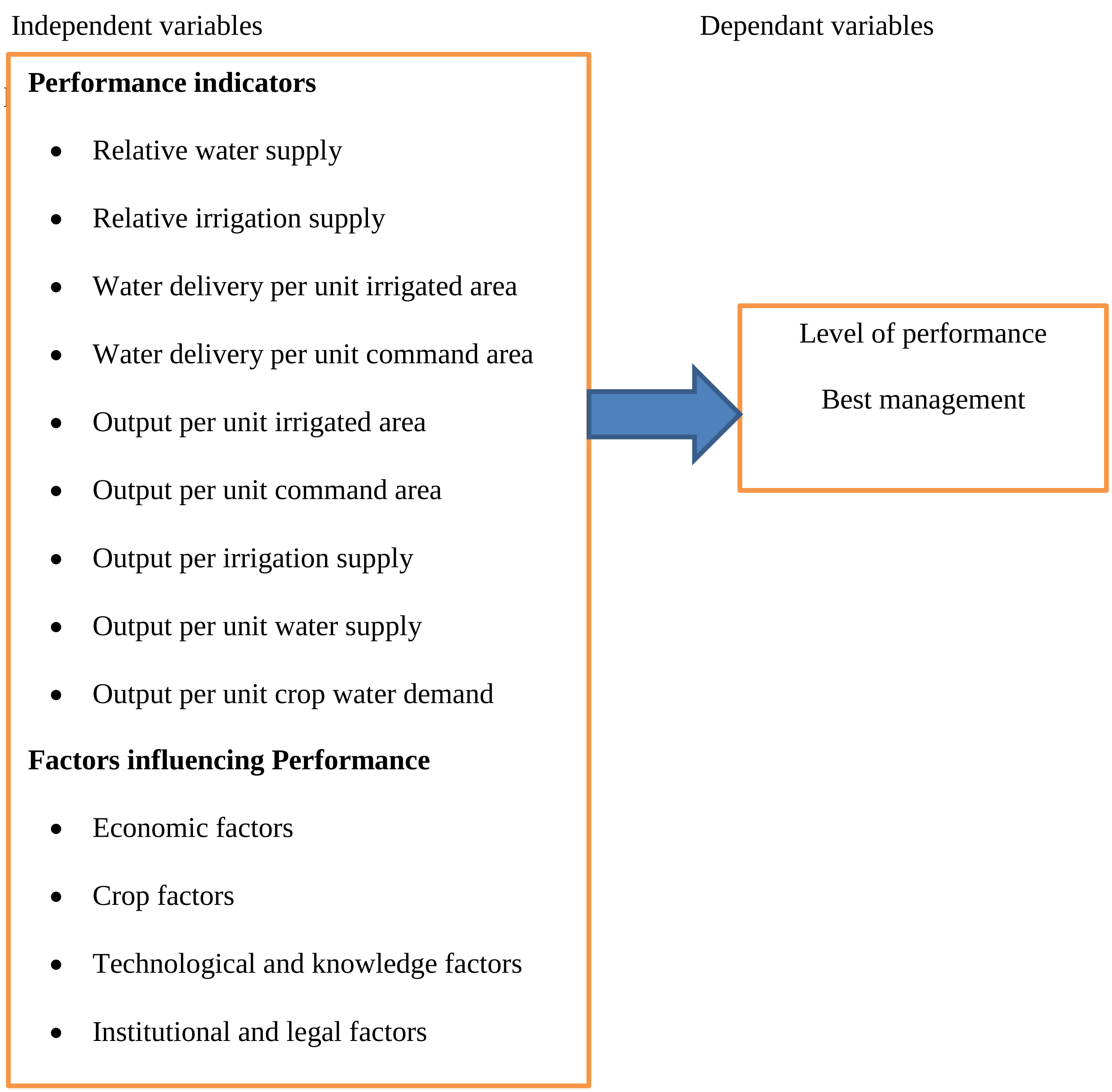


Figure 2.1: Conceptual framework

CHAPTER THREE

METHODOLOGY

3.1 Overview of Methodology of Study

This study involved evaluating and comparing performance of Ahero, Bunyala and West Kano irrigation schemes. First the performance of the irrigation schemes was evaluated using selected performance indicators and principal component analysis (PCA). Analysis of the factors affecting performance of the schemes was then undertaken with the aim of deriving best management practices for pumped surface irrigation systems. Interviews, observation, field surveys and focus group discussion methods were used to collect both quantitative and qualitative data.

3.2 Description of study area

The study was carried out in Ahero, West Kano and Bunyala irrigation schemes in western Kenya managed by National Irrigation Board (NIB) (Figure 3.1). Rice is the main crop grown in these schemes. In all the schemes, water is abstracted using electric powered pumps, conveyed with open earth canals and distributed in basins. There are no water control structures and discharge measurement facilities in all the schemes. The western Kenya region is hot and humid with bimodal rainfall pattern. The schemes are underlain by deep black cotton soils (Kipkorir et al., 2018).

Ahero Irrigation Scheme (AIS) lies at longitude 34°58’ east and latitude 00°10’ south in Kano plains, Kisumu County and draws water from river Nyando. Water is pumped using four electric driven pumps; two pumps with a capacity of 1100l/s each and the other two with a capacity of 650L/S each. The scheme has sufficient access to water for irrigation although occasionally it is not sufficient. The Scheme has total gazetted area of 1540 ha out of which 900 ha has been developed for crop production supporting 556 tenant farmers. Land is owned by government and leased to tenants. The average land holding is 1-4 acres. Rice is grown in the first season. The other main crops grown during the second seasons are soybeans, maize, sorghum, watermelon. The area receives mean annual rainfall of 1233 mm and the mean monthly temperature ranges from 23.4°C to 25.6°C.

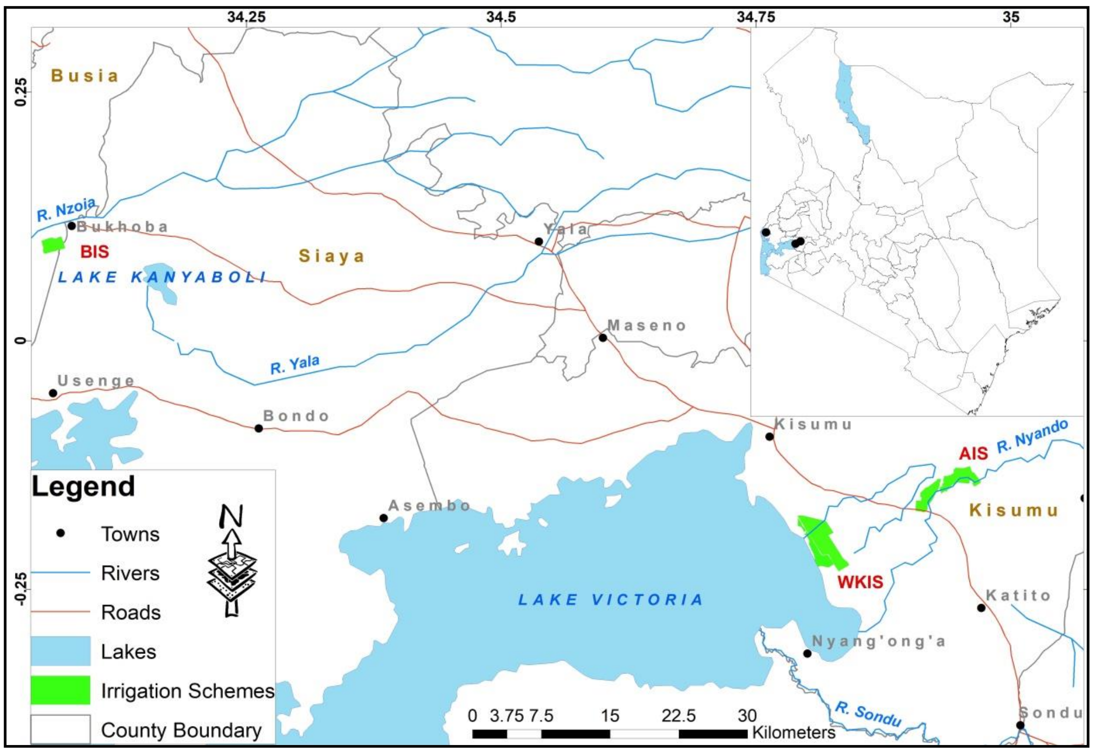


Figure 3.1: Location of Ahero Irrigation Scheme (AIS), Bunyala Irrigation Scheme (BIS and West Kano Irrigation Scheme (WKIS)

West Kano irrigation scheme (WKIS) is located between longitudes 34°48' East and 35°02' East and between latitudes 00°04' South and 00°20' South along the shores of Lake Victoria in Kano plains, Kisumu County (Kipkorir et al., 2018). Water is abstracted from Lake Victoria using three electric driven pumps each with a capacity of 750l/s. Availability of water in this scheme is abundant. An extra cost is incurred in pumping drain water back to Lake Victoria using four outlet pumps each with a capacity of 500l/s. The scheme has a service area of 1780 ha out of which 980 ha has been developed for crop production serving 845 tenant farmers. The land is owned by government and the tenant farmers have an average land holding of 2-4 acres. Rice is grown in the first season. In the second farming season, maize and sorghum are the other crops mainly grown .The area gets mean annual rainfall of 1100 mm and the mean diurnal temperature is 23°C.

Bunyala irrigation scheme (BIS) is located at longitude 34°04' East and latitude 00°06' North in Kisumu Busia / Siaya County. The scheme has a total gazetted area of 728 ha with 702 ha under irrigation supporting 1934 farmers. The original scheme comprised of 534 Acres with 131 farmer families each with an average holding of 1.6 ha (4acres). Due to expansion of the irrigation and drainage infrastructure the scheme is now 1,734 Acres with 1,934 farmers. In the expansion area (1,200 acres) the land tenure system is freehold. The average parcel of land per farmer ranges from 0.1 acres to 5 acres. Water is drawn from River Nzoia using four electric driven pumps each with a capacity of 300l/s. This scheme has abundant access to water. BIS gets mean annual rainfall of 1620 mm and an average monthly temperature of 23.6 ^{0}C. Rice is grown in the first season while pulses and horticulture crops are grown in the second season.

3.3 Evaluation of performance of irrigation schemes

Performance of the irrigation schemes was evaluated using standard external performance indicators proposed by International Program for Technology and Research in Irrigation and Drainage (IPTRID). Thirteen indicators (13) were used to evaluate performance of the three irrigation schemes.

3.3.1 Data collection

Time series data on total yield per season, local crop price per season, cropped area, total command area, revenue collected, expected revenue, cost of production, water supplied, pump speed, pumping hours was collected from records kept by irrigation scheme offices and field survey for five years period (2012-2016). Meteorological data for the period 2012-2016 was obtained from Ahero research station, West Kano weather station, Kenya Meteorological Department (KMD) and NASA POWER centre ("POWER Data Access Viewer," n.d.).

3.3.2 Data analysis

The total volume of crop water demand, total annual volume of crop irrigation demand, total annual volume of water supplied, total annual irrigation water supplied an total annual cropped area were computed as follows. These variables were used in calculating performance indicators.

a) Total annual volume of crop water demand (ET_c)

CROPWAT 8.0 software (developed by Land and Water Development Division of FAO) was used in computation of crop water demand for the period between 2012 and 2016. Number of sunshine hours, temperature, humidity, rainfall data, wind speed, soil type, transplanting date and crop pattern were used as input for the model. Daily ET_c values were computed. The total annual volume of water consumed by the crops from planting to harvesting in the entire irrigation scheme was computed using Equation (3.1) (Malano et al., 2001).

$$VEt_c = \sum_{crops} Et_c \times A \tag{3.1}$$

Where: VEt_c = Total volume of crop water demand (m^3); Et_c = crop evapotranspiration from planting to harvesting (m); A = cropped area (m^2).

b) Total annual volume of irrigation water demand

This is crop water demand less effective rainfall. Percolation losses for paddy rice are considered. Crop irrigation demand was computed using FAO CROPWAT 8.0 model. The effective rainfall was computed using USDA-Soil Conservation Method, in-built in CROPWAT 8. The total annual volume of water consumed by crops is the weighted sum of individual crop irrigation demand. It was computed using Equation (3.2).

$$VEt_{Net} = (Et_c - R_e)A \tag{3.2}$$

Where: VEt_{Net} = Total volume of water consumed by crops less effective rainfall (m^3); Et_c = crop evapotranspiration from planting to harvesting (m); A = cropped area (m^2); R_e=effective rainfall (mm).

c) Total annual volume of irrigation water supply (m^3)

It was obtained by summing up daily volume of water pumped for each season within the year. Daily volume of water pumped was obtained by product of pump efficiency, pumping hours and the pump operating speed.

d) Total annual volume of water supply (m^3)

Total annual volume of water supply was obtained by summing the total volume of water pumped for irrigation and total effective rainfall for the rice growing season in a year. The effective rainfall was computed using the USDA-Soil Conservation Method, in-built in CROPWAT 8. The effective rainfall in terms of depth was converted into volume by multiplying by the total annual cropped area.

e) Total annual cropped area (ha)

Total annual cropped area was calculated by summing up all the area under rice crop in each year.

f) Total command area of the system (ha)

This is the net area serviced by the scheme less the right of way for canals, drains, roads and villages. It was obtained from the design office of each irrigation scheme.

3.3.3 Performance indicators

Fourteen performance indicators were calculated as shown in Table 3.1.The results of each indicator for each irrigation scheme was presented in MS charts and compared with results from other rice irrigation schemes and to other rice irrigation schemes in the world which are similar in terms of water distribution, irrigation method, water delivery infrastructure, climate and management.

Table 3.1: Computation of performance indicators.

S/No.	Performance indicator	Indicator equation
System/service delivery performance		
1	Total annual volume of irrigation water supply(m^3)	*Total annual volume of water pumped for irrigation.*
2	Annual Relative water supply(RWS)	$\frac{total\ annual\ volume\ of\ irrigation\ water\ supply}{Total\ annual\ volume\ of\ crop\ water\ demand}$
3	Relative irrigation supply (RIS)	$\frac{Total\ annual\ volume\ of\ irrigation\ water\ supply}{Total\ annual\ volume\ of\ crop\ irrigation\ demand}$
4	Annual irrigation water supply per unit irrigated area (m^3/ha)	$\frac{Total\ annual\ volume\ of\ irrigation\ water\ supply}{Total\ annual\ irrigated\ area}$
5	Annual irrigation water supply per unit command area (m^3/ha)	$\frac{Total\ annual\ volume\ of\ irrigation\ water\ supply}{Total\ command\ area}$
Productivity Efficiency		
6	Total gross annual agricultural production (tonnes)	*Total annual tonnage of rice*
7	Total annual value of agricultural production (KES)	*Total annual value of production*

8	Output per unit irrigated area (tonnes/ha)	$\frac{Total\ annual\ tonnage\ of\ rice}{Total\ annual\ irrigated\ \ area}$
9	Output per unit command area (tonnes/ha)	$\frac{Total\ annual\ tonnage\ of\ rice}{command\ area}$
10	Output per unit irrigation water supply (tonnes/m^3)	$\frac{Total\ annual\ tonnage\ of\ rice}{Total\ annula\ volume\ of\ irrigation\ water\ supply}$
11	Output per unit water supply (tonnes/m^3)	$\frac{Total\ annual\ tonnage\ of\ rice}{Total\ annual\ volume\ of\ water\ supply}$
12	Output per volume of water consumed(tonnes/m^3)	$\frac{Total\ annual\ tonnage\ of\ rice}{Total\ annul\ volume\ of\ crop\ water\ demand}$
Financial performance		
13	Water fee collection performance (%)	$\frac{Annual\ Gross\ revenue\ collected}{Annual\ Gross\ revenue\ invoiced}$
14	Average revenue per unit irrigation water supply(KES/m^3)	$\frac{total\ annual\ revenue\ collected}{Total\ annual\ irrigation\ water\ supply}$

3.3.4 Estimation of overall performance

The overall scheme performance was determined by computing a single performance score. The total volume of irrigation water supply, total annual agricultural production and total annual value of agricultural production indicators were excluded in the computation of overall performance score. These indicators are based on extensive scale rather than relative scale and their inclusion could distort the results (Ntantos & Karpouzos, 2010). The relative scale is in form of a ratio between variables while extensive scale is based on continuous measurement.

Indicators were first tested for statistical correlation using the Pearson correlation coefficient (r). The person correlation co-efficient (r) gives a measure of the degree of linear correlation between two variables. Pearson (r) co-efficient is computed using Equation (3.3).

$$r = \frac{\boldsymbol{N\sum xy - \sum(x)(y)}}{\sqrt{[\boldsymbol{N\sum x^2 - \sum(x^2)}][\boldsymbol{N\sum y^2 - \sum(y^2)}]}} \quad (3.3)$$

Where; r= Pearson correlation coefficient; N= number of observations; $\sum xy$= sum of products paired; $\sum x$= sum of x scores; $\sum y$= sum of y scores; $\sum x^2$= sum of squared x scores; $\sum y^2$= sum of squared y scores.

The value of correlation coefficient (r) varies from “-1” to “+1”. A value of +1 indicates a perfect positive linear correlation while a value of -1 shows a total negative linear correlation. A value of zero (0) indicates no linear correlation. The closer the r value is to 0, the weaker the relationship between the variables. The value of a negative sign (-) indicates negative relationship while positive sign (+) indicates positive relationship. Ten indicators with low correlation were selected. The indicators were weighted using principal component analysis, then normalised using the reference to target method and finally aggregated into a single performance score using the linear aggregation method. Weighting of indicators was done using PCA.

Principal Component Analysis (PCA)

PCA is used to assign weights to variables based on eigenvalues and eigenvectors (OECD, 2008). This method is objective and relies on the underlying data structure to generate non-subjective weights which are less biased. The weight assigned to an indicator corresponds to the level variation caused by the indicator. Multicollinearity and presence of outliers can be detected using this method (Rodrı´guez-Dı´azz et al., 2008). PCA is suitable for analysis variables with unequal scale of measurement. PCA simplifies analysis of multidimensional phenomenon by reducing the number of correlated variables (Rodrı´guez-Dı´azz et al., 2008). PCA was done using SPSS windows version16 software. The extracted components were rotated using orthogonal varimax method to achieve significant components. The indicator weights were computed using rotated factor loadings and eigenvalues, as shown in Equation (3.4)

$$w_k = \sum_{j=1}^{j=n} \frac{(Factor\ loading_{kj})^2}{eigenvalue_j} \times \frac{eigenvalue\ j}{\sum_{j=1}^{j=n} eigenvalue_j} \quad (3.4)$$

Where: $\text{Factor loading}_{kj}$— factor loading of indicator *k* in the principal component *j*

eigenvalue_j—eigenvalue for j^{th} principal component

j = 1, *j* = 2,…, *j* = *n* — the extracted principal components with an eigenvalue above 1.

The indicators were normalised using reference to target using Equation (3.5).

$$I_{qs}^t = \frac{x_{qs}^t}{x_b} \quad (3.5)$$

Where: I_{qs}^t = normalised value of indicator q for scheme s at time *t*; x_{qs}^t = indicator value for scheme s at time *t*; x_b = threshold value for indicator value.

The threshold values used for normalisation of indicators are shown in Table 3.2.

Table 3.2: Indicative threshold values.

Performance indicator	**Threshold values**	**Reference**
Relative water supply	2	(Balderama et al., 2014 ; Bos et al., 2005)
Relative irrigation supply	2	(Balderama et al., 2014 ; Bos et al., 2005)
Annual irrigation water delivery per unit irrigated area	450-700 (mm)	(Brouwer, Prins, & Heibloem, 1989 ; Zwart, 2013)
Annual irrigation water delivery per unit command area	450-700 (mm)	(Brouwer et al., 1989; Zwart, 2013)
Output per unit irrigated area	3.8 tonnes/ha	(Bastiaanssen & Perry, 2009 ; Beddow, Pardey, Alston, & Europe, 2009)
Output per unit command area	3.8 tonnes/ha	(Bastiaanssen & Perry, 2009 ; Beddow, Pardey, Alston, & Europe, 2009)
Output per unit irrigation supply	$2kg/m^3$	(Bastiaanssen & Steduto, 2017: Cai, Molden, & Sharma, 2009)
Output per unit water supply	$2kg/m^3$	(Bastiaanssen & Steduto, 2017: Cai, Molden, & Sharma, 2009)
Output per water consumed	$2kg/m^3$	(Bastiaanssen & Steduto, 2017: Cai,

		Molden, & Sharma, 2009)
Water fee collection performance	100%	(Malano et al., 2001; Cin & Çakmak, 2017)
Average revenue per unit irrigation supply	7.5 KES	(Omondi, 2014)

A single performance score was finally computed using Equation (3.6) (Gómez-Limón & Riesgo, 2008).

$$CI_{st} = \sum_{k=1}^{k=n} w_k \, I_{ks} \tag{3.6}$$

Where; CI_{st} = performance score; W_k = indicator weight; I_{ks} =normalised indicator k for scheme s; for irrigation scheme s at time t.

3.4 Factors influencing performance of irrigation schemes

Both descriptive and quantitative methods were used to obtain determinants of performance of the irrigation schemes. Evaluation of factors affecting performance of selected irrigation schemes was based on farmers' perception. Data was collected from farmers, farmer co-operative representatives, water user association (WUA) representatives and scheme management officers.

3.4.1 Sampling

The study population was composed of farmers engaging in rice farming in Ahero, West Kano and Bunyala irrigation schemes. A list of registered farmers was obtained from each of the irrigation scheme management office. The total population of 2,794 was comprised of 556, 845 and 1393 in Ahero, West Kano and Bunyala irrigation schemes respectively. The sample size required to achieve 95per cent confidence level was computed using Equation (3.7).

$$n = \frac{Z^2 * p * q * N}{e^2(N-1) + Z^2 * p * q} \tag{3.7}$$

Where; *n*= the sample size; *Z*= standard variate at a given confidence level (in this case, 95per cent) =1.9; *p* = sample proportion corresponding to the probability of an event occurring; *p*=0.02; *q*= (1-*P*) =0.98; *N*= population size ; *e*= acceptable error, used 0.02

A sample size (*n*) of 176 farmers for all the irrigation schemes was derived from a total population *N*=2,794. A sample size for each irrigation scheme proportional to its population was computed as;

$$\boldsymbol{s} = \frac{scheme\ population}{Total\ population\ for\ all\ the\ schemes\ (N)} * n \tag{3.8}$$

The required sample size in Ahero, West Kano and Bunyala irrigation scheme was 35, 53 and 88 respectively. A more achievable and convenient sample size of 40 in Ahero, 50 in West Kano and 80 in Bunyala irrigation scheme was adopted. Proportionate random sampling method was used to draw a representative sample of the households. Representative blocks were first selected based on the location on the main canal i.e. at the head, middle and tail end. A representative sample of households was then sample drawn from the selected blocks.

3.4.2 Data collection

Data was collected using field observations, questionnaires and focus group discussion. Information on the condition of water delivery structures, farming practices, maintenance of the irrigation system, availability and cost of farm inputs, labour availability, water management practices, farmer characteristics and access to market was gathered. The various factors influencing productivity were weighted by farmers on a 5-likert scale.

3.4.3 Data analysis

Descriptive statistical analysis was carried out using Ms Excel. The mean, standard deviation, co-efficient of variation and frequency of the data were computed. Factor analysis was used to quantify and group various factors influencing performance of irrigation schemes. Factor analysis was done using SPSS windows version16 software. Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity (BTS) were undertaken to determine suitability of data for factor analysis.

3.5 Best management practices (BMPs)

The results from analysis of performance indicators and factor analysis were used to identify points of weakness that require improvement. The selection and ranking of the various BMPs was done by farmers and NIB irrigation technicians, engineers and officers in charge of production and managers as guided by the researcher. Development of best management practices was based on both technical aspects of irrigated agriculture and management issues. The overall ranking was done using analytical hierarchical process (AHP). AHP was carried out as follows.

i. A schematic model showing the interaction between the decision goal and the various selection criterions was developed as shown in Figure 3.2 (Gomo et al., 2014) . The main goal was to rank the various BMPS .The selection criterion are the attributes that a farmer considers before ranking BMPs such as applicability.

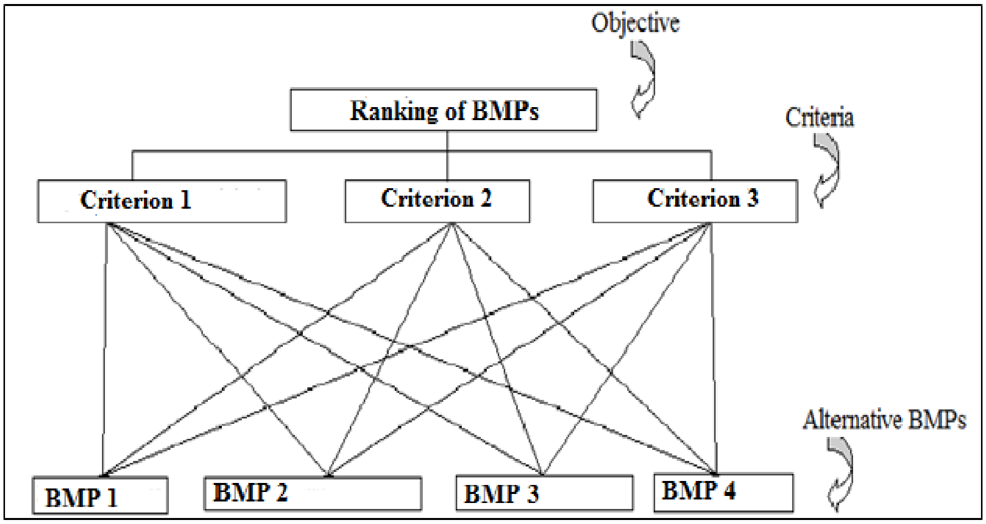


Figure 3.2: Hierarchical structure for ranking irrigation BMPs

ii. The criterion (attributes) were assigned weights on a 1 (equal importance) to 9 (extreme importance) pair-wise comparison scale. The weights assigned show the importance of one choice relative to the other. The more important alternative was assigned a weight while the less important one was assigned a reciprocal. For example, if the relative importance of alternative "A" relative to alternative "B" is i, and A≠B, then the relative importance of "B" relative to "A" will be 1/i. "A" comparison matrix was then developed. Assuming alternative "A" is twice important as "B"; "B" is 4 times important than "C"; "C" is 5 times as important as "A"; A decision comparison matrix developed from these assumptions will appear as follows.

$$\begin{bmatrix} Alternative & A & B & C \\ A & 1 & 1/2 & 5 \\ B & 2 & 1 & 1/4 \\ C & 1/5 & 4 & 1 \end{bmatrix} \qquad (3.9)$$

iii. The BMPs were then assigned weights based on 1 (equal importance) to 9 (extreme importance) pair-wise comparison scale. A second decision matrix was then developed as described in step ii.

iv. A consistency check was done to ensure logical judgment in steps (ii) and (iii) was not violated.

v. The two decision matrices developed in stages (ii) and (iii) were combined to form a single decision matrix that shows the ranking of the various BMPs.

3.5.1 Sampling

Purposive sampling method was used to select sample farmers to use in ranking BMPs. 15 farmer representatives consisting of block leaders, farmer co-operative committee, and WUA committee were selected. The sample size was small because only few farmers could understand the technical language in the questionnaires in Appendix D.

3.5.2 Data collection

Five NIB officers in each of the schemes assisted in selecting the appropriate BMPS for improving performance and achieving sustainable operation and management of irrigation schemes. They were selected because they have the technical know-how of the BMPs in irrigated agriculture. The BMPs were selected from existing BMPs discussed in section 2.5. The BMPs were evaluated based on the following attributes : (i) applicability in public irrigation schemes; (ii) acceptance by farmers; (iii) ease of implementation; (iv) increasing water saving; (v) cost-effectiveness (WMAF, 1997).The various BMPs selected are presented in Table 3.3.

Table 3.3: Best management practices.

BMP	Description
Land levelling	Mechanized grading of farms based on a topographic survey to obtain a level field.
Tail-water recovery and reuse system	Construction of ditches or installation of pipes to collect drain water into a tank then pumping back to the farms.
System of Rice intensification	Changing the management of plants, soil, water and nutrients to increase yield and reduce water use. Transplanting of very young single seedlings in a wide square pattern.
Scientific irrigation scheduling	Estimating future water requirement over relatively short periods based crop water needs.
Volumetric water measurement	Measurement of amount of water supplied per block using water meters.
Capacity building of farmers	Training on improve crop production technologies and financial management. Also building up financial capacity of farmer co-operatives
Mechanization of farming operations	Use of farming machineries in various farming stages instead of manual labour.
Change from pumping to gravity fed system	Re-designing the water delivery system to utilize force of gravity in conveying water instead of current electric pumping.

Questionnaires presented in Appendix D were administered to the farmers for ranking based on level of importance of BMPs. The various BMPs and selection criteria were assigned scores using 1-9 pairwise scale described in Table 3.4 (Saaty, 1990). The score assigned show the level of importance of one alternative to the other.

Table 3.4: Pair wise comparison scale.

Relative importance	**Definition**	**Description**
1	Equal importance	Two activities have an equal importance to the objective.
3	Moderately important	Based on judgment and experiences, one activity is strongly favoured over the other.
5	Essentially important	Based on judgment and experiences, one activity is strongly favoured over the other.
7	Very strongly important	One choice is strongly favoured over the other and its dominance demonstrated in practice.
9	Extremely important	The evidence favouring one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate judgments between two adjacent alternatives.	

Reciprocals	If activity i is assigned any one of the above numbers (1-9) when compared with activity j, then j has the reciprocal value when compared with i.

3.5.3 Data analysis

Data analysis was done using MS Excel. The mean score assigned for each BMP and selection criterion was first computed. The overall ranking of BMPs was based on Analytical hierarchical approach. Two comparison matrices were developed; 1 matrix for BMPs and 1 matrix for attributes. The scores for each alternative were normalized using Equation 3.10 (Talukder, W. Hipel, & W. vanLoon, 2017).

$$N_I = \frac{I}{\sum_1^n I} \qquad (3.10)$$

Where; N_i- normalised alternative; I- alternative

The averages of the normalised alternatives were then computed to get a single weight for each alternative. Linear combination of weights of selection criteria and BMPs formed a decision matrix for the various BMPs. The overall rank of the BMPs was obtained from the decision matrix.

CHAPTER FOUR

RESULTS AND DISCUSSSIONS

4.1 Evaluation of performance of irrigation schemes

The results of various parameters discussed in section 3.3.2 are presented in Table 4.1.The available irrigable area (command area) in all the three western Kenya Irrigation schemes has not been fully exploited as detailed in Table 4.1. This can be associated to financial inability of farmers to acquire farming inputs. The annual volume of irrigation supply for the schemes ranges between 2.2 and 8.4 MCM as detailed in Table 4.1. All the schemes abstract water from a reliable source by pumping using electricity.

The amount of water abstracted is governed by demand (cropped area) and availability of electricity as a source of power from the national grid. All the three irrigation schemes have a high fluctuation in amount of water supplied due to frequent power outages experienced in the region. Water is pumped during the day for an average of 10hrs in both Ahero and West Kano irrigation schemes. While water in Bunyala irrigation scheme is pumped for 12 hours during the day. The schemes have no functional gauging stations. The results of performance indicators are described as follows.

4.1.1 Water supply performance

The indicators under this category give measure of water supply relative to demand. Water abundance or scarcity of water can be deduced from these indicators (Bos et al., 2005). The relative irrigation supply and relative water supply indicators are presented in Figure 4.1.

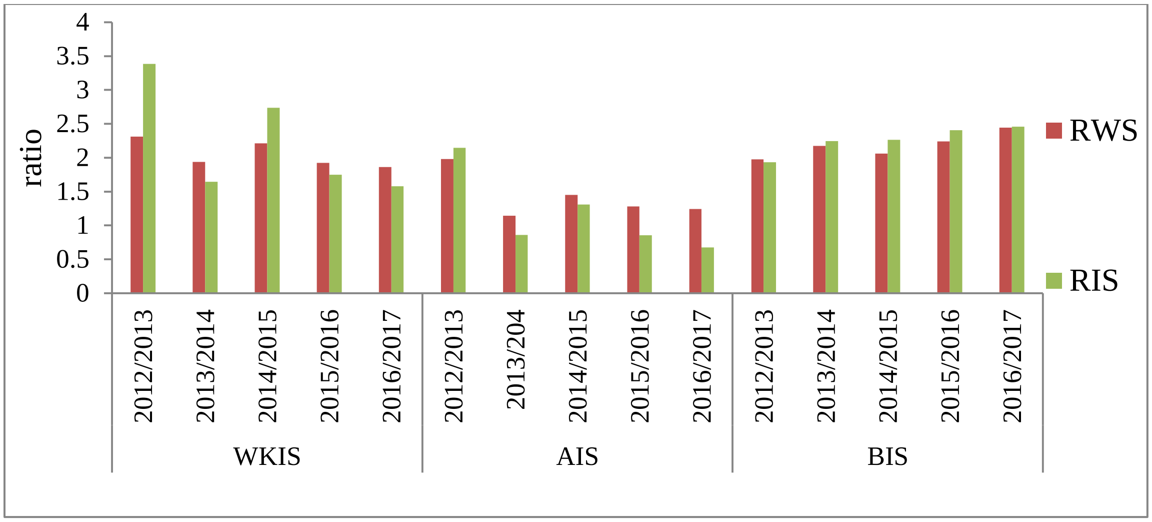


Figure 4.1: Relative irrigation supply (RIS) and relative water supply (RWS) indicators

The relative irrigation supply (RIS) values varied from 0.68 to 3.38 during the study period. Theoretically, the ideal RIS values should be 1.0. Values above 1.0 indicate abundance of water supply while below 1.0 indicate water deficit (Molden et al., 1998). RIS values above or close to 1.0 are recommended (Molden et al., 1998). For a system without shortage in water supply, RIS and RWS are always above 1. This is because irrigation efficiency is always below 100% due to unavoidable conveyance and application losses. The average RIS in Ahero, West Kano and Bunyala irrigation schemes was 1.17, 2.22 and 2.26 respectively. The values for West Kano and Bunyala irrigation scheme in some years are above the world average RIS value of 2.0 (Balderama et al., 2014). The relative water supply (RWS) varied between 1.14 and 2.44 for all the schemes. RWS above 2 shows water supplied relative to demand is adequate (Molden et al., 1998). High RIS and RWS values in West Kano and Bunyala irrigation schemes show that there is adequate supply of water.

Table 4.1: Parameters for calculating performance indicators

Scheme	Year	CA (ha)	IA (ha)	Total Value of outputs (million KES)	Output (tonnes)	CWD ($*10^6$)	IS ($*10^6$)	R_e ($*10^6$)	IR ($*10^6$)	WS ($*10^6$)	Revenue Collected (million KES)	Revenue Invoiced (million KES)
AIS	2012/ 2013	900	877	168	4,179	5.96	6.83	4.98	3.18	11.81	5.38	6.72
	2013/ 2014	900	846	148	4,182	6.61	4.94	2.63	5.73	7.57	5.51	6.48
	2014/ 2015	900	783	168	4,551	5.72	4.87	3.43	3.72	8.30	4.92	6.00
	2015/ 2016	900	824	174	4,465	6.35	4.36	3.77	5.10	8.13	5.43	6.31

	2016/ 2017	900	720	166	4,058	5.98	3.95	3.47	5.83	7.42	4.97	5.52
	2012/ 2013	902	617	86	2,679	4.00	6.93	2.30	2.05	9.23	2.50	5.55
	2013/ 2014	902	206	42	1,201	1.62	2.54	0.60	1.55	3.14	0.89	1.86
WKIS	2014/ 2015	902	195	37	1,136	1.41	2.22	0.89	0.81	3.11	0.90	1.76
	2015/ 2016	902	650	131	3,633	5.03	7.12	2.56	4.06	9.67	3.15	5.84
	2016/ 2017	902	690	155	4,083	5.62	8.41	2.05	5.32	10.46	3.54	6.21
BIS	2012/ 2013	728	701	125	3,803	4.25	4.41	3.98	2.28	8.39	6.37	6.93

2013/ 2014	728	701	71	2,146	4.40	6.22	3.36	2.77	9.58	6.51	6.93
2014/ 2015	728	701	113	3,380	4.36	5.40	3.58	2.39	8.98	6.44	6.93
2015/ 2016	728	625	132	3,850	3.94	5.39	3.44	2.24	8.83	5.87	6.18
2016/ 2017	728	666	121	3,633	4.41	8.08	2.70	3.29	10.78	6.38	6.58

CA- Total command area; IA- total irrigated area; CWD- total volume of crop water demand; IS- total volume of irrigation water inflow ; Re- total volume of effective rainfall ; IR- total volume of irrigation water demand; WS- total volume of water supply

Ahero irrigation scheme suffers from inadequate supply of water, which is evident from the low RIS values, the majority of which are below 1.Ahero irrigation scheme draws water from the river Nyando, which is occasionally affected by drought and siltation. A low RIS value of 0.4 was reported in Muda irrigation scheme, Malaysia (Molden et al., 1998). The low RIS was associated with the use of real-time monitoring of water depth in rice farms, which enabled effective use of rainfall. The average RIS values obtained in this study are similar to average RIS value of 2.31 recorded in large public rice irrigation schemes in Senegal Valley, Mauritania (Borgia et al., 2013). In similar studies, an average RWS of 0.77 was obtained in Karacabey surface irrigation system, Turkey (Kuscu, Bölüktepe, & Demir, 2015). The water supplied was less than crop water demand and water shortage was experienced in this scheme. Elsewhere in Turkey, Kuşçu (2012) obtained RWS values ranging between 0.37 and 1.97. In Malaysia, RWS varied between 0.4 and 4.3, while RIS ranged between 0.5 and 5.7. The high values in Malaysia are attributed to extensive rice farming using open channel.

The water use indicators relate volume of water delivered or supplied to land area. The results of the indicators are presented in Figure 4.2. The quantity of water supplied per unit area varies with availability of water, climate, soil type, cropping pattern, system conditions and system management (Government of Maharashtra, 2005).

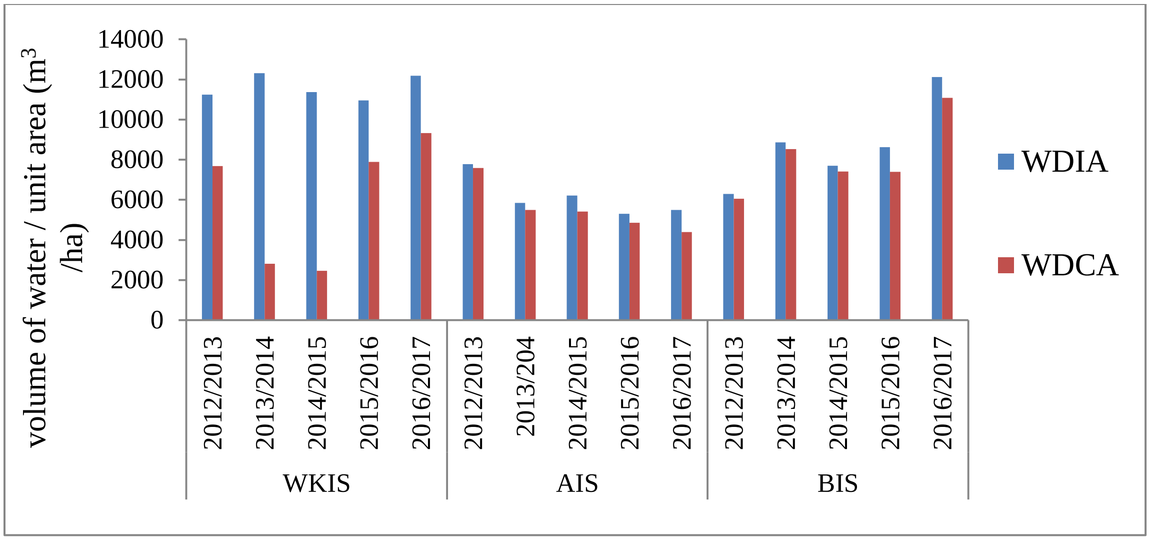


Figure 4.2: Water use indicators for West Kano Irrigation Scheme (WKIS), Ahero Irrigation Scheme (AIS) and Bunyala Irrigation Scheme (BIS)

The annual water delivery per unit command area (WDCA) varied between 2,465 m^3/ha (west Kano in 2014/2015) to 11, 089 m3/ha (Bunyala in 2016/2017). The WDCA was 4,389 m^3/ha -7,586 m^3/ha in Ahero, 2,465 m^3/ha -9,326 m^3/ha in West Kano and 6,050 m^3/ha -11,089 m^3/ha in Bunyala Irrigation Scheme. WDCA was highest in Bunyala and least in Ahero irrigation scheme. Lower WDCA values were ranging between 3.975 m^3/ha and 7.368 m^3/ha were obtained in Asartepe Irrigation association, Turkey (Cakmak, Polat, Kendirli, & Gokalp, 2009). In Susurluk river basin in Turkey, WDCA values varying from 1,465 m3/ha and 13,086 m^3/ha and WDIA values ranging from 2,169 m^3/ha to 22,098 m^3/ha were obtained (Kuşçu, 2012). A high amount of water is supplied to irrigation schemes in the Sursurluk basin because rainfall is limited during the irrigation period. In Mwea irrigation schemes, WDCA was estimated to be 23,747 m^3/ha for the period 2007/2008 (Obiero, 2010). Mwea irrigation scheme supplies too much water compared to the schemes in western Kenya.

The annual water delivery per unit irrigated area (WDIA) varied from 5,294 m^3/ha to 7,785 m^3/ha in Ahero; 11,238 m^3/ha to 12,310 m^3/ha in West Kano and 6,285 m^3/ha to 12,130 m^3/ha in Bunyala irrigation scheme. This is equivalent to depth of water (delta) supplied of 529.4mm-778.5mm in Ahero; 1,123.8 mm-1,231mm in West Kano and 628.5 mm to 12,130mm in Bunyala Irrigation Schemes. According to FAO, the average crop water need for paddy rice should be 450mm-700mm (Brouwer et al., 1989). This means that excess water is supplied in both Bunyala and West Kano irrigation schemes while in Ahero irrigation scheme the amount of water supplied is adequate.

Similar WDIA values of 22,029.43 m^3/ha, 16,026.37 m^3/ha, 11,289.10 m^3/ha, 9,795.96 m^3/ha were recorded in MARIIS, Divisoria, Lucban and Garab SWIPs respectively in Cagayan river basin, Philippines (Balderama et al., 2014). In southern Italy, high WDIA values ranging between 6500 m^3/ha and 14,900 m^3/ha were reported in the Water Users' Association (WUA's) of Calabria. Lower WDIA values were ranging between 8.586 m^3/ha and 13.611 m^3/ha were obtained in Asartepe Irrigation association, Turkey (Cakmak et al., 2009). This is because vegetables, sugar beet, fodder crops, water melon, vineyard and maize are grown in Asertepe irrigation system which does not require continuous flooding as is the case with rice.

4.1.2 Financial performance

The Financial performance indicators measures the efficiency with which an irrigation system uses resources to provide service to the farmers (Balderama et al., 2014). Water fee collection performance and average revenue per unit irrigated area were the indicators computed in this category. The results of water fee collection performance are presented in Figure 4.3.

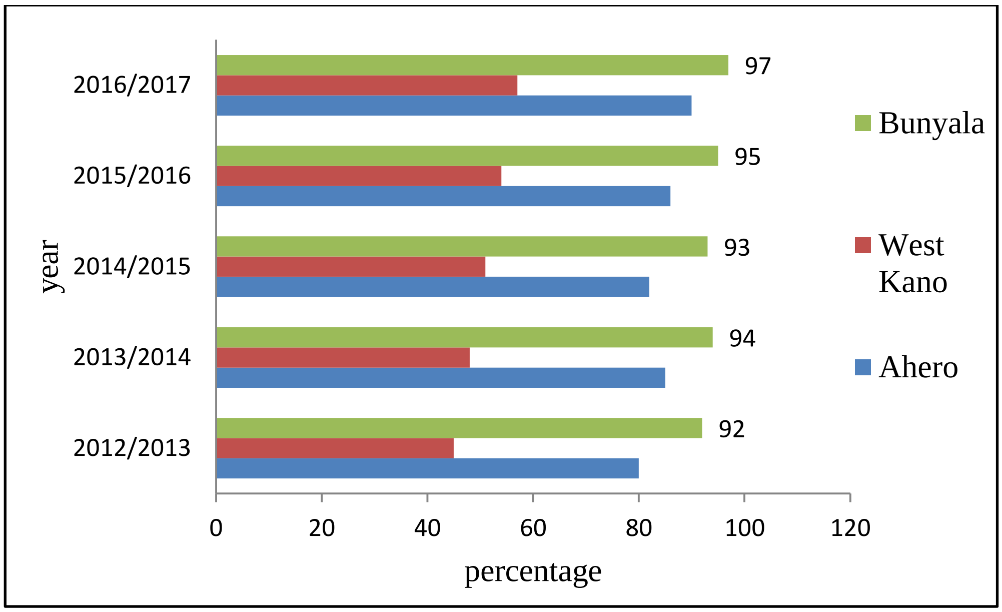


Figure 4.3: Water fee collection performance

Water fee collection performance (WFC) values range from 80% to 90% in Ahero, 45%-57% in West Kano and 92%-97% in Bunyala irrigation scheme respectively. According to Borgia et al. (2013) water fee collection value below 70% is considered unsatisfactory. Bunyala has the highest average fee collection performance of 94% while West Kano has the least average value of 51%. The ideal desirable value should be close to 100% (Malano et al., 2001). Cin & Çakmak (2017) obtained an ideal WFC of 100 % in Beypazarı Başören irrigation system, Turkey. Similarly, WFC value of 103% was recorded in Karacabey irrigation scheme in Turkey. Values of WFC equal or above 100% shows that water users pay for the cost of irrigation. WFC values above 100% are possible to obtain due to payment of accumulated arrears**.** Low WFC values indicate inability of farmers to pay water fee, poor organization of Irrigation Water Users Association (IWUA), poor collection program and financial problems within the schemes. Bunyala Irrigation Scheme is able to sustain a value above 90% because of the well-organized farmer groups. The farmer groups are mandated with mobilization of water fee. Also in Bunyala, the policy of water fee payment prior to ploughing is strictly followed.

The average revenue per unit irrigation supply indicator gives the value of irrigation water (Government of Mahrashtra, 2012). The results of average revenue per unit irrigation supply are presented in Figure 4.4.

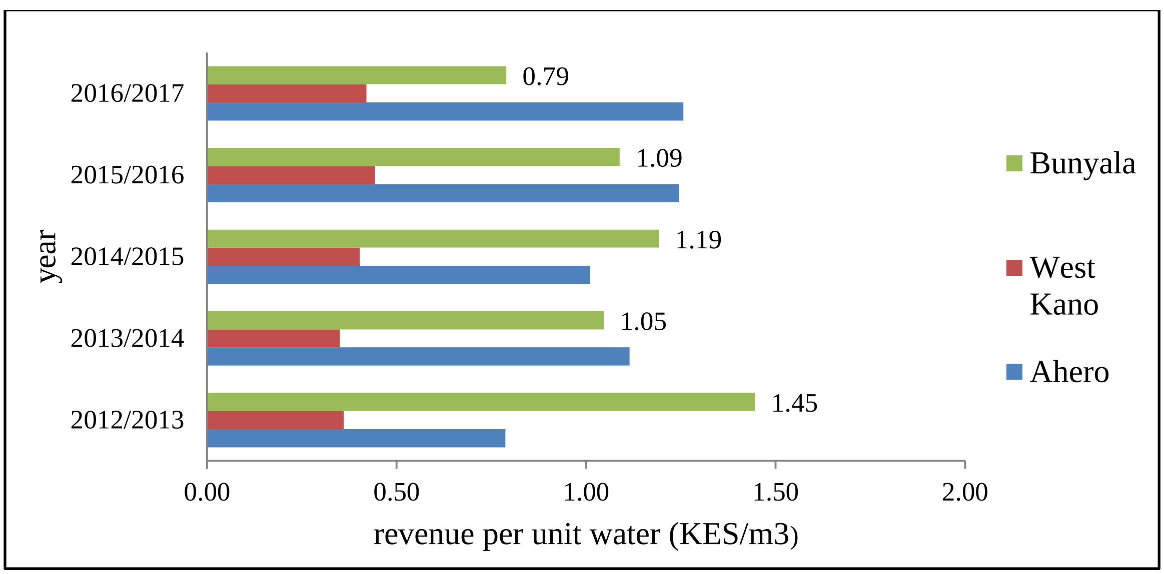


Figure 4.4: Average revenue per unit irrigation supply

The Average revenue per unit cubic meter of water supplied varied from KES.0.79 to 1.26 (0.79-1.26 US dollar cents) in Ahero irrigation scheme; KES.0.35 to 0.44(0.35-0.44 US dollar cents) in West Kano irrigation scheme; KES.0.79 to 1.45 (0.79-1.45 US dollar cents) in Bunyala irrigation scheme. There is a general increasing trend in the average revenue per unit irrigation supply between 2012 and 2017 in Ahero irrigation scheme and a slight increase in West Kano irrigation scheme. West Kano irrigation scheme registered low average revenue per unit irrigation supply because of poor water fee collection due to farmers' unwillingness to pay water fee and poor revenue collection policy. In West Kano irrigation scheme, farmers are allowed to plant before full payment of water fee for the previous season.

A decline in average revenue per unit irrigation supply has been experienced in Bunyala irrigation scheme from 2012 to 2017. These values are below the economic value of irrigation water of 7.54 US dollar cents per cubic meter obtained by Omondi (2014) in Ahero irrigation scheme. Pricing of water is an economic aid to improving water allocation and sustainable water utilization (Kuşçu, 2012). The water fee charged is KES 3,100, 3,640 and 4,000 per acre in Ahero, West Kano and Bunyala Irrigation Schemes respectively. Water fee is collected by scheme management. The pricing is based on area cropped per farming season and not the quantity of water consumed. Therefore there is no limit to the quantity of water that a farmer can use. This is a weakness and is unsuitable in terms of efficiency of water use and water conservation. This is why all the schemes suffer from low water use efficiency. Charging water fee based on amount of water consumed could increase efficiency of water use and consequently productivity.

Bunyala has the highest WFC and average revenue per unit irrigation supply. More value is attached to irrigation water in Bunyala irrigation scheme compared to the other schemes.

4.1.3 Agricultural performance

The indicators in this category give the relationship between inputs and output. It is an indicator of efficiency of crop production in terms of land used, amount of water used and the income generated (De Alwis & Wijesekara, 2011). The indicators are grouped into output relating to land and water i.e. land productivity and Water productivity. Agricultural output is expressed in terms of mass because only one crop (rice) is compared in this study. If comparison of agricultural productivity was between different crops, output would be expressed in terms of gross value in US$ (Bos et al., 2005).

4.1.3.1 Water productivity

Water productivity gives a relationship between the total agricultural produce in terms of economic value or grain yield to volume of water consumed or diverted. Comparison of value of indicators in this category is presented in Figure 4.5. The output per irrigation supply (OIS) ranges between 0.35 and1.03 kg/m^3 in all the schemes. The average output per unit irrigation supply is 0.89 kg/m^3 in Ahero, 0.47 kg/m^3 in West Kano and 0.60 kg/m^3 in Bunyala irrigation schemes. The results indicate that Ahero utilises water more efficiently compared to the others. The output per unit water supply (OWS) puts into consideration the contribution of effective rainfall. The output per water supply obtained varies between 0.22-0.55 kg/m^3. The highest value of 0.55 kg/m^3 was registered in Ahero in 2013/2014 while the least value of 0.22 kg/m^3 was obtained in Bunyala irrigation scheme in 2013/2014. The average OWS obtained was 0.51 kg/m^3 in Ahero, 0.37 kg/m^3 in Bunyala and 0.36 kg/m^3 in West Kano irrigation scheme. The average global grain productivity varies between 0.76 and 1.23 kg/m^3 (Balderama et al., 2014). The average output per water supplied in all the schemes was below average global productivity. Therefore, water productivity in Western Kenya rice irrigation schemes is poor.

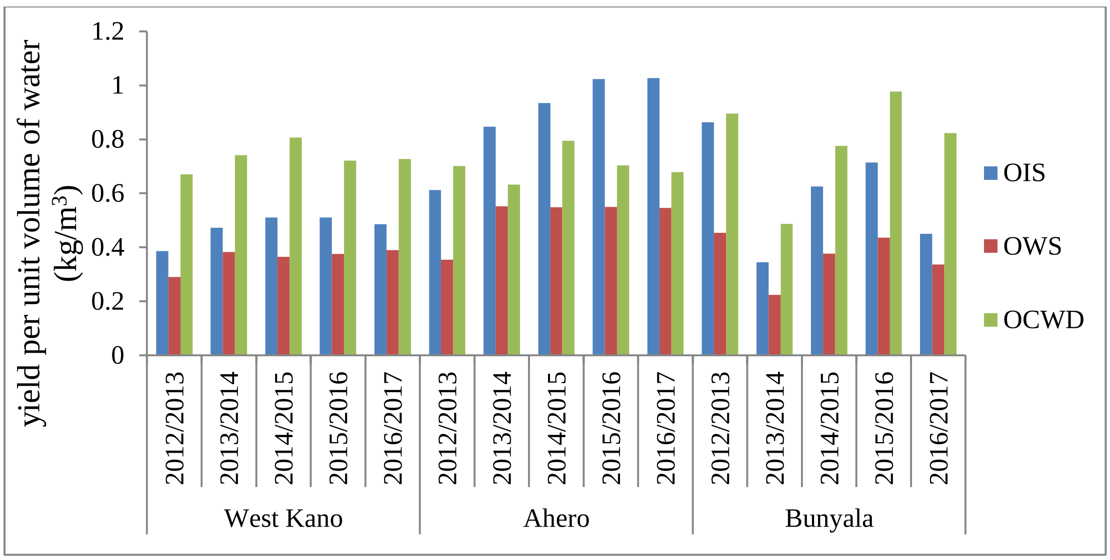


Figure 4.5: Water productivity in terms of output per irrigation supply (OIS), output per water supply (OWS) and output per crop water demand (OCWD) for the three schemes

Output per unit crop water demand (crop water productivity) in terms of evapotranspiration varied between 0.49-0.98kg/m^3. These values are within the world rice water productivity of 0.5-2kg/m^3 (Bastiaanssen & Steduto, 2017). The highest values of rice water productivity of 1.77 kg/m^3, 1.75 kg/m^3 and 1.51kg/m^3 have been reported in USA, Sri Lanka and Spain respectively (Bastiaanssen & Steduto, 2017). Ahero Irrigation Scheme is leading in terms of water productivity while West Kano is the poorest. In

Mekong River Basin, the maximum rice yield per unit evapotranspiration between 1993 and 2003 was 3.0 kg grain ha^{-1} mm^{-1} in Thailand; 3.3 kg grain ha^{-1} mm^{-1} in Cambodia; 5.8 kg grain ha^{-1} mm^{-1} in Laos and 7.7 kg grain ha^{-1} mm^{-1} in Vietnam (Sadras, Grassini, & Steduto, 2012). While it was 6.32-7.95 kg ha^{-1} mm^{-1} AIS; 6.7-8.07 ha^{-1} mm^{-1} in WKIS and 4.87-9.77 ha^{-1} mm^{-1} in BIS . Low land rain fed rice farming is practiced in Mekong river basin that is why crop water productivity values ranging from 3.0 ha^{-1} mm^{-1} to 7.7ha^{-1} mm^{-1} are slightly lower compared to values varying between 4.9 ha^{-1} mm^{-1} and 9.8 kg ha^{-1} mm^{-1} values obtained in irrigated rice farming in western Kenya.

4.1.3.2 Land productivity

This is output per unit land area. It's more relevant where land is a more constraining resource relative to water. The indicators are presented in Figure 4.6.

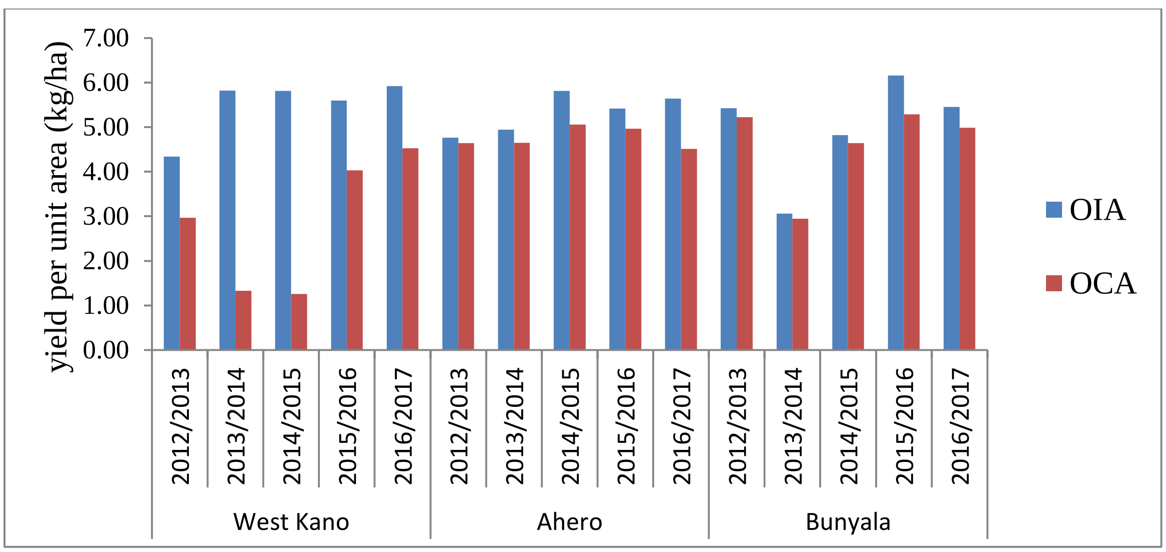


Figure 4.6: Land productivity indicators for the three schemes (OIA = output per irrigated area and OCA = output per command area)

Output per unit command area (OCA) varied between 1.26 tonnes/ha and 5.28 tonnes/ha. The OCA obtained was 4.51 tonnes/ha - 5.06 tonnes/ha in Ahero irrigation scheme, 2.95 tonnes/ha -5.28 tonnes/ha in Bunyala irrigation scheme and 1.26 tonnes/ha -4.53 tonnes/ha in West Kano irrigation scheme. On average, AIS has the highest OCA of 4.76 tonnes/ha while WKIS the least average OCA of 2.82 tonnes/ha. The sudden fall in OCA in West Kano between 2012 and 2014 is attributed to collapse of Revolving Fund committee. The committee was mandated with the responsibility of producing and marketing of the crop in West Kano Irrigation Scheme. Consequently, there was a decline in production activities that was associated with poor governance during that period. From 2015 each block in the scheme established a production management structure which induced competition amongst the blocks in terms of production activities. An increase in production was therefore realised in 2015/2016. Bunyala Irrigation Scheme experienced hail stone in 2013 which shattered mature rice crop in one of the phases (Muluwa phase 1). This contributed to the observed low harvest as shown by a sudden decline in output per unit area in 2013/2014.

Output per unit irrigated area (OIA) gives a reflection of crop intensity (Mchele, 2011). OIA varied from 3.06 tonnes/ha to 6.16 tonnes/ha (Figure 4.6). The values are comparable to global average rice yield of 3.8 tonnes/ha reported by Win Bastiaanssen et al. (2009). The OIA values obtained are comparable to 5.10 tonnes/ha obtained during rainy season and 5.13 tonnes/ha obtained during dry season in rice farming in Thailand (Bumbudsanpharoke & Prajamwong, 2015). High rice yields of 8.8 tonnes/ha has been reported in irrigated rice farms of Egypt. High yield of rice is obtained in Egypt can be associated with the high levels of sunshine (Bastiaanssen & Perry, 2009) .

4.1.4 Estimation of overall scheme performance

Correlation analysis of the 11 selected indicators is presented in Table 4.2. RWS and RIS are strongly positively correlated (r = 0.950). This means that the indicators measure similar elements. To avoid double counting, only one of them can be used in the computation of the composite indicator/performance score. RIS focuses on irrigation water supply alone and it is therefore preferred.

Principal component analysis

The principal components extracted with their factor loadings are presented in Table 4.3.

The first principal component (PC1) determines 34.9595% of the total variance in performance. The first principal component is mainly linked to indicators with absolute factor loading greater than 0.673 (WDIA, WFC, RIWS, OCA). The second principal component (PC2) accounts for 34.918% of the variance in performance. It is influenced by RIS, WDCA, OIS and OWS indicators (absolute loadings > 0.794). The third principal component (PC3) factor loading accounts for 19.93% and is linked with OIA and OCWD indicators. The results of weighted indicators are presented in Table 4.4. The performance score for each scheme in each year was obtained by summing up the weighted indicator values.

Table 4.2: Pearson correlation matrix

Variables	RWS	RIS	WSIA	WSCA	WFC	ARWIS	OIA	OCA	OIS	OCWD	OWS
RWS	1	0.950	0.711	0.458	-0.168	-0.425	-0.185	-0.305	-0.801	0.278	-0.855
RIS	0.950	1	0.648	0.455	-0.259	-0.457	-0.273	-0.292	-0.778	0.189	-0.845
ISIA	0.711	0.648	1	0.283	-0.645	-0.873	0.092	-0.570	-0.870	0.060	-0.701
ISCA	0.458	0.455	0.283	1	0.284	-0.029	-0.312	0.475	-0.432	-0.047	-0.471
WFC	-0.168	-0.259	-0.645	0.284	1	0.889	-0.180	0.696	0.469	0.125	0.278
ARIS	-0.425	-0.457	-0.873	-0.029	0.889	1	-0.125	0.662	0.723	0.109	0.514
OIA	-0.185	-0.273	0.092	-0.312	-0.180	-0.125	1	0.156	0.375	0.741	0.553
OCA	-0.305	-0.292	-0.570	0.475	0.696	0.662	0.156	1	0.566	0.301	0.480
OIS	-0.801	-0.778	-0.870	-0.432	0.469	0.723	0.375	0.566	1	0.217	0.936
OWCD	0.278	0.189	0.060	-0.047	0.125	0.109	0.741	0.301	0.217	1	0.245
OWS	-0.855	-0.845	-0.701	-0.471	0.278	0.514	0.553	0.480	0.936	0.245	1

Table 4.3: The extracted principal components.

Rotated Component Matrix (Factor Loading)				**Indicator Weights**
	Principal Component			
	1	2	3	
% of variance	34.959	34.918	19.930	
Relative irrigation supply	−0.222	−0.876	0.044	0.091
Water delivery per unit irrigated area	−0.673	−0.669	0.169	0.104
Water delivery per unit command area	0.447	−0.794	−0.047	0.093
Water fee collection performance	0.924	0.064	−0.068	0.096
Average revenue per unit irrigation water supply	0.862	0.387	−0.086	0.100
Output per unit irrigated area	−0.161	0.317	0.912	0.107
Output per unit command area	0.891	0.040	0.289	0.098
Output per unit irrigation supply	0.505	0.815	0.229	0.108
Output per crop water demand	0.149	−0.081	0.925	0.098
Output per unit water supply	0.318	0.848	0.353	0.105

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalisation.

Table 4.4. Weighted performance score for each category

Year	IS	RIS	WSIA	WSCA	WFC	ARIWS	OIA	OCA	OIS	OCWD	OWS	PS
	AIS	0.10	0.07	0.06	0.08	0.01	0.06	0.05	0.03	0.03	0.02	0.52
2012/2013	WKIS	0.14	0.10	0.06	0.04	0.00	0.05	0.03	0.02	0.03	0.02	0.51
	BIS	0.09	0.06	0.05	0.09	0.02	0.07	0.06	0.05	0.04	0.02	0.54
	AIS	0.04	0.05	0.05	0.08	0.01	0.06	0.05	0.05	0.03	0.03	0.45
2013/2014	WKIS	0.07	0.11	0.02	0.05	0.00	0.07	0.01	0.03	0.04	0.02	0.43
	BIS	0.10	0.08	0.07	0.09	0.01	0.04	0.03	0.02	0.02	0.01	0.48
	AIS	0.06	0.06	0.04	0.08	0.01	0.07	0.06	0.05	0.04	0.03	0.49
2014/2015	WKIS	0.11	0.10	0.02	0.05	0.01	0.07	0.01	0.03	0.04	0.02	0.46
	BIS	0.10	0.07	0.06	0.09	0.02	0.06	0.05	0.03	0.04	0.02	0.54
	AIS	0.04	0.05	0.04	0.08	0.02	0.07	0.06	0.06	0.03	0.03	0.47
2015/2016	WKIS	0.09	0.10	0.07	0.05	0.01	0.07	0.04	0.03	0.04	0.02	0.51
	BIS	0.11	0.08	0.06	0.09	0.01	0.07	0.06	0.04	0.05	0.02	0.60
2016/2017	AIS	0.04	0.05	0.04	0.09	0.02	0.07	0.05	0.06	0.03	0.03	0.47

WKIS	0.08	0.11	0.08	0.05	0.01	0.07	0.05	0.03	0.04	0.02	0.54
BIS	0.11	0.11	0.09	0.09	0.01	0.07	0.06	0.02	0.04	0.02	0.62

IS—Irrigation scheme; AIS—Ahero irrigation scheme; WKIS—WKano irrigation scheme; BIS—Bunyala irrigation scheme; RIS—relative irrigation supply; WSIA—irrigation supply per unit irrigated area; WSCA—irrigation supply per unit command area; WFC—water fee collection; ARIWS—annual revenue per unit irrigation supply; OIA—output per unit irrigated area; OCA—output per unit command area; OIS—output per unit irrigation supply; OCWD—output per unit water consumed; OWS—output per unit water supply.

Comparison of the trend in irrigation scheme performance of each scheme is presented in Figure 4.7. The overall performance score obtained was 45–52% in Ahero, 43–54% in West Kano and 48–62% in the Bunyala irrigation scheme. The average performance was 48%, 49% and 56% in the Ahero, West Kano and Bunyala irrigation schemes, respectively.

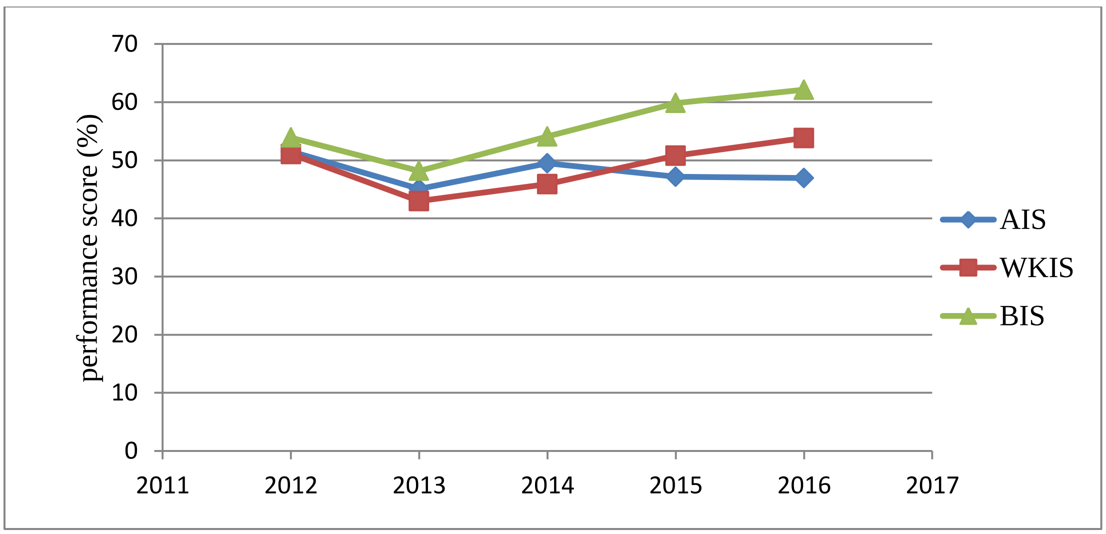


Figure 4.7. Comparison of performance score.

The performance in all of the schemes was moderate. The performance in the West Kano and Bunyala irrigation schemes increased with time. The performance in the Ahero irrigation scheme was constant during the study period. The West Kano irrigation scheme experienced a fall in performance in 2014 due to the collapse of the Revolving Fund kitty which led to reduction in the area cropped. The establishment of the production management structure, which created competition among the blocks in terms of production, increased performance from 2015. The sudden decline in performance in Bunyala in 2013 was due to hail stones that shattered mature rice crops in one of the phases (Muluwa phase 1).

A high performance of 83% (Phadnis & Kulshrestha, 2013) was obtained in the Samrat Ashok Sagar major irrigation project in India using a balanced score card method based on the Delphi technique. Agricultural productivity in India is highly enhanced by the government through artificial fixing of the minimum price of crops. The prices are therefore reasonably high, leading to the high economic value of crops. This is not the case in Kenya, where the price of rice produce is governed by market forces. According to Evans et al. (2018), the rice market price is highly driven by availability of cheap Asian imports, transport costs ,tariff regimes and distance to the market. Zema, Nicotra, Tamburino, & Zimbone (2015) used PCA to identify areas of weakness in seven Water Users' Association (WUA's) in Calabra, Southern Italy. The Ionio Catanzarese (ICZ) WUA's was ranked as the best performing with a quality index of 4470, while the Basso Ionio Reggino (BIRC) WUA's was found to be the least performing with a quality index of 1410. BIRC WUA's was found to have a weakness in both system operation performance and financial management. Lowering water prices was found to be the solution to improving performance of BRIC WUA's in Calabra, Southern Italy (Zema et al., 2015).

4.2 Factors influencing performance of irrigation schemes

Performance of irrigation schemes can be influenced by various factors. Some of the factors enhance performance while others constrain it. The results of farmer interviews are presented in Table 4.5 and Table 4.6.

Table 4.5: Irrigation scheme data.

	Ahero		West Kano		Bunyala	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Farm size (acres)	1.70	0.76	2.26	0.88	1.47	0.93
Rice yield (tonnes/acre)	2.33	0.32	2.44	0.33	2.24	0.37
Amount of seeds (kg/ acre)	22.3	2.60	24.80	2.49	20.58	2.26
Amount of fertilizers (kg/ acre)	325.5	31.91	202.00	28.50	155.83	45.37
Cost of seeds (KES/acre)	1,948.90	364.46	2,186.60	573.09	1,955.83	306.59
cost of fertilizers per acre (KES/acre)	12,600.5	957.28	7,272.00	855.00	7,736.67	2287.79
cost of fungicides /pesticides	900	184.16	1200.00	282.95	3015.00	890.45
irrigation service charge (KES/acre)	3,100	0.00	3,640	0.00	4,000	0.00
Cost of Labour (KES/acre)	35,040	2,608.79	33,834.00	2142.44	38,761.67	4,044.38

Total Cost of production (KES/acre)	53,588.9	3,693.37	48,132.6	33,38.52	55,625.00	6,797.46
Rice revenue (KES/acre)	81,200.00	12,241.16	84,000.00	11,513.47	85,120.5	13,645.92
Gross margin (KES/acre)	27,611.10	9,245.09	35,865.46	9,411.42	29,495.50	8,985.35

Source: filed survey data; SD- standard deviation

The average quantity of rice seed used per acre in Ahero, West Kano and Bunyala Irrigation Scheme was 22.3 kg, 24.80 kg and 20.58kg respectively. On average, farmers applied 325.5 kg, 202kg and 155.8kg of fertilizer (Sulphate of Ammonia and Urea) per acre in Ahero, West Kano and Bunyala Irrigation Schemes respectively. The total cost of production in the schemes was reported to be quite high. Farmers spend an average of KES.53,589; KES.48,133 and KES.55,625 per acre in rice farming at Ahero, West Kano and Bunyala Irrigation Schemes respectively. From Table 4.5 it can be seen that fertilizer is the most expensive input. Farmers spend an average of KES12, 600 in Ahero irrigation scheme; KES 7,272 in west Kano irrigation scheme and KES 7,737 in Bunyala irrigation scheme to purchase fertilizers.

The average total revenue generated per acre was KES. 81,200 in Ahero irrigation scheme; KES 84,000 in West Kano irrigation scheme and KES 85,121 in Bunyala irrigation Scheme. Farmers made an average profit of KES 27,611, 35,866 and 29,496in in Ahero, West Kano and Bunyala irrigation scheme respectively. Omondi (2014) reported that farmers in Ahero irrigation scheme made an average profit of Ksh. 39,199.59 from rice farming. The disparity can be associated to increase in cost of production of rice over time. In Kwara estate, Nigeria, farmers were reported to have made a profit of 77.33 US$ and 126.22US$ from rain fed rice farming and irrigated rice farming respectively (Babatunde, Salami, & Muhammed, 2017).This is quite high compared to average profit of 27.61 US$, 35.87US$ and 29.50 US$ made in Ahero, west Kano and Bunyala irrigation schemes respectively.

The descriptive statistical analysis is presented in Table 4.6. The results show that on average, 70%, 32% and 62% farmers in Ahero, West Kano and Bunyala Irrigation Schemes respectively had access to credit in the year 2017. About 66%, 38% and 60% of farmers in Ahero, West Kano and Bunyala Irrigation Schemes respectively had contact with extension officers. Farmers in AIS have the highest access to credit and extension and theoretically AIS is expected to have the highest performance. However, this is not the case because of AIS has inadequate supply of water evident from low RIS values majority of which are below 1. This shows that availability of water plays a great role in determining the performance of that an irrigation scheme can achieve**.** It is apparent that not all farmers have embraced use of improved seeds. About 76%, 72% and 82% of farmers interviewed in Ahero, West Kano and Bunyala Irrigation Schemes respectively reported to have used improved seeds in the year 2017.

Table 4.6: Descriptive statistics.

		Ahero		West Kano		Bunyala	
		Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
Types of seeds used	1- Traditional	12	24	14	28	8	16
	2- improved	38	76	36	72	41	82
access to extension services	1-No	17	34	31	62	19	38
	2- Yes	33	66	19	38	30	60
Access to credit facilities	1-No	15	30	34	68	18	36
	2- Yes	35	70	16	32	31	62

4.2.1 Factor analysis to determine best management practices (BMPs)

A total of fifteen variables shown in Table 4.7 were selected and weighted by farmers on a 5-likert scale based on farming operations in 2017. Factor analysis method was used to determine the effect of various factors on performance of the irrigation schemes.

Table 4.7: Average scores of Factors affecting performance of irrigation schemes.

		Ahero			West Kano			Bunyala		
No.	**Variable**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
1	Quality of seeds	3.62	0.78	0.22	2.98	0.74	0.25	3.22	0.88	0.28
2	Inputs availability	2.54	0.81	0.32	1.84	0.62	0.34	2.27	0.73	0.32
3	Availability of water	2.44	0.50	0.21	3.98	0.74	0.19	3.33	0.57	0.17
4	Use of adequate agricultural inputs	3.52	0.50	0.14	2.58	0.61	0.24	2.75	0.73	0.26
5	Availability of labour	3.12	0.77	0.25	4.02	0.77	0.19	3.98	0.79	0.20
6	Level of mechanisation	2.16	0.62	0.29	1.44	0.50	0.35	2.02	0.54	0.27
7	Water use knowledge	2.90	0.46	0.16	2.46	0.58	0.24	2.32	0.70	0.30
8	Access to credit	2.04	0.83	0.41	1.46	0.50	0.34	1.73	0.69	0.40
9	Efficiency of marketing produce	1.82	0.60	0.33	1.32	0.47	0.36	1.57	0.59	0.38
10	Access to extension services	3.10	0.61	0.20	1.88	0.63	0.33	2.57	0.72	0.28
11	On-time irrigation	2.78	0.46	0.17	2.48	0.61	0.25	2.53	0.72	0.29
12	policy implementation	3.36	0.48	0.14	2.34	0.48	0.20	4.05	0.65	0.16

13	water delivery and scheduling	3.06	0.55	0.18	2.68	0.55	0.21	3.67	0.57	0.16
14	efficiency of conflict resolution	3.04	0.75	0.25	2.86	0.64	0.22	4.12	0.67	0.16
15	Participation in water management	1.82	0.63	0.35	1.88	0.59	0.32	1.40	0.49	0.35

Note: 1=very low, 2=low, 3=moderate, 4= much, 5=very much, SD-standard deviation, CV-co-efficient of variation

The results of Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity (BTS) of the factors in are presented in Table 4.8. According to Kalantari (2008), if KMO value is greater than 0.5 and Bartlett's test is less 0.05 the data is suitable for factor analysis. A KMO value of 0.80 and a BTS test significant at 99% ($P < 0.0001$) was obtained. The data is therefore suitable for use in factor analysis.

Table 4.8: Kaiser-Meyer-Olkin (KMO) and Bartlett's test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.800
Bartlett's test of sphericity	Chi-square	1241.301
	df	105
	P-Value (Two-tailed)	<0.0001

The significant factors were extracted using principal component factor and then rotated using orthogonal Varimax rotation (Kaiser normalization) to achieve significant factors. Only factors with eigenvalues greater than one are extracted because they account for the most of the variance in original variables. The extracted values are presented in Table 4.9.

Table 4.9: Extracted factors.

Factor number	Name of factor	Total eigenvalue	Variance %	Cumulative variance %
1	Technological and knowledge factors	3.69	24.57	24.57
2	Institutional and legal factors	2.61	17.37	41.94
3	Economic factors	2.46	16.40	58.34
4	Crop production factors	1.84	12.26	70.60

The four extracted factors determine 70.60 % of total variation in performance of the irrigation schemes. In other terms, these four factors can validate 70.60% of the factors affecting performance of the irrigation schemes. The factor loading are presented in Table 4.10. Factor loading is the correlation between the observed score and the latent score. The factor loading is obtained from factor analysis of variables using SPSS version 16 software. All the factors have a factor loading greater than 0.5 and their influence in variation of performance is different. High factor loading indicates high influence of the factor on performance level while low factor loading contributes to low influence.

Table 4.10: Factor loading.

Principal factor	Variable	Factor loading
Technological and Knowledge factors	Quality of seeds	0.665
	level of mechanization	0.580
	use of adequate agricultural inputs	0.785
	access to extension services	0.815
	water use knowledge	0.848
	On-time irrigation	0.715
Institutional and legal factors	policy implementation	0.822
	water delivery and scheduling	0.829
	efficiency of conflict resolution	0.785
	Participation in water management	0.550
economic factors	Inputs availability	0.813
	access to credit	0.845
	Efficiency of marketing produce	0.847
Crop production factors	Availability of water	0.897
	Availability of labour	0.870

The factor analysis resulted to four factors with a significant effect in determining performance level of the irrigation schemes, specifically:

4.2.1.1 Technological and Knowledge factors

These factors account for 24.57 % (Table 4.9) of the total variance. This implies that improved technology and increased farmer's knowledge can cause an increase of 24.57% in productivity. The quality of seeds used, level of mechanization, adequate use of agricultural inputs, access to extension services and on-time irrigation are crucial variables in this category. Use of improved seeds is limited in the schemes because of financial inability of farmers to acquire the improved seeds. Some of the farmers opt to use local seeds which are cheaper but have a low yield. Use of inadequate agro-inputs was reported by the farmers due to lack of financial capacity to purchase the required amount. In addition, farmers used their own knowledge gained from experience to estimate the amount of inputs. Farmers in West Kano and Bunyala irrigation schemes rely on extension services offered by the government and other private institutions which are not frequent.

Lack of water-use knowledge and mistimed irrigation contributes to wastage and inefficient water utilisation. Promoting efficient use of water by installing water metering devices along the system and supplying the required amount of water can greatly improve performance of the irrigation schemes. Cuamba (2016) reported that technological knowledge and knowledge factors had an influence of 16.69 % to agricultural productivity and water management in Lower Limpopo irrigation system, Mozambique. In Pakistan, 1% increase in fertilizer use and improved seeds were reported to increase agricultural productivity by 2.17% and 0.72% respectively (Rehman et al., 2017). This shows that use of right amount of fertilizer and improved seeds have a great potential in increasing productivity.

4.2.1.2 Institutional and legal factors

These factors determine 17.37% (Table 4.9) of the total variance. This suggests that by improving institutional and legal governance, the productivity of the irrigation schemes can be increased by 17.37%. The level of policy implementation, water delivery and scheduling, efficiency of conflict resolution and farmer participation in water management are the main variables in institutional and legal factors. The poor policy implementation and poor planning in water scheduling are the main constraints to productivity in the schemes. The poor policy implementation has a direct effect on the water fee collection rate further implicating financial self-sufficiency of the schemes. In lower Limpopo irrigation system, institutional and legal factors were found to have 7.41% influence on productivity (Cuamba, 2016).

4.2.1.3 Economic factors

These factors explain 16.4% (Table 4.9) of the total variance in performance of irrigation schemes. This means that making inputs easily available, removing barriers to access credit and improving efficiency of marketing the produce has a potential of improving performance by 16.4%. Inefficient marketing and inadequate access to agricultural credit were the main issues raised by the farmers. During field data collection, farmers reported that selling of produce was done individually. This has made them vulnerable to exploitation by local middle men from Uganda. The farmers reported that market chain of selling paddy rice to the government millers is not attractive to farmers because of postdated method of payment. The payment takes long to be effected. In addition, the government millers buy at lower prices compared to businessmen. Poor access to credit facilities is a main challenge limiting production in the irrigation scheme. According to Rehman et al. (2017), improving access to credit facilities by 1% can cause 0.35 % increase in agricultural productivity. Economic factors were found to have 17% effect on optimal management of agricultural productivity (Samian et al., 2015). Access to loans, government investment and use of modern irrigation systems economic factors were identified as the main economic factors limiting optimal water management in Japan (Samian et al., 2015). These factors and their level of influence on productivity are similar to the ones identified here.

Farmer interviews revealed that revolving fund kitty in West Kano irrigation schemes had been depleted due to mismanagement in 2012/2013. This has significantly reduced the access to credit by farmers. This is supported by results of interviews tabulated in Table 4.7. Farmers in West Kano irrigation scheme reported to have a low access to credit attaching a value of 1.46. The farmers in this scheme can only access credit from family and friends or commercial institutions such as banks. However, acquiring credit from commercial institutions is expensive because of high interest rates charged. Farmers in Ahero irrigation schemes reported to have an easier access to credit from the revolving fund kitty managed by farmers' co-operative. Farmers in Bunyala irrigation scheme reported that they rely on commercial institution for credit facilities. The small organised registered farmer groups in this scheme make access to credit from these institutions easier. The limited availability of agro-inputs during peak time especially in Bunyala irrigation scheme was pointed as one of the main challenges limiting productivity. Farmers in Bunyala irrigation scheme reported that they have to travel 23kms away to Siaya town to buy pesticides and fertilizers. Cuamba (2016) reported inefficient marketing and inadequate agricultural credit as the main economic factors limiting optimal productivity and water management in Lower Limpopo Irrigation System, Southern Mozambique. According to Ngenoh et al. (2015) the size of land , amount of donor funding and operation and maintenance charges have a 1%, 10% and 10% effect respectively on economic performance of public irrigation schemes in Kenya.

4.2.1.4 Crop production factors

These factors determine 12.26 % (Table 4.9) of the total variance in performance of the irrigation schemes. Availability of water and labour are the main factors limiting productivity under this category. Increasing availability of water combined with labour have a potential of increasing productivity by 12.26%. Rice farming is both a labour and water intensive enterprise. Provision of adequate labour and water is needed to achieve high productivity. Rice farming in these schemes is quite manual and machines are only used during rotavation as evident from low level of mechanisation presented in Table 4.7. Therefore, availability of labour during the entire growing period is key determinant in the crop productivity that can be achieved. The schemes rely on family labour which is majorly composed of school going children. Opening of school causes deficit in available labour which constrains crop production. Mechanization of farming process could help in solving the problem of labour availability. Availability of water in all the schemes is limited by power outages which are rampant in the region. Mugera (2015) identified demographic characteristics, labour availability, culture, availability of agricultural support services and cost of production as the main factors influencing crop production in Hola Irrigation Scheme.

4.3 Best Management practices

BMPs were evaluated based on five criterion namely; applicability to public irrigation schemes, acceptance by farmers, ease of implementation, ability to increase water saving and cost-effectiveness. The aggregated weights of preferred criterion are presented in Figure 4.8.

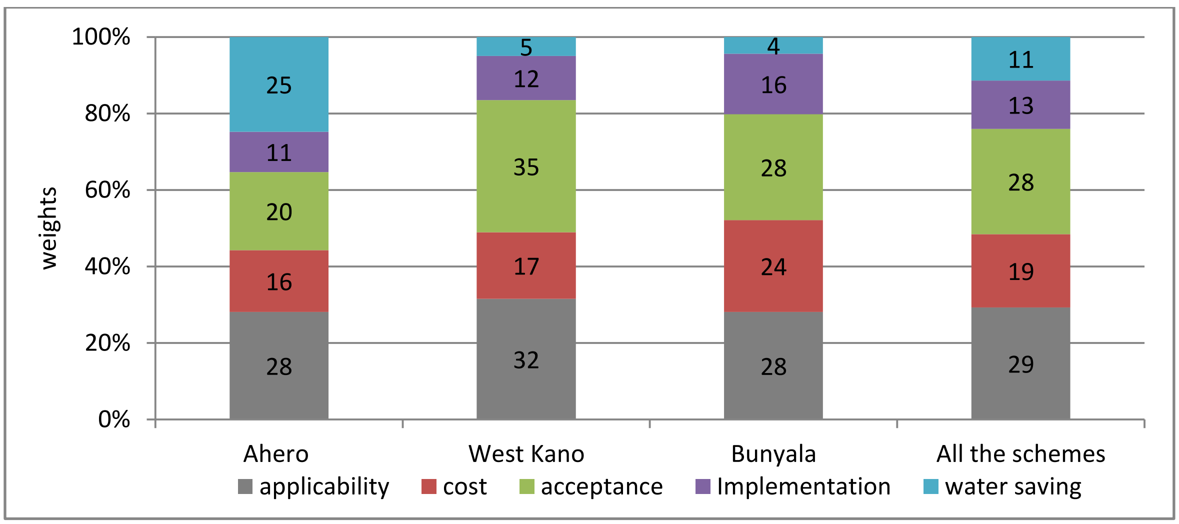


Figure 4.8: Attribute weights per irrigation scheme

The higher the weight, the more important it is to consider the attribute in selecting BMPs. The results show that the level of preference differs from one irrigation scheme to the other. It can be observed that, the selection of a BMP is mostly determined by its applicability in a public Irrigation Scheme. BMPs ability to promote water saving is the second most important consideration in Ahero irrigation scheme while it is the least considered in West Kano and Bunyala irrigation schemes respectively. In Bunyala irrigation scheme, the importance of cost of implementing BMPs is higher at 24% compared to 17% at West Kano and 16% in Ahero Irrigation Scheme. Acquiring inputs is most expensive in Bunyala Irrigation Schemes. Therefore, farmers feel financially constrained and are not willing to bear any extra cost that might arise from implementing BMPs. The level of importance of the five attributes to selection of BMPs is described as follows:

Applicability- This is the most important criterion with an average weight of 29%. The effectiveness of a BMP is highly dependent on its suitability to the irrigation system. For example installation of drip irrigation system is not applicable in rice farming.

Acceptability- this criterion was assigned an average weight of 28%. The BMPs being considered should be acceptable by the farmers. Scheme management should not select BMPs and impose it to farmers. In participatory management practiced in all public irrigation schemes in Kenya, farmers have been incorporated in decision making. Choice and implementation of BMPs without involving farmers might fail. The acceptance of BMPs by farmers and other stakeholders should be considered. This is why increasing water fee charged might not be viable because of the resistance from the farmers.

Cost –effectiveness- This is the third most important criterion with a weight of 15%. The cost of implementing BMPs should be considered. Some BMPs may be too costly to implement hence might not work for some irrigation systems.

Ease of implementation- This takes into consideration the technical know-how of the implementers of BMPs. Choice of BMPs should consider the technical knowledge of the targeted farmers. Prior training might be needed in some cases. This criterion was assigned a weight of 13%.

Water saving- Irrigation is a consumptive water user and BMPs that enhance water saving are highly recommended. This criterion was assigned the least weight of 11%. Farmers are charged water fee based on cropped area not amount of water used. This is why in their opinion water saving was not considered a weighty matter. However, to the irrigation scheme management, water saving is an important aspect in attaining sustainable development in agriculture.

4.3.1 Ranking of BMPs

The BMPs with the highest score is the most preferred option while the one assigned the least score is the least preferred option. Adopting these BMPs can increase crop productivity, improve efficiency of water use and reduce negative effects of the irrigation to the environment. Incorporating farmers in ranking of BMPs show that farmers know what is ailing irrigated farming and the possible solution needed. The results of decision matrix showing the ranking of BMPs based on weights assigned by farmers is presented in Figure 4.9. The most preferred BMP was capacity building assigned a score of 0.26 while the least preferred BMP was volumetric water measurement with a score of 0.01.The BMPs were ranked starting from the most preferred to the least preferred as follows;

4.3.1.1 Capacity building of farmers

This BMP entails agronomical training of farmers on rice farming and building up financial capacity of farmers to make them self-sufficient. Farmers in all the irrigation schemes reported to have a limited access to credit and extension services. Notably, farmers have little or no knowledge on fertilizer and pesticide application rate. They depend on their own knowledge to estimate the amount of inputs required. This is one of the reason contributing to low production. Marketing of rice produce in all the irrigation schemes is not centrally done.

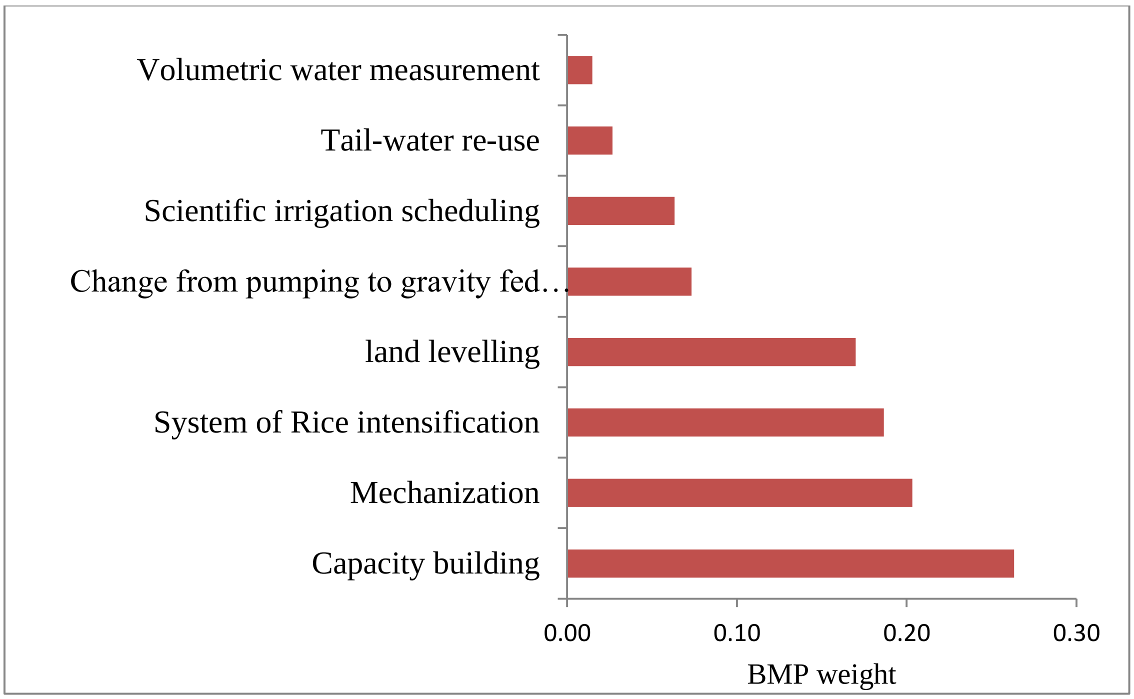


Figure 4.9: Ranking of BMPs in Western Kenya rice irrigation schemes

Farmers sell their produce individually. This makes them vulnerable to exploitation by middle men. This situation can be reversed by building financial capacity of farmers' co-operative through partnership with government or financial institution. This will enable them take up the role of marketing .Training of farmers on right farming practices and modern farming technology will increase production and water use efficiency. This BMP is highly applicable to government-owned irrigation schemes. It also enhances water saving although the amount of water saving cannot be quantified.

The cost of implementation will vary from one irrigation scheme to the other depending on scope of training. The financial implication of injecting funds into the farming co-operatives will be born through interest rates which depend on current market interest rates. The implantation of this BMP is a long term strategy and the timelines will depend on management of individual irrigation scheme and financial capability. In a similar study, Cuamba (2016) proposed training of farmers on use of improved crop production technologies and business management to reduce overreliance of farmers on government donation and achieve self-sufficiency. These findings therefore agree with results of this study.

4.3.1.2 Mechanization of farming operations

This strategy entails use of machineries in various farming activities such as rotavation, nursery preparation, transplanting of seedlings, weeding, agro-input application, harvesting, threshing and transport to drying floor. Mechanization of rice farming can be achieved through use of rotavators, nursery seeding machines, seedling trans planters, mechanical weeders, hand sprayers for application of pesticides, urea super granule (USG) fertilizer applicator, harvesters, threshers and use of tractors for transport. Currently, only rotavation is fully mechanized in all the irrigation schemes. Ahero irrigation scheme farmers' co-operative owns tractors, ploughs, trailers and threshers which are hired to farmers at a subsidised fee of KES 2,800 per acre. West Kano farmers' co-operative society in west Kano irrigation scheme -operative owns and manages 12 tractors donated through Japan international cooperation agency (JICA) and county government of Kisumu. Farmers hire these tractors at a subsidised fee of KES 2,600 per acre for rotavation and ploughing. Magombe Farmers' Cooperative Society in Bunyala irrigation scheme manages 9 tractors donated by a joint venture between JICA and Government of Kenya in 2016. The tractors are hired at a subsidised fee of KES 3,200 per acre for rotavation and ploughing.

Mechanization of rice farming is time saving, reduces labour use and cost, reduces production cost, increases cropping intensity and increases the profit margin of rice farming (Sayed, Hasan, & Ali, 2015). Use of machineries in rice farming was reported to increase yield by 1.7 tonnes per acre in Bangladesh (Sayed et al., 2015). According to Hoque, Wohab, Hossain, Saha, & Hassan (2013), use of USG applicator can save 80% of application time and save 78% labour cost compared to manual application of urea super granule (USG). Farms that applied USG had 19% more yields than those that used granular urea (Hoque et al., 2013). The cost of fully mechanizing farming activities is high and varies from one area to the other. From the market survey, average cost of purchasing mechanical weeder lies between KES.90, 000 and 300,000; rice trans planter KES10,000 and 1,000,000; combined harvester KES.1,000,000 and1,500,000 and hand sprayer between KES.5,000 and 30,000. If transplanting, weeding, agro-inputs application, harvesting and threshing activities were to be mechanized, the cost of purchasing the respective machinery ranges from KES. 1,105,000.00 to 3,330,000.00 per farmer. This is costly and may take long time before full mechanisation is embraced.

4.3.1.3 System of Rice intensification

It is a method of increasing rice yield that was developed in Madagascer in 1983 by French Jesuit Father Henri de Laulanié (De Laulanié, 2011). It involves changes in management of plants, water, soil and nutrients to increase rice yields and reduce water used. It is a low water user, labour- intensive method. Younger seedlings at two leaf stage usually 7-12 days are transplanted singly into a wide square grid. Minimum amount of water is applied approximately 1-2cm. In this farming system, the soils are kept moist as opposed to continuous flooding method that keeps the soil saturated. This water condition promotes growth of weeds and special tools are used to control weeds. SRI is therefore a water saving rice farming technology. In SRI, adopting of proper rice management practices has a potential of increasing rice yields.

SRI has been introduced in public rice irrigation schemes in Kenya although it has not been fully embraced. Therefore, this BMP is both applicable and acceptable in public rice irrigation schemes. The extra cost will be incurred in labour because SRI is more labour demanding compared to conventional method of rice farming. Typically weeding is done in 10, 20, 30 and 40 days after transplanting in SRI while in conventional method it is done at 15 and 30 days after transplanting. Another additional cost associated with SRI is purchase of a rotary hoe or mechanical- weeder. A rotary hoe costs as low as KES. 7,500. The cost of implementing this BMP is an extra KES.7,500 in purchasing a rotary hoe and spending twice on labour compared to the conventional method. However the benefits reaped from water saving and increasing yield are higher than the cost to be incurred (Ndiiri, Mati, Home, Odongo & Uphoff, 2013).

Nyang'Au, Mati, Kulecho, Wanjogu, & Kiplagat (2014), reported that planting rice four days before the actual planting date which is a SRI management practice increased yield by 0.669 tonnes/ha and 0.7656 tonnes/ha in West Kano and Ahero irrigation schemes respectively.

Chapagain, Riseman, & Yamaji (2011), reported higher yields of rice of 6.7t/hm obtained using SRI compared to 6.3t/hm of rice obtained using conventional rice farming in Japan. This was found to be statistically insignificant but the net returns from SRI farming were 1.5 times higher than in conventional method. In India, irrigated rice fields under SRI produced 49 % more grain yield and consumed 14% less water compared to farms under conventional transplanting system irrigation farming (Thakur, Mohanty, Patil, & Kumar, 2013). In addition, water productivity of 3.3 kg ha-mm^{-1} in SRI irrigated farms was 73% higher than 5.7 kg ha-mm^{-1}obtained in conventional irrigation farms. Higher return on investment per hectare ranging from US$309 to US$370 was achieved in SRI compared to US$192 -US$ 303 in conventional rice farming in India (Barah, 2010). SRI farming was reported to increase rice yields by 26%, save up to 40% and 92% water and seeds respectively (Barah, 2010). If proper management practices are not adhered to in SRI farming, the benefits might not be realised.

4.3.1.4 Land levelling

It is mechanised grading of farmlands based on topographic survey to achieve a level ground. Land levelling is undertaken to increase uniformity of water application. Farmers in all irrigation schemes reported that mechanical levelling of lands has not been done after project implementation. The fields are uneven contributing to inefficient use of water. Implementation of this BMP will involve designing levelling work based on field levels taken. The minimum slopes required for water application should be considered in levelling work. It is difficult to quantify the amount of water saving to be achieved from land levelling. Land levelling increases water application efficiency and uniformity of water application (TSSWCB, 2005). The cost of touch up land levelling prior to planting is $25 per acre.

4.3.1.5 Change from pumping to gravity fed system

This will entail relocating the water intake upstream and redesigning the water conveyance system to allow for water flow by gravity instead of pumping. This is applicable to all the irrigation schemes. The plans for changing from pump to gravity fed system in Western Kenya rice irrigation schemes are underway. The new water abstraction points have been identified. The irrigation scheme managers are still waiting for budgetary allocation to implement these proposals. The cost of constructing a gravity fed system will vary from one irrigation scheme to the other. It will include cost of construction of head works, headwork's canals, main canal and acquisition of land for main canal if needed. The cost of construction of gravity fed system is high. However, benefits from long term savings from electricity charges ranging from KES. 500,000 to KES.800, 000 per month per scheme are higher than the cost of construction. This further enhances sustainability mechanism of the three Irrigation Schemes.

Bunyala irrigation scheme will benefit from implementation of Flood Mitigation Structures (IFMS) on Lower Nzoia River and Lower Nzoia Irrigation Project (LNIP)

Phase 1. This project will enable Bunyala irrigation scheme and other areas to be commanded by gravity. Water will be abstracted from river Nzoia, upstream of the current intake works. Mobilising of equipment to start construction works has already started. This project is being financed by World Bank in collaboration with government of Kenya at a cost KES. 5,759.7 million.

4.3.1.6 Scientific irrigation scheduling

Irrigation scheduling is used to determine frequency of irrigation and amount of water to be applied to a crop. It is applicable where supply of water is adequate. Scientific irrigation scheduling entails estimating future water requirement over relatively short periods based crop water needs. The current irrigation scheduling in all the irrigation schemes is not based on crop water requirement but convenience. Adopting scientific irrigation scheduling will reduce water wastage. Intermittent power outages experienced in this region disrupt the availability of water. This disrupts irrigation schedule. Adherence to irrigation scheduling in these irrigation schemes will only be possible if abstraction of water will change from pump to gravity fed system.

The amount of water saving from irrigation scheduling is not quantifiable. It is influenced by variation in climate, quality of irrigation water, crop water requirement and cropping practices (TSSWCB, 2005). Farmers assigned a low weight of 0.06 to irrigation scheduling because they seem satisfied with the irrigation scheduling. Inco-operating crop water requirement in irrigation scheduling will enhance water saving. In lower Limpopo irrigation system, water scheduling was the most preferred BMP, scoring 0.21. Farmers wanted water schedules to be adhered to avoid delays in water delivery (Gomo et al., 2014). Irrigation scheduling was the highest ranked agricultural BMPs in central and the Southern coastal semi-arid regions of South Texas (Hernandez & Uddameri, 2010). It was ranked as the most important BMP because significant population and economic growth in this basin makes water deliveries to be highly regulated. Furthermore the quality of ground water is poor and cannot be used. Comparatively, abstraction of irrigation water in Lake Victoria, river Nyando and river Nzoia is not highly regulated and there is no limitation to the amount of irrigation water abstracted for use. This is why irrigation scheduling was assigned a low value of 0.06 compared to a score of 0.8-0.85 in south Texas. In Ahero and west Kano irrigation scheme, no cost will be incurred in implementing this BMP because there is an existing weather measurement station. Bunyala irrigation scheme has no weather measurement station and one should be constructed to implement scientific irrigation scheduling.

4.3.1.7 Tail water reuse

This BMP is typically used in furrow and basin irrigation method where a significant amount of water is released at the end of irrigated farm. It consists of: (i) channels or pipelines for collecting tail water (ii) storage reservoir; (ii) pumping system (iv) channels or pipelines for delivering tail water back to the farms. Volume of water captured and re-used can be measured using both direct and indirect volumetric water measurement. In typical furrow and basin irrigation system, the amount of tail water captured for re-use accounts for 15 % of the total volume of water applied. Tail water re-use was the second least preferred BMP with an average score of 0.03. Farmers had abundant supply of water that’s why they don’t see the need to reuse tail water. Tail water has been used successfully in Ahero Irrigation Scheme to irrigate Nyatini block. That's why farmers in Ahero assigned a higher weight of 0.04 to tail water re-use compared to 0.02 in West Kano and 0.03 in Bunyala irrigation scheme. The cost of constructing tail water system varies from site to site. The cost of setting up tail water re-use is therefore site specific and can only be estimated from preliminary designs.

4.3.1.8 Volumetric water measurement

Volumetric water measurement provides information to water users which can be used in crop water management and for assessing performance of an irrigation scheme. Volumetric water measurement can be done directly or indirectly measured using information on energy consumption. Manual flow measurement is the most accurate method of determining the amount of water used. In all the three irrigation schemes, volumetric water measurement was achieved using secondary information on energy use. There is no flow measurement at block levels or a master meter for taking readings of the water pumped from the river. The amount of water delivered to water users could not be determined. The most appropriate flow measurement in open channels is installation of flow meters such as flume, weir, or metering station.

This was the least preferred BMP because farmers feel that if volumetric measurement of water is introduced at block level; all water will be used by farmers near the main canal through unofficial channels. Furthermore, water is conveyed through open channels and can be used by anyone. The exact amount of water delivered is difficult to account for with such a system. Also, Gomo et al. (2014) found volumetric water measurement to be the least preferred BMPs by farmers in lower Limpopo irrigation system in Mozambique.

This BMP has an indirect contribution to water saving when combined with other BMPs. To the scheme management volumetric water measurement is useful in regulating water usage and hence can be used to improve efficiency of water use. Cost of installing flow meters will vary depending on the type of metering device used.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study evaluated performance of public rice irrigation schemes using comparative benchmarking indicators and principal component analysis. The main factors limiting productivity in the selected irrigation schemes were identified and strategies of improving performance formulated. The main findings of the study are:

1. The overall performance of public rice irrigation schemes in western Kenya is moderate. The Bunyala irrigation scheme is the best performing scheme while Ahero irrigation scheme is the least performing in the region. Western Kenya public rice irrigation scheme suffer from low water use efficiency.
2. The performance of public rice irrigation schemes in western Kenya is mainly influenced by: technological and knowledge factors, economic factors, legal and institutional factors, crop production factors.
3. The best management practices needed to improve performance of public rice irrigation schemes in Western Kenya are: Capacity building of farmers; Mechanization of farming operations; System of rice intensification farming method; Land levelling; Change from pumping to of gravity fed system; Scientific irrigation scheduling; Tail water reuse; Volumetric water measurement

5.2 Recommendations

1. The study recommends change in charging water fee based on amount of water used instead of area farmed in order to increase water use efficiency.

2. The study recommends capacity building of farmers, mechanization of farming operations and adoption of system of rice intensification enhance performance of irrigation schemes
3. Further long term research should be carried out in the irrigation schemes to cover environmental, social and institutional aspects of performance

REFERENCES

Aldababseh, A., Temimi, M., Maghelal, P., Branch, O., & Wulfmeyer, V. (2018). Multi-criteria evaluation of irrigated agriculture suitability to achieve food security in an arid environment. *Sustainability (Switzerland)*, *10*(3). doi.org/10.3390/su10030803

Amos, & Ouma, O. (2014). Exploring for Improving Rice Production to Reduce Hunger Poverity in Kenya. *World Environment*, *4*(4), 172–179. doi.org/10.5923/j.env.20140404.03

Ayana, M., & Awulachew, S. B. (2007). Comparison of irrigation performance based on management and cropping types. *International Water Management Institute*, 14–26.

Babatunde, R. O., Salami, M. F., & Muhammed, B. A. (2017). Determinants of Yield Gap in Rainfed and Irrigated Rice Production Systems – Evidence From Household Survey in Kwara State , Nigeria. *Journal of Agribusiness and Rural Development*, *1*(43), 25–33.

Balderama, O. F., Bareng, J. L. R., & Alejo, L. A. (2014). Benchmarking for Performance Assessment of Irrigation Schemes : The Case of National Irrigation Systems and Small Water Impounding Projects in Cagayan River Basin, I*n Proceedings of the International Conference of Agricultural Engineering, Zurich, Switzerland, 6—10 July 2014*.

Barah, B. C. (2010). System Of Rice Intensification (SRI) Economic and Ecological Benefits of Improved production practice for Food Security and Resource Conservation. *Innovation and Sustainable Development in Agriculture and Food*, 1–9.

Bastiaanssen, W., & Perry, C. (2009). *Agricultural Water Use and Water Productivity in the Large Scale Irrigation (LSI) Schemes of the Nile Basin; Nile Information System: Entebbe, Uganda*

Bastiaanssen, W., & Steduto, P. (2017). The water productivity score (WPS) at global and regional level: Methodology and first results from remote sensing measurements of wheat, rice and maize. *Science of The Total Environment*, *575*, 595–611. doi.org/10.1016/j.scitotenv.2016.09.032

Beddow, J. M., Pardey, P. G., Alston, J. M., & Europe, E. (2009). *The Shifting Global Patterns of Agricultural Productivity* (Vol. 24).

Borgia, C., García-Bolaños, M., Li, T., Gómez-Macpherson, H., Comas, J., Connor, D., & Mateos, L. (2013). Benchmarking for performance assessment of small and large irrigation schemes along the Senegal Valley in Mauritania. *Agricultural Water Management*, *121*, 19–26. doi.org/10.1016/j.agwat.2013.01.002

Bos, M. G., Burton, M. A., & Molden, D. J. (2005). *Irrigation and Drainage Performance Assessment Practical Guidelines; CABI Publishing: Wallingford, UK, 2005.*

Brouwer, C., Prins, K., & Heibloem, M. (1989). Irrigation Water Management: Irrigation Scheduling. *Training Manual, 4*, (66).

Bumbudsanpharoke, W., & Prajamwong, S. (2015). Performance assessment for irrigation water management: Case study of the great chao phraya irrigation scheme. *Irrigation and Drainage*, *64*(2), 205–214. doi.org/10.1002/ird.1889

Cai, X., Molden, D., & Sharma, B. (2009). Water productivity assessment in ten river basins: the status and implications.

Cakmak, B., Polat, E. H., Kendirli, B., & Gokalp, Z. (2009). Evaluation of Irrigation Performance of Asartepe Irrigation association: A case study from Turkey, *22*(1), 1–8.

Chapagain, T., Riseman, A., & Yamaji, E. (2011). Assessment of System of Rice Intensification (SRI) and Conventional Practices under Organic and Inorganic Management in Japan. *Rice Science*, *18*(4), 311–320. doi.org/10.1016/S1672-6308(12)60010-9

Burt, C. (2001). Rapid Appraisal Process (RAP) and Benchmarking Explanation and Tools. *Bioresources Agricultural Engineering*, *32* (5).

Cin, S., & Çakmak, B. (2017). Assessment of Irrigation Performance in Başören Irrigation Cooperative Area of Beypazarı, Ankara. *Journal of Agricultural Faculty of GaziosmanpasaUniversity*, *34*(2), 10–19. doi.org/10.13002/jafag4221

Córcoles, J. I., de Juan, J. A., Ortega, J. F., Tarjuelo, J. M., & Moreno, M. A. (2012). Evaluation of Irrigation Systems by Using Benchmarking Techniques. *Journal of Irrigation and Drainage Engineering*, *138*(3), 225–234. doi.org/10.1061/(ASCE)IR.1943-4774.0000386

Cornish, G. A. (2005). *Performance Benchmarking in the Irrigation and Drainage Sector*.

Cuamba, E. M. (2016). Performance Assessment for Sustainable Irrigation Water Management A case study of Lower Limpopo Irrigation System , Southern Mozambique.University of Dar es salaam.

De Alwis, S. M. D. L. K., & Wijesekara, N. T. S. (2011). Comparison of Performance Assessment Indicators for Evaluation of Irrigation Scheme Performances in Sri Lanka. *Engineer,* 44, 39–50.

De Laulanié, H. (2011). Intensive rice farming in Madagascar. *Tropicultura*, *29*, 183–187.

Dlamini, M. A. (2013). *T*he Relationship Between Production Performance and Governance In Smallholder Irrigation Schemes In Swaziland. University of Zibambwe.

ICID. (1996). *Guidelines for Water Management and Irrigation*.

Elshaikh, A. E., Jiao, X., & Yang, S. (2018). Performance evaluation of irrigation projects: Theories, methods, and techniques. *Agricultural Water Management*, *203*(January), 87–96. doi.org/10.1016/j.agwat.2018.02.034

Evans, A. A., Florence, N. O., & Eucabeth, B. O. M. (2018). Production and marketing of rice in Kenya: Challenges and opportunities. *Journal of Development and Agricultural Economics, 10*(3), 64–70. doi.org/10.5897/JDAE2017.0881

Ghosh, S., Singh, R., & Kundu, D. K. (2005). Evaluation of irrigation-service utility from the perspective of farmers . *Water Resources Management*, *19*, 467–482.

Gitonga, K. (2017). *Grain and Feed Annual 2017 Kenya Corn, Wheat and Rice Report;* USDA Foreign Agricultural Service: Washington, DC, USA.

Gómez-Limón, J., & Riesgo, L. (2008). Alternative approaches on constructing a composite indicator to measure agricultural sustainability. *107th EAAE Seminar "Modelling of Agricultural and Rural Development Policies, Sevilla, Spain, January*

29th -February 1st, 2008, 1–25. doi.org/10.4018/978-1-61520-881-4.ch011

Gomo, T., Senzanje, A., Mudhara, M., & Dhavu, K. (2014). Assessing the Performance of Smallholder Irrigation and Deriving Best Management Practices in South Africa. *Irrigation and Drainage*, *63*(4), 419–429. https://doi.org/10.1002/ird.1815

Government of Kenya. (2013). *National Water Master Plan 2030 in the republic of Kenya final report volume -v sectoral report (2/3)*,Nairobi, Kenya

Government of Kenya. (2015). *Agricultural Sector Development Strategy; 2010-2020*. *Government of Kenya Issue*, Nairobi, Kenya.

Government of Maharashtra. (2005). *Report on benchmarking of irrigation projects in Maharashtra*. *Water Resources*, Mumbai, India

Government of Mahrashtra. (2012). *Benchmarking of irrigation systems in Maharashtra state 2010-11*, Mumbai, India.

Hernandez, E. A., & Uddameri, V. (2010). Selecting Agricultural Best Management Practices for Water Conservation and Quality Improvements Using Atanassov's Intuitionistic Fuzzy Sets. *Water Resources Management*, *24*(15), 4589–4612. doi.org/10.1007/s11269-010-9681-1

Hoque, M. A., Wohab, M. A., Hossain, M. A., Saha, K. K., & Hassan, M. S. (2013). Improvement and evaluation of Bari USG applicator. *Agricultural Engineering International: CIGR Journal*, *15*(2), 87–94.

Indian National Committee on Irrigation and Drainage. (2002). *Guide lines for Benchmarking of Irrigation Systems in India*.

Iqbal, S., & Mastorakis, N. (2005). Performance evaluation of irrigation system using RS and GIS, 153–156.

Jamilah, M., Zakaria, A., Md. Shakaff, A. Y., Idayu, N., Hamid, H., Subari, N., & Mohamad, J. (2012). Principal Component Analysis – A Realization of Classification Success in Multi Sensor Data Fusion. In *Principal Component Analysis - Engineering Applications* (pp. 1–25). InTech. doi.org/10.5772/37459

Kang'au, S. N., Home, P. G., & Gathenya, J. M. (2011). Evaluation of the performance of smallholder pumped irrigation systems, in arid and semi-arid areas of Kenya. *Agricultural Engineering International: CIGR Journal*, *13*(4), 1–22.

Karina, F. Z., & Mwaniki, A. W. (2011). *Impact of the Economic Stimulus Programme and Long-term Prospects for Food Security in an Era of Climate Change*, Nairobi, Kenya.

Kenya National Bureau of Statistics. (2016). *Economic Survey of Kenya.*

Kenya National Bureau of Statistics. (2018). *Economic Survey 2018*. *Annual Economic Survey*.

Kipkorir, E. C., Webi, P. O. W., Cheserek, G. J., Daudi, F., Kiptoo, K. K. G., Mugalavai, E. M., Songok, C. K. (2018). Rice productivity , Water and Sanitation Baseline Survey Report Western Kenya Rice Irrigation Schemes

Kiseto, H. R. (2014). *Participation of Farmers in Irrigation Schemes in Tanzania: A Case Of Kwamadebe Irrigation Scheme In Kondoa District*. Sokoine University of Agriculture,Tanzania

Knox, J. W., Daccache, A., Hess, T. M., Else, M., Kay, M., Burton, M., & Malano, H. (2013). *Benchmarking agricultural water use and productivity in key commodity* *crops*

Kumari, S., & Mujumdar, P. P. (2016). Fuzzy Set–Based System Performance Evaluation of of an Irrigation Reservoir System. *Journal of Irrigation and Drainage Engineering*, *143*(1965), 1–14.

uşçu, H. (2012). Benchmarking performance assessment of irrigation water management in a river basin: Case study of the Susurluk river basin, Turkey. *African Journal of Business Management*, *6*(8), 2848–2859. https://doi.org/10.5897/AJBM11.1030

Kuscu, H., Bölüktepe, F. E., & Demir, A. O. (2015). Evaluation performance of irrigation water management: A case study of Karacabey irrigation scheme in Turkey. *International Journal of Agricultural Sciences*, *5*(5), 824–831.

Maillu, J. K. (2016). *Evaluation of Performance of an Irrigation Scheme: The case of Mwea Tebere Irrigation Scheme, Kenya*. University of Nairobi.

Malano, H., Burton, M., & Makin, I. (2001). *Guidelines for Benchmarking Performance in the Irrigation and Drainage Sector*. *FAO, Rome.* (1st ed.) 53. FAO, Rome.: International Programme for Technology and Research in Irrigation and Drainage (IPTRID) Knowledge Synthesis Report No. 5.

Malano, H., Hungspreug, S., Plantey, J., Bos, M. G., Vlotman, W. F., Molden, D., & Burton, M. (2004). *Benchmarking of Irrigation and Drainage Projects*. , New Delhi, India: International Commission on Irrigation and Drainage (ICID).

Mchele, A. R. (2011). Summary for Policymakers. In Intergovernmental Panel on Climate Change (Ed.), *Climate Change 2013 - The Physical Science Basis* (53) pp. 1–30).

Burt, C. (2001). Rapid Appraisal Process (RAP) and Benchmarking Explanation and Tools. *Irrigation Institutions Window The World Bank*, (October 2002), 5.

Ghosh, S., Singh, R., & Kundu, D. K. (2005). Evaluation of irrigation-service utility from the perspective of farmers . *Water Resources Management*, *19*, 467–482.

ICID. (1996). *Guidelines for Water Management and Irrigation*.

Kumari, S., & Mujumdar, P. P. (2016). Fuzzy Set–Based System Performance Evaluation of of an Irrigation Reservoir System. *Journal of Irrigation and Drainage Engineering*, *143*(1965), 1–14. doi.org/10.1061/(ASCE)IR.1943-4774.0001155.

Ministry of Agriculture. (2008). *National Rice Development Strategy (2008 – 2018)*.

Ministry of Water and Irrigation. (2017). Irrigation Sub-Sector MTP111 Zero draft(2), Nairobi, Kenya

Miruri, R. K., & Wanjohi, J. M. (2017). Performance of Irrigation Projects: Case of Nthawa Irrigation Project of Mbeere North Sub- County, Embu County, Kenya. *International Academic Journal of Information Sciences and Project Management*, *2*(1), 447–463.

Molden, D., Sakthivadivel, R., Perry, C. J., De Fraiture, C., & Kloezen, W. H. (1998). *Indicators for comparing performance of irrigated agricultural systems*. Colombo, Sri Lanka *:IWMI*

Montazar, a., & Snyder, R. L. (2012). A multi-attribute preference model for optimal irrigated crop planning under water scarcity conditions. *Spanish Journal of Agricultural Research*, *10*(3), 826. doi.org/10.5424/sjar/2012103-484-11

Montazar, A., Gheidari, O. N., & Snyder, R. L. (2013). A fuzzy analytical hierarchy methodology for the performance assessment of irrigation projects. *Agricultural Water Management*, *121*, 113–123. doi.org/10.1016/j.agwat.2013.01.011

Mugera, W. (2015). *Factors Influencing Crop Production in Irrigation Schemes in the Arid And Semi Arid Lands of Kenya : The Case Of Hola Irrigation Scheme , Tana River County, Kenya*. University of Nairobi, Kenya.

Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences*, *1324*(1), 7–14. doi.org/10.1111/nyas.12540

Ngenoh, E., Kirui, L. K., Mutai, B. K., Maina, M. C., Koech, W., & Victoria, L. (2015). Economic Determinants of the Performance of Public Irrigation Schemes in Kenya. *Journal of Development and Agricultural Economics*, *7*(10), 344–352. doi.org/10.5897/JDAE2015.0676

Ndiiri, J. A., Mati, B. M., Home, P. G., Odongo, B., & Uphoff, N. (2013). Adoption, constraints and economic returns of paddy rice under the system of rice intensification in Mwea, Kenya. *Agricultural water management*, *129*, 44-55.

Ngigi, S. N. (2002). Review of Irrigation Development in Kenya. In H. G. Blank, C. M. Mutero, & H. Murray-Rust (Eds.), *The changing face of irrigation in Kenya: Opportunities for anticipating change in eastern and southern Africa. xiv* pp. 35–54. Colombo, Sri Lanka: International Water Management Institute (IWMI). doi.org/http://dx.doi.org/10.3910/2010.006

Ntantos, P. N., & Karpouzos, D. K. (2010). Application of data envelopment analysis and performance indicators to irrigation systems in Thessaloniki Plain (Greece).

International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering, *46*(10), 56–62.

N Nyang'Au, W. O., Mati, B. M., Kulecho, K., Wanjogu, R. K., & Kiplagat, L. K. (2014). Assessment of the Adaptability of Management Practices to System for Rice Intensificatio in Kenya , using v4.5 CERES Rice Model. *Proceedings of 2013 Mechanical Engineering Conference on Sustainable Research and Innovation, 5*(3), 292–300. doi.org/10.2166/wcc.2014.114

Obiero, O. B. P. (2010). *Analysis of economic efficiency of irrigation water-use in mwea irrigation scheme, kirinyaga district, kenya*. Kenyatta University,Nairobi.

OECD. (2008). *Handbook on Constructing Composite Indicators: Methodology and User Guide; OECD Publishing:* Paris, France.

Okada, H., Styles, S. W., & Grismer, M. E. (2008). Application of the Analytic Hierarchy Process to irrigation project improvement. Part I. Impacts of irrigation project internal processes on crop yields. *Agricultural Water Management*, *95*(3), 199–204. doi.org/10.1016/j.agwat.2007.10.003

Omondi, S. O. (2014). *Economic Valuation of Irrigation Water in Ahero Irrigation Scheme*. University of Nairobi, Kenya

Payen, J., Faurès, J., & Vallée, D. (2012). Small reservoirs and water storage for smallholder farming The case for a new approach. *Report*, 1–60.

Phadnis, S. S., & Kulshrestha, M. (2013). Evaluation for measuring irrigation service performance using a scorecard framework. *Irrigation and Drainage*, *62*(2), 181–192. doi.org/10.1002/ird.1725

Phadnis, S. S., & Kulsreshtha, M. (2011). Benchmarking As a Tool for Improvement of System Performance : Case of Samrat Ashok Sagar Irrigation Project , Madhya Pradesh , India, *5*(4), 984–996.

POWER Data Access Viewer. (n.d.). Retrieved October 15, 2018, from https://power.larc.nasa.gov/data-access-viewer/

Ray, S. S., Dadhwal, V. K., & Navalgund, R. R. (2002). Performance evaluation of an irrigation command area using remote sensing: A case study of Mahi command, Gujarat, India. *Agricultural Water Management*, *56*(2), 81–91. doi.org/10.1016/S0378-3774(02)00006-9

Rehman, A., Chandio, A. A., Hussain, I., & Jingdong, L. (2017). Fertilizer consumption, water availability and credit distribution: Major factors affecting agricultural productivity in Pakistan. *Journal of the Saudi Society of Agricultural Sciences*. doi.org/10.1016/j.jssas.2017.08.002

Renault, D., Facon, T., & Wahaj, R. (2007). *Modernizing Irrigation Management: The MASSCOTE Approach-Mapping System and Services for Canal Operation Techniques* (Vol. 63). Rome: FAO.

Rodrı´guez-Dı´azz, J. A., Camacho-Poyato a, E., Lo ´pez-Luque, R., & Pe ´rez-Urrestarazu, L. (2008). Benchmarking and multivariate data analysis techniques for improving the efficiency of irrigation districts: An application in spain. *Agricultural Systems*, *96*(1–3), 250–259. doi.org/10.1016/J.AGSY.2007.07.010

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26. doi.org/10.1016/0377-

2217(90)90057-I

Sadras, V. O., Grassini, P., & Steduto, P. (2012). Status of water use efficiency of main crops . *SOLAW Background Thematic Report - TR07*.

Samian, M., Mahdei, K. N., Saadi, H., & Movahedi, R. (2015). Identifying factors affecting optimal management of agricultural water. *Journal of the Saudi Society of Agricultural Sciences*, *14*(1), 11–18. doi.org/10.1016/j.jssas.2014.01.001

Sayed, A., Hasan, M., & Ali, M. (2015). Farm Machinery Used and Problems Associated with Rice Cultivation as Well as Farmers Expectation in Two Villages of Comilla District

Siwar, C., Diana Mohd Idris, N., Yasar, M., & Morshed, G. (2014). Issues and Challenges Facing Rice Production and Food Security in the Granary Areas in the East Coast Economic Region (ECER), Malaysia. *Research Journal of Applied Sciences, Engineering and Technology*, *7*(4), 711–722. doi.org/10.19026/rjaset.7.307

Talukder, B., W. Hipel, K., & W. vanLoon, G. (2017). Developing Composite Indicators for Agricultural Sustainability Assessment: Effect of Normalization and Aggregation Techniques. *Resources*, *6*(4), 66. doi.org/10.3390/resources6040066

Tanui, J. K. (2017). *Identifying Constraints to Formal Market Access by Small-Scale Rice Farmers in Ahero Irrigation Scheme, Kisumu County, Kenya*. Van Hall Larenstein University of Applied Sciences, The Netherlands.

Thakur, A. K., Mohanty, R. K., Patil, D. U., & Kumar, A. (2013). Impact of water management on yield and water productivity with system of rice intensification

(SRI) and conventional transplanting system in rice. *Paddy and Water Environment*, *12*(4), 413–424. doi.org/10.1007/s10333-013-0397-8

Tran, T. X. M., Malano, H. M., & Thompson, R. G. (2003). Application of the analytic hierarchy process to prioritise irrigation asset renewals: The case of the La Khe irrigation scheme, Vietnam. *Engineering, Construction and Architectural Management*, *10*(6), 382–390. doi.org/10.1108/09699980310509354

TSSWCB, T. S. S. and W. C. B. (2005). *Water Conservation Best Management Practices (BMP) Guide for Agriculture in Texas Report 362. Development*. Texas, USA.

Waskom, R. M. (1994). *Best Management Practices For Irrigation Management*.

WMAF, W. M. of A. and F. (1997). *Best Management Guidelines for Sustainable Irrigated Agriculture MAF Policy Technical Paper No 00/05*.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338–353. doi.org/10.1016/S0019-9958(65)90241-X

Zema, D. A., Nicotra, A., Tamburino, V., & Zimbone, S. M. (2015). Performance Assessment Of Collective Irrigation In Water Users' Associations Of Calabria (Southern Italy). *Irrigation and Drainage*, *64*(3), 314–325. doi.org/10.1002/ird.1902

Zwart, S. J. (2013). Assessing and improving water productivity of irrigated rice systems in Africa. In *Realizing Africa's rice promise* (Vol. 28, pp. 265–275). Wallingford: CABI. doi.org/10.1079/9781845938123.0265

APPENDIX A

Table A 1: CROPWAT model simulation of crop water requirements and irrigation water requirements

(a) West Kano

Year	Area (acres)	Transplanting date	ET_c (mm)	Effective rainfall (mm)	Irrigation Requirement (mm)
2012/2013	278	23-04-12	661.5	504	432.8
	442	30-05-12	611.7	522	351.5
	430	13-07-12	648.2	507.5	392.9
	373	29-08-12	682.7	607.5	288.9
2013/2014	278	23-04-12	661.5	504	432.8
	125	22-05-13	764.4	334.9	703.5
	177	04-07-13	790.2	237.6	798.4
	208	18-08-13	793.6	308.5	730.7
2014/2015	112	30-05-13	683.3	485.5	413
	177	02-07-13	695.8	461.2	482.6
	194	27-08-13	764.8	433.9	507.5
2015/2016	273	31-05-15	760.3	275.4	690.2
	345	04-07-15	794.6	322.3	731
	430	13-08-15	781.3	408.9	610.8
	372	30-08-15	765.5	470.4	530.6

	185	13-09-15	763.7	514	493.3
	273	31-05-15	760.3	275.4	690.2
	283	22-06-16	721.4	332.7	655.7
	340	28-07-16	765.7	325.3	688.1
2016/2017	475	01-09-16	831.1	278.6	802.6
	372	30-09-16	869.8	251.7	865
	235	13-11-16	873.8	323.1	801.3

(b) Ahero irrigation scheme

Year	Area (acres)	Transplanting date	ET_c (mm	Effective rainfall (mm)	irrigation requirement (mm)
2012/2013	513	17-06-12	630.6	513.8	368.4
	447	28-07-12	667.7	506.6	421
	503	12-09-12	683.1	622.1	288.4
	705	12-10-12	719	607	371.1
2014/2015	568.5	23-04-13	739.4	400.7	568.8
	490.5	30-06-13	791.3	238.7	792.3
	323	31-07-13	797	286.8	744.6
	708	11-10-13	803.2	301	740.8
2015/2016	433	20-05-14	684.2	480.9	407.4
	414	05-07-14	702.2	460.8	437.2

	460	08-08-14	736.7	449.6	545.8
	628	15-09-14	778.2	385.2	600.3
2016/2017	456	20-07-16	757.4	343.5	667.3
	442	29-08-16	821.6	467.2	590
	433	11-10-16	875	567.7	498
	449	30-10-16	884.3	555.3	548.3

(c) Bunyala irrigation scheme

Year	Area (acres)	Transplanting date	ET_c (mm)	Effective rainfall (mm)	Irrigation requirement (mm)
2012/2013	241.25	20-04-12	578.3	595.8	263.4
	293	04-04-12	613.6	548	374.9
	294	12-05-12	578.3	592.4	315.5
	406	14-06-12	609.2	563.5	347.2
	324	12-07-12	620.6	549.2	355.6
	174	09-08-12	641.4	566.6	275.2
2013/2014	241.25	20-04-12	578.3	595.8	263.4
	235	05-04-13	603.4	513.4	354.8
	299	04-03-13	659.6	509.2	439.3
	294	10-05-13	599.6	478.3	386.2
	406	12-06-13	615.7	429.4	417

	324	28-07-13	637.1	467	404.4
	174	07-09-13	670.7	527.7	352.9
	235	15-04-14	612.7	495	402
	299	21-05-14	592.1	493.8	315.4
	294	11-06-14	598.7	496.8	337.3
2014/2015	406	16-07-14	625.3	512.3	379.4
	324	16-08-14	644	537.1	281.6
	174	07-09-14	671.1	531	360.5
	218.25	27-04-15	601.3	556.3	259.9
	316	12-05-15	607.6	537.4	371.4
2015/2016	295.25	12-06-15	638	493.6	370.5
	385.5	15-07-15	649	520.8	439.6
	329	27-08-15	644.2	648.5	308.8
	240	05-05-16	600.9	448.1	420.1
	306	19-05-16	611.5	428.3	437
	250	06-06-16	628.9	404.8	460.1
2016/2017	390	13-07-16	658.8	381.8	504.7
	285	15-08-16	697.6	402.4	546
	174	10-10-16	838.7	371.9	688.4

Table A 2: Crop co-efficient (Kc) values for all growth stages of rice

Stage	K_c value
Initial	1.1
Growth	1.2
Late	1

Appendix B

Table B 1: Attributes decision matrix

(a) Ahero irrigation scheme

	applicability	cost	acceptance	Implementation	water saving
applicability	1.00	0.50	2.00	0.50	0.33
cost	2.00	1.00	0.50	1.00	2.00
acceptance	0.50	2.00	1.00	0.50	2.00
Implementation	2.00	1.00	2.00	1.00	3.00
water saving	3.00	0.50	0.50	0.33	1.00

(b) West Kano irrigation scheme

	applicability	cost	acceptance	Implementation	water saving
applicability	1.00	0.50	1.00	0.33	0.20
cost	2.00	1.00	3.00	0.50	0.25
acceptance	1.00	0.33	1.00	0.33	0.20
Implementation	3.00	2.00	3.00	1.00	0.20
water saving	5.00	4.00	5.00	3.00	1.00

(c) Bunyala irrigation scheme

	applicability	cost	acceptance	Implementation	water saving
applicability	1.00	0.33	2.00	0.25	0.20
cost	3.00	1.00	0.50	3.00	0.25
acceptance	0.50	2.00	1.00	0.33	0.20
Implementation	4.00	3.00	3.00	1.00	0.33
water saving	5.00	4.00	5.00	3.00	1.00

Table B 2: BMPs decision matrix

(a) Ahero irrigation scheme

	land levelling	Tail-water reuse	System of Rice intensification	Scientific irrigation scheduling	Volumetric water measurement	Capacity building of farmers	Mechanization of farming operations	Change from pumping to gravity fed system
land levelling	1.00	0.15	0.36	0.29	0.15	3.10	0.34	0.30
Tail-water recovery and reuse system	6.70	1.00	6.40	5.00	0.32	6.20	5.80	5.40
System of Rice intensification	2.80	0.16	1.00	0.29	0.14	2.50	0.40	0.42

Scientific irrigation scheduling	3.50	0.20	3.50	1.00	0.31	3.40	2.80	2.50
Volumetric water measurement	6.50	3.10	7.30	4.50	1.00	6.50	6.10	5.60
Capacity building of farmers	0.32	0.16	0.40	0.29	0.15	1.00	0.34	0.32
Mechanization of farming operations	2.90	0.17	2.50	0.36	0.16	2.90	1.00	0.36

Change from pumping to gravity fed system	3.30	0.19	2.40	3.20	0.18	3.10	2.80	1.00

(b) West Kano irrigation scheme

	land levelling	Tail-water reuse	System of Rice intensification	Scientific irrigation scheduling	Volumetric water measurement	Capacity building of farmers	Mechanization of farming operations	Change from pumping to gravity fed system
land levelling	1.00	0.16	2.00	0.26	0.15	3.10	0.32	0.22
Tail-water recovery and reuse system	6.40	1.00	6.70	3.60	0.24	6.80	5.60	2.70

System of Rice intensification	0.50	0.15	1.00	0.23	0.15	2.50	0.26	0.29
Scientific irrigation scheduling	3.90	0.28	4.30	1.00	0.18	4.80	3.50	0.36
Volumetric water measurement	6.50	4.20	6.70	5.50	1.00	7.10	6.80	5.20
Capacity building of farmers	0.32	0.15	0.40	0.21	0.14	1.00	0.27	0.24
Mechanization of farming operations	3.10	0.18	3.80	0.29	0.15	3.70	1.00	0.29

Change from pumping to gravity fed system	4.50	0.37	3.50	2.80	0.19	4.20	3.50	1.00

(c) Bunyala irrigation scheme

	land levelling	Tail-water reuse	System of Rice intensification	Scientific irrigation scheduling	Volumetric water measurement	Capacity building of farmers	Mechanization of farming operations	Change from pumping to gravity fed system
land levelling	1.00	0.20	1.80	0.30	0.20	2.80	2.40	0.36
Tail-water recovery and reuse system	5.10	1.00	5.40	2.80	0.29	6.20	5.50	4.80

System of Rice intensification	0.56	0.19	1.00	0.24	0.19	2.80	2.50	0.40
Scientific irrigation scheduling	3.30	0.36	4.20	1.00	0.26	4.30	3.80	3.10
Volumetric water measurement	5.00	3.50	5.40	3.80	1.00	6.30	5.90	4.80
Capacity building of farmers	0.36	0.16	0.36	0.23	0.16	1.00	0.36	0.30
Mechanization of farming operations	0.42	0.18	0.40	0.26	0.17	2.80	1.00	0.33

Change from pumping to gravity fed system	2.80	0.21	2.50	0.32	0.21	3.30	3.00	1.00

APPENDIX C

Evaluation of performance of Western Kenya rice irrigation scheme

I am Faith Mawia Muema from Pan African University, Institute of Basic Science and Technology. I am undertaking a study on performance of rice irrigation schemes in western Kenya. Kindly assist me in filling this questionnaire

The information collected is confidential and will only be used for this research.

Scheme……………………….. …………..

Date of interview………………….. ………

Section A: Background information

1. Location

Canal location: Head [ ] Tail [ ] Middle [ ]

2. Gender: Male [ ] or Female [ ]

3. cropped area ……………………………………………………………………….

Section B: Crop production and marketing

4. How much rice did you harvest last season?

Crop	Area cultivated	Amount harvested (80 kg bags)	Amount consumed at home (80 kg bags)	Amount sold (80 kg bags)	Price per bag/kilo	Total Income
Rice						

5. What was your point of sell of rice produce last season?

i. Brokers on farm [ ]

ii. Local traders with mill [ ]

iii. Local consumers[ ]

iv. Government miller [ ]

v. Co-operative society[ ]

vi. Other

(specify)…………………………………………………………………………

6. Any reason for choice of buyer

i. I sell to the available buyer [ ]

ii. provides transport [ ]

iii. buys without conditions on quality of paddy [ ]

iv. pays cash immediately [ ]

v. Offers highest price [ ]

7. Do you have an organised market for your rice produce?

i. Yes [ ] No [ ]

ii. Rank the level of organisation

(a) slightly not at all [ ]

(b) little [ ]

(c) moderate [ ]

(d) quite a bit [ ]

(e) extremely [ ]

Section C: Farm inputs and production cost

8. Which type of seeds do you use? Local [ ] improved seeds [ ]

i. Reason :-

(a) Readily available [ ]

(b) Affordable [ ]

(c) High yield [ ]

9. How much of the following agricultural inputs did you use in the previous season?

Item	Source	Amount (kg/ acre)	Cost per acre (KES)
Seeds			
Fertilizers			
Pesticides/fungicide			
Total			

10. How do you know the amount of fertilizer and other agro-chemicals to use?

i. It depends with the amount I can afford [ ]

ii. Through experience from amount applied last season [ ]

iii. By consulting extension officers [ ]

11. Do you use adequate inputs? Yes [ ] No [ ]

i. If No, Rate the level of adequacy

ii. Poor [ ]

iii. Fair [ ]

iv. Good [ ]

v. Satisfactory [ ]

vi. Excellent [ ]

12. On average, what is the level of availability of agricultural inputs

i. Poor [ ]

ii. Fair [ ]

iii. Good [ ]

iv. Satisfactory [ ]

v. Excellent [ ]

13. What was the cost of production in the previous season?

Inputs/activity	Cost per acre (Ksh per acre)
Inputs (seeds and agro)	
Irrigation service charge (O&M charges)	
rotavation	
Canal de-silting and bud repair	
Nursery Preparation	
Transplanting	
weeding	
Agro-inputs application	
Bird scaring	
Draining	
harvesting	

Transport to drying floor	
Drying and winnowing	
Packaging, Storage and marketing	
Total / acre	

14. Do you use machines in your farms? Yes [ ] No [ ]

15. If yes to question (14) at what farming stage

Stage	Specify machine(s) used		Cost of hiring
	Hired	own	
Field preparation			
Planting			
Weeding			
Fertilizer and pesticide application			
Harvesting			
Threshing			

16. Which is your main source of labour?

i. Family [ ]

ii. Hired [ ]

iii. All the above [ ]

17. How is the availability of labour for all farming activities?

i. Poor [ ]

ii. Fair [ ]

iii. Good [ ]

iv. Satisfactory [ ]

v. Excellent [ ]

Section D: Organization, operation and maintenance of irrigation scheme

18 Do you receive enough water for irrigation; No [ ] yes [ ]

(a) What is the degree of availability of water?

i. Poor [ ]

ii. Fair [ ]

iii. Good [ ]

iv. Satisfactory [ ]

v. Excellent [ ]

19. Do you have a planned irrigation scheduling? No [ ] Yes [ ]

20. How do you decide when to irrigate?

i. Looking at the leaves [ ]

ii. By looking at how dry the soil is [ ]

iii. It depends on irrigation scheduling [ ]

iv. Through advice from extension officers [ ]

v. Using a measuring stick [ ]

21. Is water delivered on time? No [ ] yes [ ]

i. If No, what might the problem?

ii. Favouritism by water distributers [ ]

iii. Delay by gate rider [ ]

iv. Water scarcity [ ]

v. Stealing of water by individuals before their turn [ ]

vi. All the above [ ]

vii. Others (specify)……………………………………………………………………

22. What is your level of satisfaction with irrigation scheduling and timeliness of water delivery?

i. Poor [ ]

ii. Fair [ ]

iii. Good [ ]

iv. Satisfactory [ ]

v. Excellent [ ]

23. How are the water conflicts regarding water management resolved?

i. No actions taken [ ]

ii. By management without involving farmers [ ]

iii. Through negotiations between parties involved [ ]

iv. Conflicts resolved with aid of IWUA [ ]

24. What is the level of efficiency of conflict resolution?

i. Poor [ ]

ii. Fair [ ]

iii. Good [ ]

iv. Satisfactory [ ]

v. Excellent [ ]

25. Have you received any training on irrigation water use, management and water saving?

No [ ] Yes [ ]

26. What is your level on knowledge of water use?

i. Poor [ ]
ii. Fair [ ]
iii. Good [ ]
iv. Satisfactory [ ]
v. Excellent [ ]

27. How effective is IWUA?

i. Poor [ ]
ii. Fair [ ]
iii. Good [ ]
iv. Satisfactory [ ]
v. Excellent [ ]

28. Are you a member of farmers' organization? No [ ] Yes [ ]

a) If No, why haven't you joined?

....

Section E: Agricultural support services

29. Have you received agricultural extension services in the past twelve months?

No [ ] Yes [ ]

30. If yes to question (30) is it adequate No [ ] Yes [ ]

31. Which of the following training have you received?

Stage	Yes/no	Adequate/inadequate
Land preparation		
Nursery management		
Trans planting		
Crop management		
Harvesting and post- harvest handling of crops		

32. Have you received credit services in the last 12 months? No [ ] Yes [ ]

i. If yes, was it adequate? No [ ] Yes [ ]

33. Why do you access credit services?

i. Expensive inputs [ ]
ii. The rates are affordable [ ]
iii. No any other source of income [ ]
iv. Its available [ ]

2. Questionnaire administered to NIB officers

Scheme……………………….. …………..

Date of interview………………….. ………

1. What policies, program and regulations exist regarding water provision for irrigation schemes? ……………………………………………………………………………………

2. What is the level of degree of policy implementation

i. Poor [ ]

ii. Fair [ ]

iii. Good [ ]

iv. Satisfactory [ ]

v. Excellent [ ]

3. Which is maximum and minimum irrigation service fee chargeable?

i. Maximum

ii. Minimum

4. What is the current irrigation service fee?

5. Is the amount of water abstracted limited? Yes [ ] No [ ]

(a) What limits it?

i. Environmental flow [ ]

ii. Water scarcity [ ]

iii. Other (specify)………………………………………… ……………………

5. Do you have a maintenance schedule of the water distribution system?

6. What is the average length of canal maintained last year?...

7. What are the main constrains to rice irrigation farming?

…………………………………………………………………………………………………

8. How do you control and minimise water wastage in the scheme?

…………………………………………………………………………………………………

9. How do you rate the performance of the scheme on a scale of 0-10?

10. What do you think can be done to improve the performance of the scheme?

……………………………………………………………………………………………………

……

11. What is limiting the area under cultivation?

……………………………………………………………………………………………………

……

12. Which is the greatest challenge facing the scheme?

13. How can it be overcome?

....

14. Do you have any area within the scheme which has salinity problems?

Yes [ ] No [ ]

If yes, specify the size of the area…………………………………………………

15. Are all the irrigation structures such as weirs, division boxes and turn outs etc in good working condition? Yes [ ] No [ ]

16. If not what is the percentage of structures that were repaired last season?

17. Which of the following greatly influences performance of irrigation?

i. Cost of inputs
ii. Availability of Labour
iii. Availability of water

APPENDIX D

Ranking of best management practices (BMPs)

I am Faith Mawia Muema from Pan African University, Institute of Basic Science and Technology. I am undertaking a study on performance of rice irrigation schemes in western Kenya. Kindly assist me in filling this questionnaire

General information

Date:

……………………………………………………………………………………………..

Schemes:

…………………………………………………………………………………………

On the tables below, please rank the best management practice on a scale of 1-9 according to your own preference of the one on the left relative to others. 1- The least preferred and 9- the most preferred. The enumerator will show you where to put the scores.

Table 1

	Score		
Land levelling			Tail water reuse
			System of Rice intensification
			Scientific irrigation scheduling
			Volumetric water measurement
			Capacity building of farmers
			Mechanization of farming operations

			Change from pumping to gravity fed system-

Table 2

	Score		
Tail water reuse			Land levelling
			System of Rice intensification
			Scientific irrigation scheduling
			Volumetric water measurement
			Capacity building of farmers
			Mechanization of farming operations
			Change from pumping to gravity fed system-

Table 3

	Score		
System of Rice intensification			Tail water reuse
			Land levelling
			Scientific irrigation scheduling
			Volumetric water measurement
			Capacity building of farmers
			Mechanization of farming operations
			Change from pumping to gravity fed system-

Table 4

	Score		
Scientific irrigation scheduling			Tail water reuse
			System of Rice intensification
			Land levelling
			Volumetric water measurement
			Capacity building of farmers
			Mechanization of farming operations
			Change from pumping to gravity fed system-

Table 5

	Score		
Volumetric water measurement			Tail water reuse
			System of Rice intensification
			Scientific irrigation scheduling
			Land levelling
			Capacity building of farmers
			Mechanization of farming operations
			Change from pumping to gravity fed system-

Table 6

	Score		
Capacity building of farmers			Tail water reuse
			System of Rice intensification
			Scientific irrigation scheduling

			Volumetric water measurement
			Land levelling
			Mechanization of farming operations
			Change from pumping to gravity fed system-

Table 7

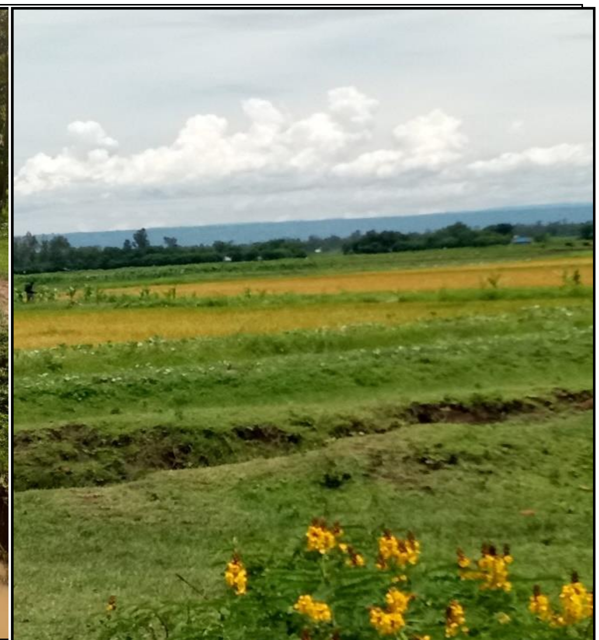
	Score		
Mechanization of farming operations			Tail water reuse
			System of Rice intensification
			Scientific irrigation scheduling
			Volumetric water measurement
			Capacity building of farmers
			Land levelling
			Change from pumping to gravity fed system

Table 8

	Score		
Change from pumping to gravity fed system			Tail water reuse
			System of Rice intensification
			Scientific irrigation scheduling
			Volumetric water measurement
			Capacity building of farmers
			Mechanization of farming operations
			Land levelling

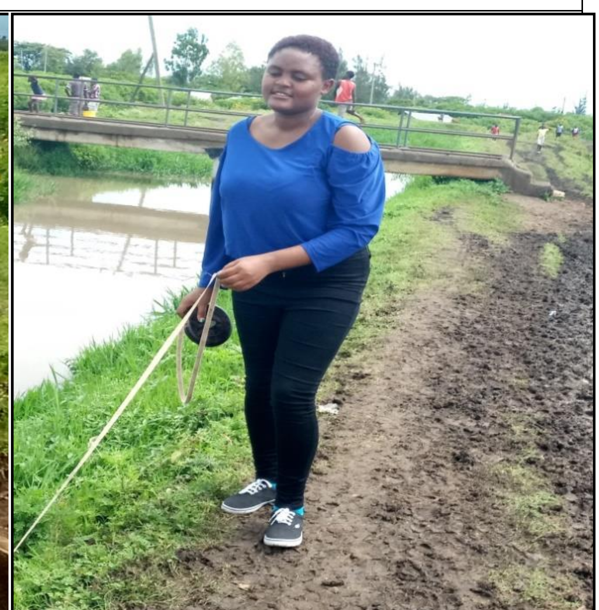
APPENDIX E

(a) Gate in Bunyala irrigation scheme



(a) Mature rice crop in Ahero irrigation scheme (block F)

(c) Broken gate in Ahero irrigation scheme



(d) Field measurement along main canal in West Kano irrigation scheme

Figure E 1: Field survey photographs