EVALUATING THE HYDRAULIC, MANAGERIAL, SOCIO-ECONOMIC AND ENVIRONMENTAL PERFORMANCE OF AHERO IRRIGATION SCHEME

GEORGE KHATETE MOYALE

MASTER OF SCIENCE

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Evaluating the Hydraulic, Managerial, Socio-Economic and Environmental Performance of Ahero Irrigation Scheme

George Khatete Moyale

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DECLARATION

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

Signature………………………………………………..Date.......................................

George Khatete Moyale

This thesis has been submitted for examination with our approval as the University Supervisors

Signature………………………………………………..Date.......................................

Prof. Patrick G. Home, PhD

JKUAT, Kenya

Signature………………………………………………..Date.......................................

Prof. (Eng). James M. Raude, PhD

JKUAT, Kenya

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ACRONYMS AND ABBREVIATIONS

AIS	Ahero Irrigation Scheme
BETA	Bottom-up Economic Transformation Agenda
ELECTRE	ELimination and Choice Expressing REality
EoI	Effectiveness of Infrastructure
ERHT	Equity Ratio for Head and Tail
FAO	Food and Agriculture Organization
IQR	Interquartile Range
MASSCOTE	Mapping Systems and Services for Canal Operation Techniques
NIA	National Irrigation Authority
OECD	Organization for Economic Co-operation and Development
PIS	Public Irrigation Scheme
RAP	Rapid Appraisal Procedure
USDA	United States Department of Agriculture
WAF	World Agriculture Forum

ABSTRACT

Many of Kenya's public irrigation schemes are performing below potential resulting in low yields suggesting the need for irrigation performance assessment of the schemes. The hydraulic, management, environmental and socio-economic factors are crucial in the performance evaluation of an irrigation scheme. The aim of this study was to evaluate the hydraulic, managerial, socio-economic and environmental performance of Ahero Irrigation Scheme (AIS) in Kenya. This information will be crucial when doing performance improvement of the scheme. To evaluate the technical performance, the indicators used were: adequacy, equity, efficiency and dependability of irrigation water supply. Adequacy was calculated as the ratio of the amount of water delivered to the amount of water required by the crops. Efficiency was calculated as the amount of water delivered to farms to the amount of water supplied from the pump station. Dependability was measured as the variance in the temporal water supply. Equity was measured as variance in the spatial water supply. The indicators used under the managerial parameter include: effectiveness of infrastructure, land renovation ratio and training to farmers. To determine the effectiveness of infrastructure, the number of functional structures were counted and a ratio of functional to total number of structures calculated. Similarly, land renovation was calculated as a ratio of area under irrigation to the total command area of the irrigation scheme. Questionnaires were used to gather feedback on level of extension services if any, advanced to farmers in order to determine the training level. For the socio-economic parameter, the indicators were the credit ratio and farmer incomes. Credit ratio was calculated as ratio of credit required by farmers to the credit given. For the environmental performance evaluation, the indicator used was the drainage ratio calculated as a ratio of the drained water to the incoming water. On the technical parameter, the canal's conveyance efficiency was found as 60% which was rated as poor; adequacy in the upper, mid and lower streams of the scheme was 0.99 rated as very good, 0.82 rated as good and 0.74 rated as poor respectively. Equity was 0.57 corresponding to a rating of poor; the coefficient of variance for dependability for the 2020 April-July season was 5.3 rated as good based on standard classifications, while for the whole year, dependability was 16.23 and rated poor. The water distribution and utilization in the scheme was inefficient as per the technical performance findings. On the managerial parameter, effectiveness of infrastructure was found to be 89% while the irrigation ratio was found as 62%. It was also found that training to farmers was not undertaken regu1larly, implying farmers were not well-abreast with effective farming operations. On the socio-economic parameter, the credit ratio was 0.5-0.75, meaning farmers could not access their full loan requirements compromising on their farming operations and hence production. Credit was given to farmers based on their capacity to pay back. On the environmental parameter, the drainage ratio was found as 33% and hence the ponding of irrigation water in the scheme due to poor drainage. Under limited resource conditions and based on the overall AHP analysis, the technical parameter (51%) should be given more priority followed by the socio-economic (32%), management (11%) and the environmental parameters (6%) respectively while prioritizing the most important parameters to be fixed. The study recommends lining of the main canal to enhance the hydraulic performance coupled with prompt repairs of damaged hydraulic structures. The study also recommends further research to utilizing more hydraulic performance

indicators such as the groundwater ratio for better understanding of the scheme performance situation.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Agriculture remains the most important source of food in the world. However, approximately 60% of water diverted for agriculture in the world does not directly contribute to the production of food. The water is wasted through inefficient systems of irrigation, poor control of water and poor management practices on the farm (Alordzinu et al., 2017). According to Agide et al. (2016), the rate of increase in the withdrawal of water for agriculture in a few decades to come will not be similar to the previous three or four decades because of competition from the increasing world populations and industries requiring water for their operations. Based on a forecast by Stephan et al. (2011), the expected water abstraction for agricultural use by 2030 will be approximately 14% more than that of 2000. The implication of this prediction is that agriculture is faced with the challenge of embracing the concept of using less water to produce more food. The discrepancy in irrigated land expansion and water withdrawal can only be minimized through improved irrigation efficiency resulting in reduced withdrawals of irrigation water per unit area of irrigated land (Angualie et al., 2021). It is expected that production from irrigated agricultural land should rise by approximately 13% per decade in order to feed the ever-increasing world population (Gomo et al., 2014). This can best be achieved through improved irrigation water management targeting productivity optimization, particularly in Africa where overall irrigation performance efficiencies are low.

In Africa and particularly the sub-Saharan region, agriculture forms the largest water user. With a fast-growing population, there is rising demand for food and water in the region. Implementations of practices which improve the productivity of water and land in the production of crops directly contributes to the improvement of livelihoods, reduction in poverty and increase in food security (Miruri et al., 2017). A number of irrigation schemes especially in least developed and emerging countries have low overall performance level. The performance of public irrigation schemes both technically and economically in the said countries has generally been significantly below potential (Degirmenci et al., 2003). Aspects of poor performance in irrigation include insufficient infrastructural maintenance, field water losses and operational leakages, mismatch of demand and supplies, poor irrigation service, inadequate operation of irrigation structures, waterlogging and salinization. A greater contribution to poor performance is as a result of inadequate management of water at the scheme.

According to Awulachew (2019), the scarcity of water is a potential limitation to food production. A possible way in conserving the scarce water resource is by improving performance of already existing irrigation schemes. In Ethiopia for example, the government had initiated the development of new irrigation projects, yet the performance of the irrigation schemes that already existed were given less attention. The performance of several irrigation schemes was below potential because of poor design and construction, operation, ineffective control of water and poor installation of the measurement structures. After evaluating the hydraulic performance of Hare irrigation scheme, it was established that the performance was poor and required high maintenance. In Tahtay Tsalit Irrigation Scheme, sedimentation at various reaches of the scheme and a number of malfunctioned irrigation structures constituted the poor hydraulic performance. As a way forward for addressing performance inefficiencies, awareness creation and capacity building for the irrigation water users was recommended (Efriem & Mekonen, 2017). In Kenya, awareness creation on effective operations that will add knowledge leading to efficient management of irrigation water especially on large scale irrigation projects is similarly important.

Kenya is classified as a water scarce country, with a per-capita water consumption of 597.4m^3/person/year against a recommended minimum of 1,000 m^3 /person/year by the United Nations (Onjala, 2002). This is still way below the recommended figure based on Falkenmark Water Stress Index threshold. The current situation is projected to continue worsening because of the effects associated with the change in climate and pressure from increasing population. Most of the irrigation systems in Kenya including Ahero, Mwea, Bunyala and West Kano suffer poor irrigation water use efficiencies, thus affecting rice productivity. The inefficiencies are partly attributed to the canals that are unlined for all the schemes and especially Ahero, that has 0% lining in all the canals, and also the method of irrigation used, that is, flood.

Considering that shortage of water shall be a big constraint in agriculture, and that there exists need to increase crop production in irrigation schemes, the general performance of these schemes require improvement. There is need to use water more efficiently with the diversions of water per unit land area under irrigation reduced. With a projected slowdown in expanding land under irrigation, much focus should be put on improving existing irrigation schemes. In addition, with reducing resources of freshwater, there is need to enhance the productivity of the existing irrigation systems by addressing their poor performance and management deficiencies in a holistic way. This study sought to evaluate the hydraulic, managerial, environmental and socio-economic performance of Ahero Irrigation Scheme against rice yields to provide basic information for performance improvement of the scheme. These performance parameters will be assessed at scheme level to give an overview of the performance of the entire scheme.

1.2 Statement of the Problem

Majority of Public irrigation schemes in Kenya have experienced low crop productivities over time, a factor that has further endangered Kenya's food security situation, and has caused extremely low farmer returns (Miruri et al., 2017). The public irrigation schemes in Kenya utilize large volumes of water for irrigation, most of which is wasted through overland flows and deep percolation (Evans et al., 2018). The Ahero Irrigation Scheme (AIS) uses on average, 4,989,382m^3 of water annually (National Irrigation Authority, 2023) yet the productivity is 20% below the recommended optimal yield of 8,473 tonnes annually. Studies have shown that failure in fully utilizing productive resources efficiently, is a big contributor to lower yields.

The system hydraulics of an irrigation scheme, management, socio-economic and environmental performances of an irrigation scheme must function in a way that efficiently utilizes water, reduces general operational costs and improves yields (Bos et al., 2005). The evaluation of performance in these four areas has not been done for AIS. This study therefore sought to evaluate the hydraulic, managerial, environmental and socio-economic performance of Ahero Irrigation Scheme against rice yields. This information will form basis for performance improvement of an irrigation scheme.

1.3 Objectives

1.3.1 Main Objective

The main objective of this study was to evaluate the hydraulic, managerial, socio-economic and environmental performance of Ahero Irrigation Scheme.

1.3.2 Specific Objectives

The specific objectives of this study were to:

i. Determine the hydraulic performance of Ahero Irrigation Scheme open channel conveyance system;
ii. Investigate the managerial, socio-economic and environmental performance of Ahero Irrigation Scheme;
iii. Evaluate the significance of the hydraulic, managerial, socio-economic and environmental parameters using the Analytical Hierarchical Process (AHP) model.

1.4 Research Questions

i. What is the hydraulic performance of Ahero Irrigation Scheme open channel conveyance system?
ii. What is the managerial, socio-economic and environmental performance of Ahero Irrigation Scheme?
iii. What is the significance of the hydraulic, managerial, socio-economic and environmental parameters and the recommendations that can be given to address the performance situation in Ahero Irrigation Scheme?

1.5 Justification

A number of large-scale irrigation schemes in developing countries are generally gravity systems with water conveyance through earthen canals that waste a lot of water. It is therefore necessary to continuously monitor flows and hydraulic structures in order to ensure that delivery of water is responsive to demand. Water saving is crucial in Kenya's irrigation schemes to ensure sustained irrigation activities while at the same time, realizing optimum production. This study sought to evaluate the hydraulic, managerial, socio-economic and environmental performance of Ahero Irrigation Scheme, to provide important information that can aid in future improvement of the scheme. Having irrigation schemes perform within recommended ranges of key indicators will result in steady crop productions that will enhance food security in the country; add to the country's export basket; and realize improved farmer compensations. The findings of this study will go a long way in revamping irrigation schemes in the country through the adoption of similar strategies. The move to improve rice productivity in Kenya's public irrigation schemes shall be a big step towards realizing sustainable productions, enhance food security and improved farmer returns. It shall help achieve one of the Government's Bottom-up Economic Transformation Agenda (BETA) which has prioritized 6 key pillars at national level in order to achieve rapid transformation of people's lives by increasing the availability of food, through the improved rice productions. This research contributes towards sustainable food production through optimal utilization of water resources.

1.6 Scope and Limitations of the Study

The focus of this study was to evaluate the hydraulic performance, managerial, socio-economic, environmental and socio-economic performance of Ahero Irrigation Scheme. The study used four hydraulic performance indicators namely, efficiency, adequacy, equity and dependability to evaluate the scheme's hydraulic performance. Under the managerial performance, the study used three indicators namely, effectiveness of structures, land renovation ratio and training. For the socio-economic performance evaluation, two indicators were used, namely, credit ratio and farmer income. For the environmental performance, the study used one indicator, namely, drainage ratio. The AHP model was used to rank, in order of significance, the priority non-technical factors to be addressed for better performance of the scheme. Although there are more indicators for each of the performances evaluated, this study was restricted to the key indicators highlighted. Also, this study only served to provide information on the performance of the scheme, and does not provide practical designs and steps for performance improvement of the scheme.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Overview

Irrigated agriculture accounts for approximately 20% of the total cultivated land and contributes 40% of the total food produced worldwide. Irrigated agriculture is, on average, at least twice as productive per unit of land as rainfed agriculture, thereby allowing for more production intensification and crop diversification. With the increase in population, urbanization, and the changing climate, the pressure on water resources is expected to rise, with a particular effect on agriculture. The world population is expected to rise to more than 10 billion people by the year 2050, and whether rural or urban, this population will require food in order to meet its basic needs. It is approximated that agricultural production will need to expand by about 70% by 2050 (Philip et al., 2014). Resolving future challenges requires a thorough reconsideration of how water is managed in the agricultural sector, and how it can be repositioned in the broader context of overall water resources management and water security (Gideon et al., 2007).

2.1.1 Performance Evaluation of Surface Irrigation Schemes

Several key factors can affect the performance of an irrigation scheme: design and infrastructure, water management, biophysical factors and socio-economic factors.

2.1.1.1 Design and Infrastructure

Poor design and inadequate infrastructure are major contributors to low irrigation scheme performance. This includes issues with the irrigation canals, water distribution system, and drainage. Proper design and maintenance of the physical infrastructure is crucial for efficient water delivery and preventing waterlogging or salinization.

2.1.1.2 Water Management

Inadequate irrigation scheduling and operation plans negatively impact scheme performance. Proper water management requires understanding crop water requirements, rainfall patterns, and soil characteristics to optimize irrigation timing and amounts. Lack of coordination among farmers and poor governance of water resources can also lead to inefficient use.

2.1.1.3 Biophysical Factors

Spatial variability in biophysical factors across an irrigation scheme can cause differences in crop water productivity and evapotranspiration. Key variables include: Distance of plots from irrigation inlet - plots further away may receive less water; Elevation - higher plots may have lower water availability; Soil texture - sandy soils have higher infiltration rates; Soil nutrients - deficiencies can limit crop growth and yield. Accounting for this spatial heterogeneity is important for optimizing water and nutrient management within a scheme.

2.1.1.4 Socioeconomic Factors

Farmer characteristics like education, experience, and access to inputs and credit can influence their efficiency and productivity within an irrigation scheme. Poverty, lack of extension support, and insecure land tenure are some socioeconomic constraints that may reduce incentives for farmers to invest in their land and water management practices.

In summary, irrigation scheme performance depends on a combination of physical infrastructure, water management practices, biophysical conditions, and socioeconomic factors. Identifying and addressing the key constraints in each of these areas is crucial for improving productivity and sustainability of irrigated agriculture.

The aim of performance evaluation is to achieve effective and efficient use of resources by providing important feedback to management at every level. Additionally, it also helps in obtaining important information that will enhance corrective actions that shall maximize benefits of the irrigation project (Bos et al., 2005).

Performance evaluation also helps with the verification of important project lessons learned and in coming up with benchmarks that improve planning, execution and management of other similar projects (Bos et al., 2005). There are several studies that show how these assessment processes helped in developing and enhancing performance in irrigation schemes (Gideon et al., 2007).

Performance evaluation can be assessed through benchmarking, remote sensing, and analytical models and through the direct measurement of indicators (Muema et al., 2018). Benchmarking compares well-performing irrigation projects with the under-performing ones in order to identify areas of improvement for projects that are not performing well. Remote sensing ap plies data that has been remotely sensed from an irrigation scheme in order to suggest possible areas that require improvement. Analytical models such as the fuzzy techniques theory and the Analytical Hierarchy Process Model (AHP) are used in evaluating the performance of schemes by investigating individual parameters and isolating those that significantly affect scheme operations (Sun et al., 2017). Direct measurement of indicators involves taking field measurements of flows and calculating the ratios for water delivery. The analytical hierarchy process model and direct measurements techniques have been applied in this study to evaluate performance of AIS (Baradaran & Tavazoei., 2022). These techniques were selected because of their detailed nature, and also because they cover the critical components being investigated in the scheme.

2.1.2 Framework for Performance Assessment

The framework is used to describe the importance of the performance assessment, and the data that is needed, the analytic techniques that shall be used, and the consumers of the provided information. Without a good framework, the performance evaluation program may fail to gather all required data, and may not give the information required (Bumbudsanpharoke & Prajamwong, 2015)

Performance evaluation of irrigation projects is usually a complex process, because several regular tasks have to be performed concurrently and sequentially. These tasks have to be coordinated within the available resource constraints. So as to enhance this process, several efforts have been made to assess the effects of these interventions so that further improvement can be introduced (Elshaikh et al., 2018).

2.2 Performance Indicators

Performance indicators are parameters or ratios used to investigate the temporal and spatial performance of irrigation schemes, while evaluating causes and providing recommendations that will improve the general scheme productivity. Important and widely used indicators include efficiency, equity, adequacy and dependability. The scale of hydraulic performance indicators is shown in Table 2.1. ‘Poor’ means the performance of the scheme is below average; ‘fair’ means the scheme’s performance is average whereas ‘good’ means the scheme’s performance is above average in the respective hydraulic performance indicators (Bos et al., 2005).

Table 2.1: Range for Hydraulic Performance Indicators

	Poor	Fair	Good
Dependability (P_D)	>0.20	0.11-0.2	0.00-0.10
Adequacy (P_A)	<0.80	0.80-0.89	0.90-1.00
Equity (P_E)	>0.25	0.11-0.25	0.00-0.10
Efficiency (P_F)	<0.70	0.70-0.84	≥0.85

2.2.1 Efficiency of Water Delivery

Efficiency of water delivery expresses the desire to keep water by matching the delivery of water to the requirements (Bos et al., 2005). Efficiency is a good indicator for conservation of water by a system and is calculated using Equation 2.1.

$$P_F = \frac{1}{T}\sum_T \left(\frac{1}{R}\sum_R \frac{Q_D}{Q_S}\right) \qquad \textbf{(0.1)}$$

Where:

P_F = Efficiency of the system (%)

T = Time served by the irrigation system (hrs)

R = Region served by the irrigation system (ha)

Q_D = Amount of irrigation water delivered (at the outlet) (m^3/hr)

Q_S = Amount of irrigation water supplied (from the inlet) (m^3/hr)

In Pakistan, a basin-wide excursion done by Kumari & Mujumdar, (2017) reported that the overall efficiency of irrigation systems in the country was 0.38 (rated as poor). The study showed that the Godavari, Krishna, Mahanadi and Cauvery irrigation systems had averagely low irrigation efficiency of approximately 0.27 (rated as poor) whereas the Ganga and Indus systems were performing better at 0.43-0.47 (rated as poor) irrigation efficiencies. Some of the reasons given for low surface irrigation efficiencies in Pakistan include: lack of channels in the field, irrigation systems that are dilapidated, and a lack of volumetric water supplies. The optimal and equitable use of canal irrigation water in Pakistan has been a subject of growing concern. Efriem & Mekonen, (2017) while studying the hydraulic performance of Tahtay Tsalit irrigation scheme found that the efficiency of the irrigation system was fair at 0.77 (rated as fair).

Agide et al. (2016) used the efficiency performance indicator while analyzing performance of water delivery for Ethiopia's small scale irrigation schemes. The efficiency of irrigation water application at Koga was found as 0.45 which is by far low and could be considered as low sustainability level. In Turkey, performance of the Lower Seyhan scheme was evaluated where an efficiency of 0.8 (rated as fair) was found (Kanber et al., 2005). These studies present a general picture of how inefficient irrigation systems are, especially in terms of water delivery. The efficiency of 0.45 for Koga irrigation scheme for instance, implies that more than half of the water leaving the pump station is lost through deep drainage within the canals. If the delivery efficiency of Koga irrigation scheme is improved to be within the 'good' range (>0.8), the water will be able to supply an extra farm field of the same size as Koga Irrigation scheme. For the Lower Seyhan scheme, though it is performing better than Koga irrigation scheme in delivery efficiency, it is still below the 'good' range. There is therefore need to investigate these inefficiencies in water delivery for the various open channel irrigation projects, to device strategies aimed at enhancing better delivery performances, and which will massively save water.

2.2.2 Adequacy of Irrigation Water Supply

Adequacy is another important hydraulic performance indicator in evaluating irrigation schemes. Adequacy expresses the desire of delivering the water amount required over a command region served with the system (Babayan et al., 2005). The adequacy (P_A) for a region R, served by the system through a period T is given by Equation 2.2:

$$P_A = \frac{1}{T}\sum_T \left(\frac{1}{R}\sum_R \frac{Q_D}{Q_R}\right) \tag{2.2}$$

Where:

P_A = Adequacy (%)

T = Time served by the system (hrs)

R = Region served by the system (ha)

Q_D = Amount of irrigation water delivered (m^3/hr)

Q_R = Amount of irrigation water required (m^3/hr)

Tebebal & Ayana (2015) found an adequacy value of 0.64 (rated as poor) while studying the hydraulic performance of Hare irrigation scheme. Efriem & Mekonen, (2017) established adequacy to be fair at 0.84 for Tahtay Tsalit irrigation scheme. Based on a reach wise assessment of Metahara irrigation scheme in Ethiopia, adequacy of water delivery by the off-take was found to be poor and was linked to poor operation of the reservoir used for night storage and the hyper-proportional state by the off-takes. An operation plan that responds to demand was recommended for the scheme, based on a rigorous hydraulic evaluation of flow characteristics and condition using adequacy as a performance measure. This is an important undertaking towards the efficient management of irrigation water. It will prevent cases of over or under-supplying of irrigation water.

Several factors influence the adequacy of irrigation water supply to the farms including water availability, pumping capacity, soil type, irrigation scheduling and crop water requirements. The amount of water available from groundwater, surface water sources like rivers and lakes, or reservoirs is crucial. Factors like drought, competition for water, and legal restrictions on withdrawals can limit availability (Eshete et al., 2020). The capacity of the pumping system to deliver water to the irrigation system is important. Factors like pump size, well depth and diameter, and power supply affect pumping capacity. Proper irrigation scheduling to meet crop water requirements is essential. Factors like soil type, crop stage, and weather affect irrigation scheduling. Over-irrigation can lead to water losses while under-irrigation stresses crops. Soil type, depth, and water holding capacity affect irrigation requirements. Sandy soils require more frequent irrigation than clay soils. The water needs of the crop, which vary by type, stage of growth, and weather conditions, determine irrigation requirements (Shongwe et al., 2011).

2.2.3 Dependability of Irrigation Water Supply

Another performance indicator in the evaluation of irrigation schemes is dependability. This is the temporal variability in ratio of delivered amount of water to required amount which occurs in a region (De Alwis & Wijesekera, 2012). Equation 2.3 is used to compute dependability.

$$P_D = \frac{1}{R}\sum_{R} CV_T\left(\frac{Q_D}{Q_R}\right) \qquad (0.2)$$

Where:

P_D = Dependability (%)

R = Region served by the system (ha)

Q_D = Amount of irrigation water delivered (m^3/hr)

Q_R = Amount of irrigation water required (m^3/hr)

CV_T = is the temporal variation coefficient of the ratio Q_D/Q_R in a time period T (hrs) (Degirmenci et al., 2003).

Tebebal & Ayana (2015) found a dependability value of 0.21 (rated as poor) while studying the hydraulic performance of Hare Irrigation Scheme. Efriem et al. (2017) found a dependability of 0.057 (rated as good) for Tahtay Tsalit irrigation scheme. A dependability value of 0.21 implies that the irrigation water supply is not dependable. In this case, farmers have to majorly work with an alternative irrigation water supply other than the conventional supply, if they are to maintain optimal crop production. For farmers that fully rely on the conventional water supply, a dependability value of 0.21 would hamper crop production significantly. It is important for the scheme to adopt a water rescheduling plan that will ensure > 0.8 dependability of the irrigation water by all farmers across the network.

2.2.4 Equity of Irrigation Water Supply

Equity on the other hand, measures the spatial uniformity of the delivered amount of water. An appropriate performance measure for equity is the average spatial variability for ratio of delivered to required amount over the interest time period (Dejen et al., 2015). The proposed measure is calculated using Equation 2.4:

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_D}{Q_R}\right) \tag{0.3}$$

Where:

P_E = Equity (%)
R = Region served by the system (ha)
Q_D = Amount of irrigation water delivered (m^3/hr)
Q_R = Amount of irrigation water required (m^3/hr)
CV_R (Q_D/Q_R) = the spatial variation coefficient of the ratio Q_D/Q_R in the region R.

Equity was found as 0.67, 0.69 and 0.77 (poor) at the head, middle and tail reaches of the irrigation schemes (Wukro, Meki, Koga, Dessie-Zuria, Megech, Hare diversion, Gelana, Waro, May-Nigus and Hare weir), respectively (Agide et al., 2016). According to Kalu et al. (1995), productivity declines under poor equity conditions and therefore, to improve food security and the role of irrigation, equity in all the reaches has to be improved.

Equity measures the variability in relative delivery of water from one point to another over the region. The closer the PE value to zero, the higher is the equity degree in delivery as presented in Table 2.1. Tebebal & Ayana (2015) conducted a study to evaluate the hydraulic performance of Hare irrigation scheme in Ethiopia and found an equity value of 0.34 (rated as poor). Fan et al. (2018) examined the management of irrigation water at Jiamakou irrigation project in China, where findings indicated that water was poorly allocated. The recommendation was that farmers be trained on irrigation water allocation. Off-take operation in the Metahara Irrigation Scheme of Ethiopia was found to be inadequate based on the overall equity. Inequity was linked directly to the scarcity of knowledge by the operators and managers of the canal on the system hydrodynamic features and the hydraulic state of flow control structures (Dejen et al., 2015). Gideon et al. (2007) while assessing the hydraulic performance for canals in Sudan's Rahad agriculture scheme, found good distribution of water based on management and actual equity measures. Based on hydraulic structure, equity was however poor in the early and late seasons and fair during the mid-season.

2.3 Modelling of the Managerial, Socio-Economic and Environmental Parameters in Performance Evaluation

Multi-attribute models for decision making have been regarded as appropriate tools in assessing performance of networks under irrigation and drainage. Because of the challenge of uncertainty in input and output data, techniques that are both qualitative and quantitative are put together to create new methods such as the multi-attribute models for decision making. The ELCTRE ENTROPY, Fuzzy set theory, TOPSIS-ENTROPY and AHP models are most significant in using new methods (Montazar & Snyder, 2012).

2.3.1 ELECTRE Entropy Technique

The Electre technique is used in disregarding some of the problem alternatives that are not acceptable. Thereafter, another multi criteria decision assessment technique can be used in choosing the best alternative (Rangel et al., 2009). The Elecre-entropy method was used in assessing the environmental criteria for Ardabil irrigation network in Iran. Findings indicated that the evapotranspiration and water volume sub-criteria had the most significant effect in assessing the pattern of cropping in the irrigation network for Varamin (Mohammad & Mohammad., 2017). Therefore, when designing the irrigation network and cropping pattern of Ardabil irrigation project, evapotranspiration and water volumes are primarily considered. Many researchers have used the electre entropy model in evaluating the management of water resources for various locations (Rangel et al., 2009). However, this model is complex based on input and flow. Some of the data required could not be established from the scheme and is why it was not considered for this study.

2.3.2 Fuzzy-Set Theory

Fuzzy set theory deals with problems relating to subjective, ambiguous and imprecise judgments. The theory can quantify available data and individual or group preferences for easy decision making (Varun, 2018). Fuzzy set theory allows for the gradual evaluation of element membership in a set. This is explained using a membership function valued in the unit interval [0, 1]. Fuzzy sets usually generalize sets that are classical and has a wide range of applications where information is imprecise or incomplete. Kumari & Mujumdar (2017) presented performance measures based on the fuzzy set theory to determine the probability of the Bhadra irrigation reservoir system in India to fail and how possible it is to recover from the failure. The author established that the state of success or failure was linked to the deficit in evapotranspiration of the crops in the given time period. The author noted that the fuzziness inclusion in performance evaluation provides solutions that are more realistic. This is because the fuziness captures uncertainties in the operating policy models in the reservoir. Baradaran & Tavazoei (2022) used the fuzzy set system to design automatic irrigation systems in several agricultural fields. The author used parameters of air temperature, relative humidity, wind speed, soil moisture, daily rainfall, soil permeability, air pollution and vegetation. The outputs were the water pump condition, reference and the water stress evapotranspiration, irrigation efficiency, crop water requirements, water pump operation duration and water losses.

The objective of the fuzzy system was to predict the consumption of water under different climates. Results showed that the consumption in winter and autumn was lower than in the summer and spring. In the context of evaluating the significant parameters affecting performance of AIS, fuzzy-set theory can be used. However, considering the reletively higher level of accuracy required in this study, the AHP model is preferred. Other reasons for adopting AHP over fuzzy technique include: AHP is simpler to apply and understand compared to fuzzy techniques, which can be more complex mathematically; The pairwise comparison process in AHP is straightforward for decision making using the AHP model; AHP provides a consistency ratio to check the logical consistency of the pairwise comparisons, whereas fuzzy AHP lacks a well-defined consistency measure. Inconsistent judgments can lead to unreliable results; AHP generates crisp priority weights that are easier to interpret than the fuzzy numbers produced by fuzzy AHP. The fuzzy weights require additional defuzzification steps; AHP is more widely accepted and applied in practice compared to fuzzy AHP; There is a larger body of literature and case studies demonstrating the effectiveness of AHP; AHP is less sensitive to rank reversal when alternatives are added or removed, while fuzzy AHP can exhibit rank reversal issues; AHP requires fewer pairwise comparisons from decision makers compared to fuzzy AHP. This reduces the cognitive burden on experts.

2.2.1 TOPSIS-Entropy Theory

TOPSIS-ENTROPY is an effective tool especially where decision making is complex and can help the decision maker establish priorities and come up with the best decision. The model considers a number of criteria used for evaluation and a number of options from which the best decision is desired. The model establishes a weight for each criterion used for evaluation according to the criteria’s pairwise comparisons by the decision maker. The criteria with most weight will be the most significant parameter. TOPSIS-ENTROPY theory was applied in a study in Gilan, Iran, to assess performance of Sefidroud’s network for irrigation. A list of parameters and sub-parameters used in the evaluation was made, and this is summarized in Table 2.2 (Saaty, 1980).

Table 2.2: Non-technical Parameters and Sub Parameters for Evaluating Performance of Sefidroud Irrigation Scheme using the TOPSIS-Entropy Theory

Managerial	Effectiveness of Infrastructure (EoI)	Measurement equipment required to existing equipment
	Equipping and renovation of land ratio	Land of modernization equipment to the whole network land
	Training	Capacity building and the regularity; whether farmers are satisfied with the existing arrangement or not
Environmental	Drainage ratio	Volume of water drained to volume of water entering the scheme
	River water ratio	Ratio of irrigation water abstracted from the river to water drawn from other sources
	Groundwater ratio	Depth of available groundwater to the critical depth of groundwater
Socio-economic	Credit ratio	Credits required to credits available
	Income	Revenues from rice sales and whether they are satisfactory.

The weights of the parameter and sub-parameter was found using a questionnaire with the format for TOPSIS. According to the findings, the performance of networks for irrigation and drainage can be altered by reducing the significance of the management and technical criteria while increasing the significance of the social and economic criteria (Rangel et al., 2009).

2.3.3 Analytical Hierarchical Process (AHP) Model

The AHP model was introduced by Saaty Thomas in 1990 and is effective in handling complex decision making. The model reduces decisions that are complex into a sequence of pairwise comparisons and then establishes results. Montazar & Zadbagher (2010) used AHP model to assess the productivity of water Saveh and Dez amongst other irrigation networks in Iran. An analysis of the AHP model indicated that the criteria for crop water demand and cultivated area had great importance.

A study was conducted using AHP to benchmark the performance of public irrigation schemes in Kenya. This model is also preferred because it incorporates consistency checks for evaluation by the decision maker. This minimizes bias in the making of decisions (Muema et al., 2018).

2.4 Research Gap

Information on the hydraulic, managerial, socio-economic and environmental performance of Ahero Irrigation Scheme (AIS) that may inform policy on some interventions towards improvement is not available. Information on the efficiency of irrigation water delivery, equity of irrigation water distribution in the farms and blocks, adequacy of irrigation water on the farms and the dependability of the irrigation water through the rice planting and growing season is important in designing for scheme performance improvement to increase yield and lower operational costs. This research sought to evaluate the performance of Ahero Irrigation Scheme to provide this important information that will help in managing irrigation water more efficiently and improve on rice yields while lowering the overall operational costs. Additionally, the study sought to evaluate and provide useful information on the managerial, environmental and socio-economic performance of the scheme.

2.5 Conceptual Framework

Figure 2.1 presents the conceptual framework of this research work, illustrating the interrelation between the technical and non-technical parameters used in the performance evaluation of AIS. The limiting resources include water, land and farm inputs.

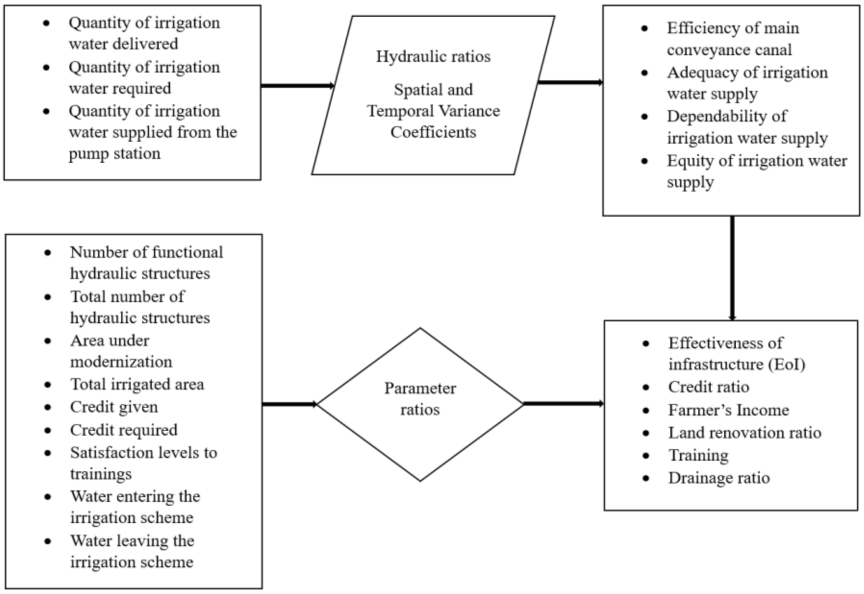

Figure 0.1: Conceptual Framework in the Evaluation of the Hydraulic, Managerial, Socio-economic and Environmental Performance of Ahero Irrigation Scheme

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Ahero Irrigation Scheme (AIS) is located in Kisumu County, Kenya between the Nyabondo plateau and the Nandi Escarpment in an area commonly referred to as the Kano plains. The scheme's construction started in 1966, while operations commenced in 1969. The main crop grown in the scheme under basin irrigation is rice. Other periphery crops grown at the scheme include watermelon, soya beans, tomatoes, sorghum and cowpeas. Sindano rice variety accounts for 90%, basmati 5%, while the remaining 5% is the hybrid type. This cropping pattern was consistent throughout the seasons considered in this study. The gazette area for the scheme is 4,176 acres and the area under irrigation is 2,586.5 acres. Irrigation water is pumped from River Nyando into a partially lined earth canal at a head of 5m. This is the height between the canal and the water surface in the river. The scheme has 2,000 farmers, 570 farm holders, and 20,000 dependents (National Irrigation Authority, 2023). Figures 3.1 presents the location of AIS. The farm layout is presented in Figure 3.2.

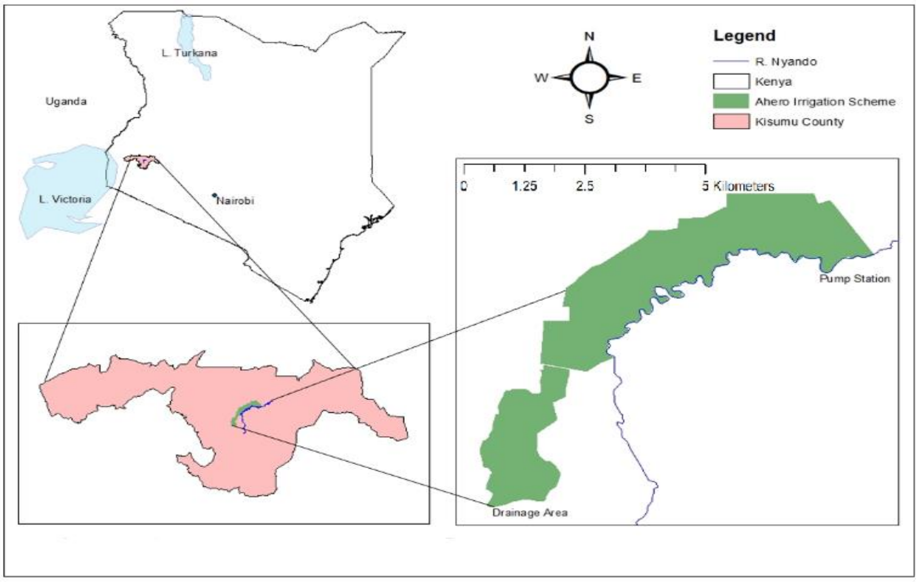

Figure 3.1: Location of Ahero Irrigation Scheme in Kisumu County, Kenya

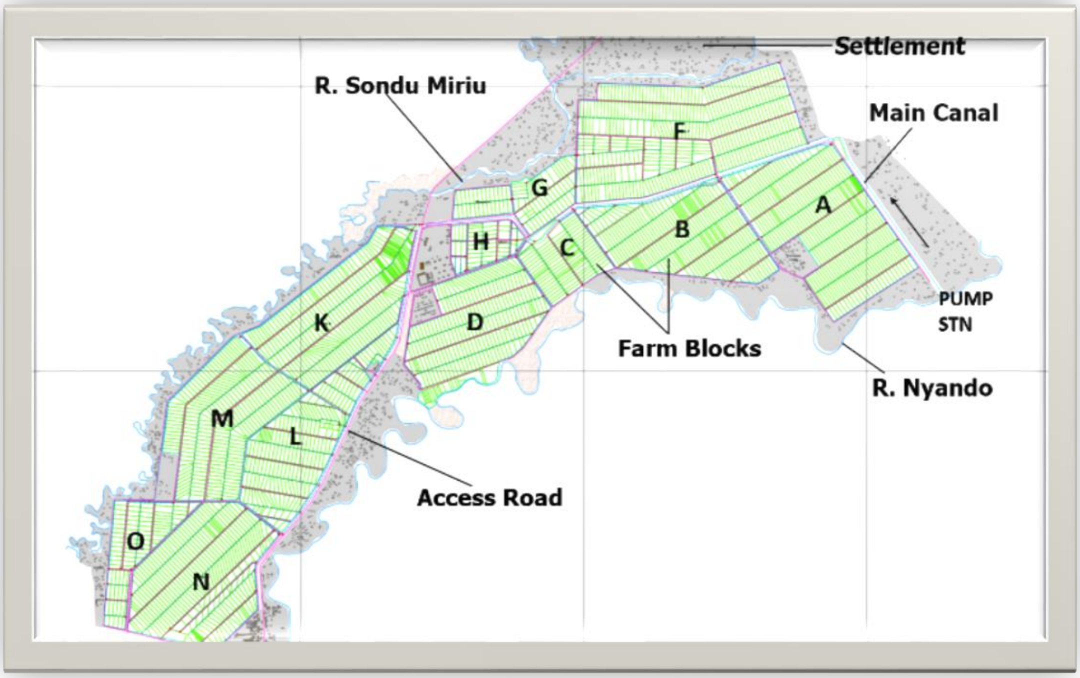

Figure 3.2: Farm Layout in Ahero Irrigation Scheme

3.2 Hydraulic Performance Evaluation

3.2.1 Discharge Measurements

Measurements of discharge in the main canals of each block was calculated using the velocity-area method. Velocity was measured using an Otto C2 current meter. This represented the component Q_D for amount of irrigation water delivered in the main canals of each block. The current meter was used to measure the amount of water to each canal in the farm, the amount of irrigation water entering respective blocks (Staubli et al., 2014). The irrigation water required for each block was calculated and tabulated against the discharge required. Temporal discharge measurements in each block were done for a total base period of three months between April and July in 2020.

3.2.2 Determination of Crop Water Requirements

The water required in each block was found by determining crop evapotranspiration requirements. The evapotranspiration for rice crop was calculated using the FAO Penman-Monteith equation in the CROPWAT 8.0 model (FAO, 1998. The input parameters to the model were climatic data, obtained from the CLIMWAT model for Kisumu. Soil information was gathered from literature (Christian, 2013).

3.2.3 Determination of Conveyance Efficiency

The ratio of irrigation water reaching the farm to the irrigation water supplied from the pump station was computed according to Equation 2.1 to establish the system's hydraulic efficiency (Bos et al., 2005). The calculated conveyance efficiency shall be classified based on the ranges given in Table 3.1.

Table 3.1: Range of Conveyance Efficiencies for any Lining type and their Description

Range (%)	Description
85 - 100	Good
70-84	Fair
<70	Poor

Source: (Bos et al., 2005)

3.2.4 Determination of Adequacy

The ratio of irrigation water required to irrigation water delivered was computed according to Equation 2.2 to determine adequacy of supply of irrigation water in each of the blocks (Bos et al., 2005). The calculated adequacy was classified based on the ranges given in Table 3.2.

Table 3.2: Adequacy Ranges

Adequacy (%)	Status	Water supply
<60	Extremely poor	Inadequate
60-78	Very poor	Deficit
80-90	Good	Deficit
90-100	Very good	Slight deficit
100-110	Good	Slight excess
110-130	Very poor	Excess
>130	Extremely poor	Excess

Source: (Bos et al., 2005)

3.2.5 Determination of Dependability

The ratio of mean to standard deviation for the temporal discharges measured in each block for each of the three months was calculated to find the coefficient of temporal variance CV_T. This coefficient was used to determine dependability by multiplying it with the fraction of the irrigation water delivered against the irrigation water required over the region R, as given by Equation 2.3 (Bos et al., 2005). The calculated coefficient of variance relative to dependability shall be described based on the ranges given in Table 3.3.

Table 3.3: Classification of Dependability

Coefficient of Variance (%)	Classification
0 - 10	Good
10 - 25	Fair
>25	Poor

Source: (Bos et al., 2005)

3.2.6 Determination of Equity

The ratio of mean to standard deviation gave the coefficient of spatial variation CV_R. CV_R was an important parameter in the calculation of equity in irrigation water distribution on the farm. Equity was then determined based on Equation 2.4 (Bos et al., 2005). The calculated coefficient of variance relative to equity were described based on the ranges given in Table 3.4.

Table 3.4: Classification of Equity

Coefficient of Variance (%)	Classification
0 - 10	Good
10 - 25	Fair
>25	Poor

Source: (Bos et al., 2005)

3.3 Managerial, Socio-Economic and Environmental Performance of AIS

3.3.1 Managerial Performance

The indicators used under the managerial parameter include: effectiveness of infrastructure, land renovation/ modernization ratio and training. The total number effectiveness of infrastructure was calculated as the ratio of functional to total number of hydraulic structures in the scheme according to Equation 3.2. Functional structures were identified based on their operationability at the time of data collection. A hydraulic structure whose function was completely impaired was considered dysfunctional (Bos et al., 2005). According to Likis (2021), the range for the effectiveness of structures in irrigation schemes that is considered good is typically around 94% to 96.2%. Land renovation ratio (LRR) was calculated as a ratio of area under irrigation to the total gazette land of the irrigation scheme (Henok, 2014). In order to determine training levels, a questionnaire as given in Appendix A, was used to seek information from farmers on their satisfaction levels with respect to training. The frequency of training in the scheme was evaluated and compared to recommendations (Kijima et al., 2012). Training frequency was an indicator for farmer knowledge and adoption levels of current technologies and best rice farming practices.

$$Land\ Renovation\ Ratio\ (LRR) = \frac{Area\ under\ under\ modernization\ (ha)}{Total\ Irrigable\ Area\ (ha)} \quad \textbf{(3.1)}$$

$$Effectiveness\ of\ Infrastructure\ (EoI) = \frac{Number\ of\ functional\ hydraulic\ structures}{Total\ number\ of\ hydraulic\ structures}$$

(3.2)

3.3.2 Socio-Economic Performance

3.3.2.1 Credit Ratio

As part of the questionnaire responses, farmers gave their average credit requirements against the amount of credit accessible from the Agricultural Finance Corporation (AFC). Credit ratio was then calculated as a ratio of credit required to credit access. Access to credit is essential for farmers to invest in inputs, equipment, technology, and infrastructure, ultimately improving productivity and increasing agricultural output.

3.3.2.2 Farmer’s Income

This was evaluated as a satisfaction measure in the questionnaire administered. Sales after harvest and the profits were used as indicators for farmers income. Income is important for farmers and also helps them invest in inputs, equipment, technology, and infrastructure, ultimately improving productivity and increasing agricultural output.

The questionnaire as given in Appendix A was used to obtain information on farmer satisfaction with incomes, crop yields and the general scheme operation (Rangel et al., 2009). This was further complimented with information from Key Informant interviewers where a checklist was used. Sample size used was calculated at 95% confidence level using Equation 3.3.

$$n = [z^2 * p * (1 - p) / e^2] / [1 + (z^2 * p * (1 - p) / (e^2 * N))] \quad \textbf{(3.3)}$$

Where,

z = 1.96 corresponding to a confidence level of 95%;

p = population proportion in decimals. 0.5 was used in this case, as it represents the worst case percentage;

N = population size;

e = margin of error. 0.05 was used as it corresponds to the 95% confidence level.

Based on this calculation, a total of 235 farmers were interviewed, from a population of 600 farmers in the scheme.

3.3.3 Environmental Performance

The indicator used to monitor environmental performance was the drainage ratio (Montazar & Snyder, 2012). A current meter was placed at the outlet of each main drainage line to measure the total amount of water drained. The total amount of irrigation water entering the farm was also measured. Water in each of the irrigation outlet was measured then the volumes summed up to obtain the total amount of irrigation water entering the farms (Darghouth, 2005). Drainage ratio was then calculated using Equation 3.4.

$$\text{Drainage Ratio (DR)} = \frac{Qo}{Qi} \quad \textbf{(3.4)}$$

Where Q_o = Irrigation water leaving the farm; and Q_i = Irrigation water entering the farm

If $Qo/Qi \approx 1$, then there is no waterlogging in the scheme (Elshaikh et al., 2018).

3.4 Weighting by Pairwise Comparison

The Analytic Hierarchical Process (AHP) model was used to run pairwise comparisons for the managerial, socio-economic and environmental factors to establish the most significant parameter that affects the scheme's performance (Rangel et al., 2009). This is an important step in the use of the Analytical Hierarchical Process (AHP) model. Two criteria were assessed at a time, based on their relative importance. Index values ranging between 1 and 9 were used, as shown in Table 3.5.

Table 3.5: Scale of Relative Importance

Value	Level of Importance
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
1/3, 1/5, 1/7, 1/9	Values for inverse comparison

If the managerial parameter was exactly as important as the socio-economic parameter, the pair was given an index of 1. If the managerial parameter was much more important than the socio-economic parameter, the index assigned was 9. All gradations in between were possible. For a relationship that involved less importance, the fractions 1/1 to 1/9 were given. If for instance the managerial parameter was less important than the socio-economic parameter, the assigned rating was 1/9. The values were entered into a cross matrix, row by row. The diagonal in the matrix contained values of 1. Filling was started from the right upper half of the matrix until each criterion was compared with all the rest. If the rating of managerial to socio-economic was "n", then socio-economic to managerial was rated as "1/n". The pairwise comparison is as illustrated in Table 3.6. The most significant factor established informed the recommendations provided for mitigation (Saaty, 1980).

Table 3.6: Pairwise Comparisons of the Non-technical Parameters Affecting Performance of AIS

Managerial	-	Socio-economic
Managerial	-	Environmental
Managerial	-	Technical
Socio-economic	-	Environmental
Socio-economic	-	Technical
Environmental	-	Technical

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Hydraulic Performance of Ahero's Open Channel Conveyance System

The hydraulic performance of Ahero Irrigation Scheme was presented as the conveyance efficiency of the main canal, adequacy, equity and dependability of irrigation water supply as shown in the following sections.

4.1.1 Conveyance Efficiency of the Main Canal

Results from field data collection of the water inflow and outflow rates of the various blocks in AIS as well as the computed overall conveyance efficiency of the main canal are summarized and presented in Table 4.1.

Table 4.1: Inflow, Outflow Rates in AIS Blocks and the Overall Efficiency of the Main Canal

Block Number/Name	**Inflow (m^3/s)**
A	0.004
B	0.008
C	0.076
Research	0.050
H	0.368
K	0.044
Total Flows to the Farms	**0.55**
Pump Station Outflow (m^3/s)	**0.917**
Conveyance Efficiency of Main Canal (%)	**59.98**

Table 4.1 presents measurements on average inflow into blocks and the total average outflow from the pump station. The blocks included in Table 4.1 were those with inlets, from where the discharge measurements were done. Blocks F and G share inlets with blocks B and C respectively. Blocks M, L, O and N share an inlet with block K. The calculated overall conveyance efficiency of the main canal was found to be 59.98% rated as poor based on Table 3.1. This finding implies that AIS loses over 40% of the total pumped water through conveyance.

The main canal is earthen and partially lined, therefore encouraging seepage and deep percolation losses of substantial amounts of irrigation water into the ground. At the time of taking these measurements, it was also noted that the main canal was heavily silted and had overly grown grass that impeded free flow of irrigation water and thus contributing to additional losses. According to FAO (1998) guidelines, the conveyance efficiency of well-maintained earthen canals with loam soils should be at least 70%. The implication is that the main canal of AIS is not properly maintained and therefore there is need for developing a routine maintenance schedule of the canal in order to improve on the conveyance efficiency. Evaporation is identified as one of the main ways through which irrigation water is lost in major irrigation canals, along with seepage through the canal bunds and overtopping of the bunds and hence the inefficiencies in water supply. Alordzinu et al. (2017), while evaluating the technical performance of Okyereko irrigation scheme in Ghana, established conveyance efficiencies in the range of 61-97% showing that there was no serious decline in the system or increased unlawful withdrawals of water in the season. This was the result of farmers accessing adequate irrigation water, which in turn enhanced good maintenance practices. A study by Jadhav et al. (2014) in India established a conveyance efficiency of 75% in trapezoidal canals that were lined with concrete. Findings from this study confirm the suggestion that lining of irrigation water conveyance canals results in improved conveyance efficiencies. Lining of the canal reduced seepages significantly; the slight inefficiencies were majorly contributed by evaporation of the irrigation water in the main canal. This is further supported by Mojira & Dagalo (2021) findings who while evaluating the hydraulic performance of Kuraz Sugar Development Project in Ethiopia, established a conveyance efficiency of 81% (good). The study also revealed that proper irrigation canal maintenance is a factor that contributed to the good conveyance efficiencies. Some good practices can be borrowed from these studies and implemented at AIS in order to improve the conveyance efficiency.

4.1.2 Adequacy of Irrigation Water Supply

Adequacy in the upper, mid and lower stream sections of the scheme were calculated using Equation 2.2 and was established as 0.99 (very good), 0.82 (good) and 0.74

(poor) respectively, based on Table 3.2. This implies that the irrigation water at the upper and mid sections of the scheme was adequately supplied and the rice crop experienced no deficit supplies at the time of measurement. At the lower section of the scheme, a significant amount of irrigation water had been lost through conveyance inefficiencies hence the lower adequacy levels. Bwambale et al. (2019) while evaluating the adequacy for Doho Rice Irrigation Scheme in Uganda, established percentages of 100%, 84% and 68% at the head, middle and tail riches of the scheme respectively. The recommendation was to line the main canal so that more water can be delivered at the tail reaches of the scheme. These findings corroborate with the findings reported in this study. Mojira & Dagalo (2021), while evaluating the hydraulic performance of Kuraz Sugar Development Project in Ethiopia, found an adequacy of 98% (good). Findings for maintenance at the scheme revealed that the system required minimum maintenance. There was a strong relationship between maintenance levels of the canals and the conveyance efficiency, suggesting the importance of computing and comparing adequacy of irrigation water delivered to the various sections of the scheme.

Sserunkuuma et al. (2009) also reported inadequate deliveries of irrigation water at the downstream of Doho Rice Irrigation Scheme in Uganda and this compares to the findings at the downstream of AIS. Tarate et al. (2018) while assessing water delivery for India's Jayakwadi Irrigation Project, reported an average adequacy score of 50% suggesting inadequate irrigation water delivery.

4.1.3 Equity of Irrigation Water Supply

Table 4.2 presents the coefficient of variance established after measuring irrigation water volumes in 83 different farms in a single block of the scheme.

Table 4.2: Equity in the Tail Reach of the Farm

Farm No.	CVa*(d/r)	Farm No.	CVa*(d/r)	Farm No.	CVa*(d/r)	Farm No.	CVa* (d/r)	Farm No.	CVa*(d/r)	Farm No.	CVa*(d/r)	Farm No.	CVa*(d/r)	Farm No.	CVa*(d/r)
1	**0.52**	12	**0.24**	23	**0.05**	34	**0.36**	45	**0.19**	56	**0.13**	67	**0.97**	78	**1.40**
2	**0.20**	13	**1.39**	24	**0.32**	35	**0.25**	46	**0.39**	57	**0.44**	68	**0.90**	79	**0.90**
3	**1.29**	14	**0.52**	25	**0.63**	36	**0.10**	47	**0.37**	58	**0.13**	69	**1.20**	80	**1.25**
4	**0.77**	15	**1.50**	26	**0.41**	37	**0.26**	48	**0.39**	59	**1.03**	70	**0.68**	81	**0.63**
5	**1.27**	16	**0.65**	27	**0.67**	38	**0.08**	49	**0.52**	60	**2.01**	71	**0.83**	82	**0.83**
6	**0.75**	17	**0.84**	28	**0.26**	39	**0.03**	50	**0.20**	61	**1.66**	72	**0.93**	83	**0.56**
7	**0.50**	18	**0.50**	29	**0.29**	40	**0.34**	51	**0.22**	62	**0.68**	73	**0.92**	Average	**0.57**
8	**0.24**	19	**0.99**	30	**0.24**	41	**0.06**	52	**1.05**	63	**0.39**	74	**0.54**		
9	**0.30**	20	**0.11**	31	**0.31**	42	**0.17**	53	**1.42**	64	**0.42**	75	**0.31**		
10	**0.52**	21	**0.18**	32	**0.04**	43	**0.15**	54	**0.46**	65	**0.30**	76	**0.75**		
11	**0.44**	22	**0.60**	33	**0.34**	44	**0.28**	55	**0.44**	66	**0.44**	77	**0.28**		

Equity of water distribution was calculated using Equation 2.4 and was found as 0.57 (poor).

According to Degirmenci et al. (2003), productivity declines under poor equity conditions. To improve food security and the role of irrigation, equity in all the reaches has to be improved. The closer the Equity (PE) value is to zero, the higher is the equity degree in delivery. Fan et al. (2018) examined the management of irrigation water at Jiamakou irrigation project in China, where findings indicated that water was poorly allocated. The recommendation was that farmers be given training on irrigation water allocation. Similarly, with poor equity in AIS, it was found that farmers had little knowledge on the hydrodynamic characteristics of the flow, and also on rice crop water requirements. Therefore training in water allocation will help in addressing inequitable supplies from farm to farm in AIS.

4.1.4 Dependability of Irrigation Water Supply

The dependability values for AIS in year 2020 and 2021 for the April-July season are as shown in Table 4.3. One season of April-July 2020 was considered primarily for this study, but for purposes of comparison, the April-July season 2021 was also evaluated.

Table 4.3: Seasonal Dependability Values for Ahero Irrigation Scheme for Years 2020 and 2021 (April-July Season)

Category	Low (mm)	High (mm)	Average (mm)	Mean	Stddev	CV_T (%)
4/30/2020	78.0	172.0	133.1			
5/31/2020	87.8	166.5	140.1	130.2	6.9	**5.3**
6/30/2020	90.0	148.0	124.5			
7/31/2020	74.6	148.0	123.2			
4/30/2021	112.0	193.0	145.9			
5/31/2021	102.4	160.4	139.4	128.4	14.6	**11.3**
6/30/2021	88.0	143.0	116.9			
7/31/2021	83.6	152.2	111.5			

The dependability of irrigation water supply in Ahero Irrigation Scheme in 2020 (April-July season) was 5.3 (good). However, in 2021 and for the same April-July season, dependability was 11.3 (fair). The variation in average volumes of irrigation water supplied monthly for the aforementioned season is within acceptable range for the year 2020. However, for the following year 2021 and same reference season (April-July), findings established significant variations in irrigation water supplies onto farms in the scheme.

An evaluation on the monthly variability in water supplies was also done for 2020 and 2021, to gather a general overview on stability of irrigation water supplies across the year. The findings are as shown in Table 4.7. The coefficient of variance for 2020 was 16.23 (poor) while for 2021 was 12.81 (poor).

Variation in irrigation water supply is more significant when basing on an entire year than when considering cropping seasons alone. Irrigation water supply in the scheme is affected by water levels in River Nyando. Weather is an important criterion in defining these gage levels in the river. When considering an entire year, there are months that are usually dry, while others are wet and hence the variation in the river volumes. On the other hand, when considering a season, the weather patterns in the reference season are more uniform, and therefore insignificant variability in river volumes. This consequentially implies that the abstraction and supply volumes of irrigation water on farms will fairly be uniform.

Alordzinu et al. (2017), while evaluating the technical performance of Okyereko irrigation scheme in Ghana, established a dependability of 1 in block 1 and block 5, meaning that the delivery of water to the plot's edges was being done as planned. The period of waiting between two water applications in the blocks was 7 days. Dependability for blocks 2, 3, 4, and 6 however was less than 1. The period of waiting between two seasons was about 4 days for the reference season. In this case, farmers could access water at whatever time and therefore did not need to wait for the scheduled day of irrigation water delivery.

Based on questionnaire feedback gathered from farmers in AIS, yields have been varying significantly from season to season, and this has greatly been influenced by variations in supply volumes of irrigation water, dictated by the seasonal weather changes. Therefore, to realize optimal rice production in the scheme, irrigation supply volumes should be maintained within a temporal variance of 0-10%. This can be achieved by optimizing water use in the scheme while saving the otherwise excess waters for use during dry seasons. The other option is to maintain seasonal planting, which has the disadvantage of not maximizing production since planting will be restricted to wet seasons alone, as is the case at the moment.

Korkmaz & Avci (2012) found dependability to be fair while evaluating the irrigation and water delivery performances of the Menemen Left Bank irrigation district. This finding compares with the dependability finding in this study since both are below average and were majorly influenced by unstable flows in the main rivers and the illegal water abstractions from the main canals. Table 4.4 presents the actual evapotranspiration values for the reference years 2020 and 2021, for which dependability was calculated. The AET is an indicator of the amount of irrigation water supplied to the crop within the reference months.

Table 4.4: Annual Dependability Values for Ahero Irrigation Scheme for Years 2020 and 2021

Year	Month	AET (mm)	Mean	SD	CV_T (%)
2020	Jan	148.4			
	Feb	155.5			
	Mar	114.9			
	Apr	90			
	May	121.5			
	Jun	139			
	Jul	144.9	132.7	21.5	**16.2**
	Aug	146.9			
	Sep	106			
	Oct	123.8			
	Nov	132			
	Dec	169.5			
2021	Jan	154.2	129.4	16.6	**12.8**
	Feb	129.8			
	Mar	148.8			
	Apr	132			
	May	110.7			
	Jun	98			
	Jul	133.5			
	Aug	143.8			
	Sep	140			
	Oct	136.3			
	Nov	117			
	Dec	108.8			

To enhance the dependability of irrigation water supply in Ahero Irrigation Scheme, several strategies can be implemented based on the observations and measurements made at the scheme: Enhancing the canal conveyance efficiency which can lead to better water supply reliability; Investing in water supply infrastructure that meets legal requirements for water use and designing systems to provide sufficient water per crop water needs; Designing for sufficient water capacity at the scheme, such as ensuring at least 1 inch of water every three days per acre irrigated, which will help meet peak summer demands and provide a buffer for irrigation downtime, thus improving the reliability of water supply; Monitoring water levels, recharge rates, and potential withdrawal sites will also help maintain a dependable water supply in the irrigation scheme (Juharsyah, 2002).

4.2 Managerial, Socio-economic and Environmental Performance of Ahero Irrigation Scheme

The indicators used for managerial performance in Ahero Irrigation Scheme were the Effectiveness of hydraulic Infrastructure (EoI), Land Renovation Ratio and Training also referred to as capacity building for farmers.

4.2.1 Managerial Performance

4.2.1.1 Effectiveness of Infrastructure

Findings of the different hydraulic structures and their functionality as used in evaluation of EoI in the different blocks of Ahero Irrigation Scheme are presented in Table 4.5. The selection of the hydraulic structures was informed by literature and also based on the existing structures in the scheme.

Table 4.5: EoI in the Different Blocks of the Scheme

Block/Canal	Gates	Weirs	Division boxes	Culverts	Pumps	Flume	Basin
A	6/10*	Nil	4	16/18	Nil	Nil	Nil
B	8/11	Nil	5	10/12	Nil	Nil	Nil
C	2	Nil	1	4/5	Nil	Nil	Nil
D	4/5	Nil	2	8/12	Nil	Nil	Nil
Research Station	8/12	Nil	14	20	Nil	Nil	Nil
F	3/4	Nil	2	11	Nil	Nil	Nil
G	8	Nil	3/4	18/20	Nil	Nil	Nil
K	2	Nil	1	2	Nil	Nil	Nil
L	3/6	Nil	3	7	Nil	Nil	Nil
M	2/3	Nil	1	3	Nil	Nil	Nil
N	9/12	Nil	5	8	Nil	Nil	Nil
O	3/6	Nil	3	10	Nil	Nil	Nil
P	4/8	Nil	3	9	Nil	Nil	Nil
Main canal	24	6/7	4	26	2/4	1	4
Main drain	Nil	Nil	Nil	8	Nil	Nil	Nil
Total No. of functional hydraulic structures							317
Total No. of dysfunctional hydraulic structures							39
EoI							89%

*****6/10 means 6 functional hydraulic structures out of 10 hydraulic structures.

Functional structures are those that are operational while dysfunctional structures are those whose functionality has been impaired. From Table 4.9, EoI was computed according to Equation 3.2 and found to be 89% which is more than the recommended minimum of 80% according to Elshaikh et al. (2018). This can be attributed to the regular repair and maintenance of the hydraulic structures at the scheme. Hydraulic structures that are faulty and beyond repair are also usually replaced on a regular basis. It should however be noted that an EoI of at least 80% does not necessarily mean that the system is functional. In an instance where a critical unit is dysfunctional and the rest are functional, the minimum EoI of 80% would be met, yet the system will not function because of the one critical component that is not functioning. EoI is therefore meant to provide a general indication on the condition of the hydraulic structures in the scheme. Thus, based on the findings, the hydraulic structures in Ahero Irrigation Scheme are generally in good condition, hence the maintenance schedule of the hydraulic structures in the scheme can be maintained.

4.2.1.2 Land Renovation Ratio in Ahero Irrigation Scheme

The total irrigated area was 2,586.5 acres and the irrigable area was 4,176 acres. Hence, the irrigation ratio was established as 62%. The reason for not utilizing the full capacity of the scheme could be limited storage for harvested rice, limited market, failure by farmers to embrace farming, low returns from rice farming, failure to mobilize resources needed in rice farming, portions of land set aside for other activities and limited pumping capacity of irrigation water. Currently, even with the scheme farming on only 62% of its total irrigable land, the harvested rice still does not have a market stable market because of cheap imports that flood the markets. Farmers for instance explained how they still had their harvest lying in the stores for over one year without proper markets. On pumping, there have been challenges with reliability of the water supply linked with frequent electricity outages and pump breakdowns. In terms of resources therefore, the scheme was not ready to manage irrigation on the entire 4,176 acres of land. Kartal et al. (2019) while ranking irrigation schemes based on principle component analysis in the arid regions of Turkey found an average irrigation ratio of 55.68% and recommended an improvement of the distribution systems of water and also the technology utilized on both farm and management levels. Tu et al., (2021) studied land accumulation as an alternative to improving the environmental and technical efficiencies of rice production in the Mekong Delta, Vietnam. The author established that land accumulation was positively linked with both the technical and environmental efficiencies and hence rice production. Therefore, if Ahero Irrigation Scheme improves the production area from the current 2,586.5 acres to its full capacity of 4,176 acres, rice production will significantly improve. This will however need to be marched up with newer markets to cater for the extra rice yields. Also, irrigation water and infrastructural requirements will have to be improved as shall be discussed in the later sections.

4.2.1.3 Training of Farmers

From the feedback gathered, 42 farmers were satisfied with the training schedules while 98 farmers were dissatisfied. A few farmers were indifferent. It was noted that the training of farmers was done once in every three years, meaning that the farmers had inadequate competencies that were necessary to optimize rice production. Farmers could stay for over two years without getting extension service aimed at enhancing their competencies in rice farming. This has the negative effect of farmers continuing with their traditional farming methods informed by little science. The dynamics of farming including how to deal with new emergent crop diseases, could therefore not be addressed in time. Also, knowledge on efficient crop water management was lacking, a factor that contributes to mass water wastages at the scheme. With limited training therefore, farmers are unable to cope with emerging farming trends and end up not farming optimally. According to Augier et al. (1995), to improve performance of an irrigation, it is vital to not only promote the execution of irrigation scheduling methods, but to concurrently improve system performance and design and to better the skills of farmers in managing and controlling their irrigation system in a more efficiently manner during operation. Nakano et al. (2015) studied the effect of technological adoption and productivity training of rice farming in Tanzania. The author established that farmers who were not trained learned new ideas from trained farmers by checking their plots and through social forums. As a result, the directly trained farmers had their paddy yield increased from 3.1 tons per ha to 4.7 tons per ha. On the other hand, paddy yield of the non-trained farmers improved from 2.6 tons per ha to 3.7 tons per ha. This study signifies the importance of training to farmers and the effectiveness of farmer-to-farmer extension. In Ahero Irrigation Scheme therefore, the strategy of training a few farmers then encouraging them to train the rest of the farmers can be helpful if training costs are to be reduced and enhance more regular and sustainable trainings. Kijima et al. (2012) evaluated the effect of training on lowland productivity of rice in Uganda. The study established that farmer participation in training significantly improved the adoption of the improved practices of rice cultivation. Also, the profit margins from the production of rice were improved by the training program. The findings of the study agree with the hypothesis that among the bigger constraints on growth of rice production in sub-Saharan Africa if the lack of extension programmes. These findings agree with the results of this particular study. It should be noted that leasing of land did not have a direct effect on training since the farmers considered here were those owning/possessing and farming the land at the time of the study.

4.2.2 Socio-economic Performance of the Scheme

Findings on farmer’s credit ratio and income are as discussed in sections 4.3.1 and 4.3.2 respectively.

4.2.2.1 Farmer’s Credit Ratio

The credit ratio by the Agricultural Finance Corporation (AFC) for AIS was found to be in the range of 0.5-0.75. Credit given to farmers was based on the capacity of the farmers to pay back. Capacity was evaluated in terms of their farm sizes and expected yield. Most farmers owned 4 acre parcels of land, while a few had 2 acre sizes of farmland. It was therefore expected that farmers with 4-acre lands would be given more credit than those that owned 2-acre farmlands. Credit advanced to farmers was recovered through deductions from rice sales. This low credit access by farmers in Ahero Irrigation Scheme make them struggle to afford essential inputs like seeds, fertilizers, and machinery. This leads to reduced yields and lower productivity as farmers are unable to invest adequately in their crops. Also some farmers experienced delayed planting due to the inability to purchase planting supplies on time. This delay impacted crop growth and development, ultimately affecting the overall production output.

Evans et al. (2018), while studying Kenya’s rice production and marketing, recommended that in order to integrate and promote rice agribusinesses in the country, there was need for the rice farmers to have easy access to financial services which shall provide affordable funds and in a sustainable manner. Njeru et al. (2016) assessed the role of credit access in the production of rice in Mwea Irrigation Scheme. The author established that fertilizer use and paddy yield per hectare were not different among borrowers from rice traders, cooperative society and non-borrowers. It was however noted that those who borrowed from rice traders got lower incomes and profits in comparison with non-borrowers because of the high interests. The author recommended policies to improve credit markets for both equity and efficiency of rice production in sub-Saharan Africa. The findings of this study agree with those of AIS since credit access is poor. The improvement of credit markets through policies would lower interests and make it easier for rice farmers to access credit. This should in turn significantly augment rice production in the scheme. Duy et al. (2015) identified credit access as an important factor in increasing rice production, while evaluating the effect of credit access on rice production efficiency in the Mekong Delta, Vietnam.

4.2.2.2 Farmer's Income

Income to farmers was poor, as indicated by the responses in Figure 4.2 and this was the result of poor markets for the harvested rice. The local Kenyan market was heavily endowed by cheap imported rice, a factor that made it difficult for the local rice to sell. Evans et al. (2018) cited competition from cheap imported rice as one of the reasons constraining the rice sub-sector in the country. It was noted for instance, that farmers had spent over 1 year without getting proceeds of their previous harvest. The main source of income for most farmers was from rice farming and therefore most of their farming operations relied on revenues generated from the sale of rice. In scenarios where a previous payment is delayed, their subsequent farming operations will be negatively affected. According to a study by Yamane (2023) on the role of rice cultivation income on farmer's livelihoods in Kenya as evidenced from AIS, wage labor income was higher and more sustainable than that from rice cultivation. The author also noted that farmers relied on several income sources to balance their everyday income and expenditures. Kipkorir et al. (2001) reported a vicious cycle of poverty in Bunyala, West Kano and Ahero irrigation schemes while evaluating the challenges of farmers with rice productivity in the mentioned schemes. These results correspond to the findings of this research, that revealed poor farmer incomes as a result of poor markets for the harvested rice. It was noted that there was readily available market for poor quality rice with moisture content of >14% in Uganda. In Kenya, millers can only buy rice at moisture contents of <14%. Also, the rice preference by Kenyan consumers is mostly whole grain, unlike in neighbouring countries like Uganda where all grades can be taken. Rice farmers also face the challenge of disposing off rice to brokers so as to attend to their immediate needs, hence fetching lower returns.

4.2.3 Environmental Performance of the Scheme

The drainage ratio for AIS was found as 33%. The implication is that out of the total inflows into the scheme from the pump station, only 33% is drained. The remaining 67% accounts for the rice crop uptake and the ponding in various sections of the scheme. According to Elshaikh et al. (2018) if the drainage ratio is close to 100%, then waterlogging is not a challenge. It should be noted however that the ratio here includes only water measured at the inflow and at the outflow of the scheme. Water lost through deep drainage is not factored and therefore the value of 33% does not necessarily imply that the scheme has a problem of waterlogging. The problem of flooding in the scheme has majorly been the result of excess rains during the wet season but has been exacerbated by the poor drainage conditions at the scheme. The flooding usually results in tremendous damage to crops and infrastructure, and therefore flood control mechanisms should always be installed to alleviate this danger in flood prone areas. In Ahero and West Kano irrigation schemes for instance, rice worth KS. 800 million were destroyed after River Nyando's banks were broken by flood waters that swept through the farms. The floods also extensively damaged the infrastructure by the National Irrigation Authority (NIA) in the two schemes. Extensive areas of land were submerged in water with seedlings that were newly planted being washed into Lake Victoria. By addressing management criteria, this environmental criterion will be taken care of, and therefore crops and infrastructure will remain safe.

The other environmental parameter that is of significance is the change in water table. Lower water tables affect farmers extremely, since there will be no water to irrigate crops. On the other hand, a rise in water table/waterlogging bring with it salts, that are left on the cultivable part of the soil when the water evaporates. Low irrigation efficiencies in the range of 20 - 30% is one of the main reasons for the rise in water table. Poor systems of water distribution, poor management of the main system and in-field irrigation practices that are archaic are other reasons. The recommendation by ICID to improve field application efficiency to about 50% can greatly minimize rise in groundwater. The environment criteria although significant in irrigation scheme performance, is comparatively of less in this study (FAO/ICID Joint Publication, 1997).

Figure 4.1 presents the feedback obtained from farmers on the various parameters considered.

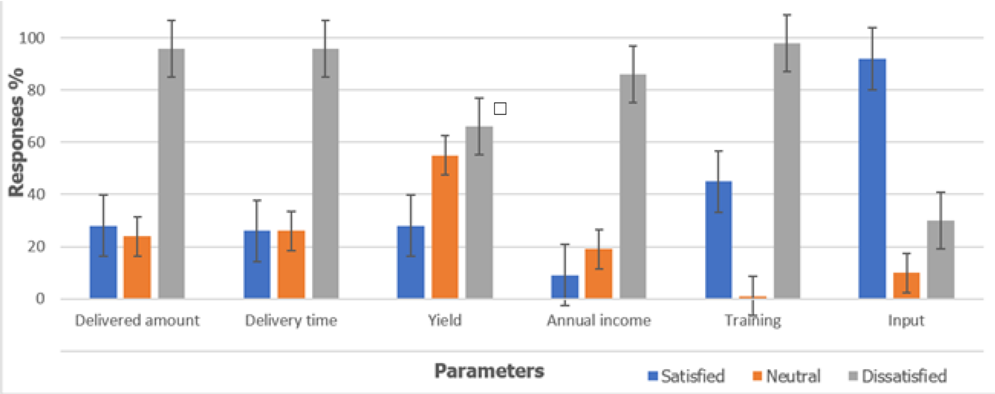

Figure 4.1: Farmer Feedback on the Technical, Environmental and Socio-economic Performance of AIS

4.3 Prioritization of Scheme Performance Criteria

The hydraulic, management, socio-economic and environmental performance criteria for Ahero Irrigation Scheme were evaluated for their significance using the Analytical Hierarchical Process (AHP) model and based on feedback from farmers. Table 4.6 illustrates the pairwise comparisons between these criteria used.

Table 4.6: Pair-wise Comparison Matrix

	Hydraulic	**Management**	**Socio-economic**	**Environmental**
Hydraulic	1.0	5.0	3.0	5.0
Management	0.2	1.0	0.2	3.0
Socio-economic	0.3	5.0	1.0	7.0
Environment	0.2	0.3	0.1	1.0
Sum	**1.7**	**11.3**	**4.3**	**16.0**

Each value in the pairwise comparison matrix was expressed as a fraction of the sum to obtain the normalized pairwise matrix as presented in Table 4.7. The average of each criteria was calculated to form the criteria weights. Consistency calculations were done to check accuracy of the findings, and are as presented in Table 4.8.

Table 4.7: Normalized Pair-wise Matrix

	Hydraulic	**Management**	**Socio-economic**	**Environmental**	**Criteria Weights**
Hydraulic	0.588	0.442	0.698	0.313	0.510
Management	0.118	0.088	0.047	0.188	0.110
Socio-economic	0.176	0.442	0.233	0.438	0.322
Environment	0.118	0.027	0.023	0.063	0.057

Table 4.8: Consistency Calculations

	0.510	**0.110**	**0.322**	**0.057**			
	Hydraulic	**Management**	**Socio-economic**	**Environmental**	**Weighted sum**	**Criteria weights**	
Hydraulic	0.510	0.550	0.967	0.287	2.315	0.510	4.536
Management	0.102	0.110	0.064	0.172	0.449	0.110	4.080
Socio-economic	0.170	0.550	0.322	0.402	1.445	0.322	4.484
Environment	0.102	0.037	0.032	0.057	0.228	0.057	3.974
						λ_{max}	**4.269**

Table 4.10 presents calculated random indices for the given “n” attributes.

Table 4.9: Random Indices for ‘n’ Attributes

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Consistency Ratio, CR = 0.0897/ 0.90 = 0.0997 0.0997 < 0.10, hence OK. We therefore can proceed with the process of decision-making using Table 4.10 that summarizes the weights of the various non-technical criteria used.

Table 4.10: Criteria Weights for the Evaluated Parameters

Criteria	**Weightage**
Hydraulic	0.51
Socio-economic	0.32
Management	0.11
Environment	0.06

From Table 4.10, the hydraulic parameter should be given more priority followed by the socio-economic, management and the environmental parameters respectively. From the data gathered, there’s 51% weight that water delivery challenges are to be addressed; 32% weight that poor market and low farmer returns are to be countered; 11% weight that the scheme management is to be fixed; and an almost insignificant weighting for the need to address environmental problems. The hydraulic parameters to be improved are the efficiency, adequacy, equitability and timeliness of water supply in the scheme. On water delivery to farms, farmers preferred the introduction of a gravity system to the existing pumped system. On various occasions, electricity outages are suffered, affecting pump operation, and hence water deliveries on farms. However, with a gravity system, continual flow of water will be guaranteed, enabling farms to receive adequate flows. Montazar & Zadbagher (2010) used AHP model to assess the global productivity of water for Saveh and Dez irrigation networks in Iran. An analysis of the AHP model indicated that the criteria for crop water demand and cultivated area had great importance. Hasily et al. (2020) used AHP while evaluating networks for irrigation and drainage in Khuzestan Province. Findings indicated that the field and climate factors in Hendijan and Shahid Rajae networks had the most weight in the Ramshir network. Economic factors had the least weight. The simplicity of this technique and the available literature guiding its use made it convenient for utilization in this study. This model is also preferred because it incorporates consistency checks for evaluation by the decision maker. This minimizes bias in the making of decisions.

On the Effectiveness of Infrastructure (EoI), despite finding a value of 0.89 (good), the parameter is not to be regarded as an exhaustive indicator on the managerial performance of the scheme. This is because it only expresses the ratio of functional hydraulic structures to the total number of infrastructure in the scheme. This means that despite the good state of infrastructure, their number and distribution in the scheme is limited. The total number of flow measuring devices should be increased to at least twelve representing each of the twelve blocks. This will help track flows entering individual farm blocks, making it possible for farmers to schedule irrigation water application (Bwambale et al., 2019).

Concerning returns, it was noted that the farmers were spending well over one year waiting to make sales of a previous harvest because of the constrained markets. The crop was facing competition in the market from imported rice. There was therefore need for the scheme's management to look for new markets for the crop both locally and internationally. Also, farmers preferred the incentive of fertilizer provision by NIA to further enhance returns. Okada et al. (2008) conducted a research to quantify effects of management and hardware improvements on performance of an irrigation project using AHP. The research revealed that the quality of water delivery service had a significant effect on crop production. This compares well with findings from this study that shows significance of water delivery on the farms.

Sun et al. (2017) evaluated the management of agricultural water in northern China's irrigation districts using an improved Analytical Hierarchy Process method. The index system that was used in the evaluation included engineering, technology, management, economic and environment. The agricultural water management grades for Shijin Renmin Shengliqu and Fenhe irrigation districts were established by the Fuzzy Comprehensive Evaluation and the Grey correlation method. The weights of the engineering, management, technology, economics and environment were found as 0.2147, 0.2138, 0.2128, 0.1797 and 0.1791 respectively. Thus, the engineering index was the most important factor in influencing the management of agricultural water in the irrigation districts, followed by management. The study therefore provided a better theoretical background to aid in improving the management of agricultural water in the considered districts. These findings conform to the findings of this research work since the hydraulic parameter has been found to be the most critical factor in influencing the performance of Ahero Irrigation Scheme.

Okada et al. (2008) applied the AHP model to evaluate the effects of the internal processes of an irrigation project on crop yield. The study quantified the impacts of hardware and management improvement on the performance of an irrigation project. The study started by developing the AHP model using the project's internal process indicators of the improvement process. The model was then applied in scoring 16 projects that have been dealt with in FAO Water Reports 19. The effects of the assessment factors on the performance of the irrigation project were then analyzed by varying the weights of the factors used for evaluation and making comparisons of the correlations between the scores of the AHP model and the crop yields. Findings revealed that crop production were significantly influenced by the quality of service of water delivery. The correlation analyses did not indicate any serious relationship between water delivery services, hardware and management. The study in AIS also revealed serious relationship between the quality of water service delivery to the crop yield. The low reaches of the scheme that had poor water deliveries had low yields, while the upper reaches that had better water service deliveries, had better yields.

Aghajani et al. (2017) used AHP and the Topsis method to evaluate the performance of both the irrigation and drainage networks in Sefidroud. The attributes used include management, hydraulic, environmental, social and economic criteria. For each of the attributes, several sub-criteria were selected. The weights of the criteria and sub-criteria were measured using AHP and TOPSIS. Findings indicated that management had the highest significance with a weight of 0.384, while the environmental criterion had the least significance with a weight of 0.09. Findings for AIS also showed that the environmental criterion had the least impact on the performance of the scheme.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The following conclusions can be made from this study:

i. The efficiency of irrigation water supply, adequacy of irrigation water reaching the farms, equity of irrigation water distribution within the blocks and dependability of irrigation water supply was found to be below the standard recommendations. On the hydraulic parameter, the canal's conveyance efficiency was found as 60% which was rated as poor; adequacy in the upper, mid and lower streams of the scheme was 0.99 rated as very good, 0.82 rated as good and 0.74 rated as poor respectively. Equity was 0.57 corresponding to a rating of poor; the coefficient of variance for dependability for the 2020 April-July season was 5.3 rated as good based on standard classifications, while for the whole year, dependability was 16.23 and rated poor. The water distribution and utilization in the scheme was inefficient as per the hydraulic performance findings.

ii. The managerial, socio-economic and environmental performance of Ahero Irrigation Scheme (AIS) can generally be rated as fair, based on the recommended standards applied for each case. On the managerial parameter, effectiveness of infrastructure was found to be 89% while the irrigation ratio was found as 62%. It was also found that training to farmers was not undertaken regu1larly, implying farmers were not well-abreast with effective farming operations. On the socio-economic parameter, the credit ratio was 0.5-0.75, meaning farmers could not access their full loan requirements compromising on their farming operations and hence production. Credit was given to farmers based on their capacity to pay back. On the environmental parameter, the drainage ratio was found as 33% and hence the ponding of irrigation water in the scheme due to poor drainage.

iii. Based on the overall AHP analysis, the hydraulic parameter (51%) should be given more priority followed by the socio-economic (32%), management (11%) and the environmental parameters (6%) respectively while prioritizing the most important parameters to be fixed.

5.2 Recommendations

i. The study recommends improvement in the conditions highlighted for poor hydraulic, managerial, socio-economic and environmental performance of the Ahero Irrigation Scheme. Canal lining is a practical step to reducing water losses and achieving better irrigation water delivery efficiencies, adequacies, equity, dependability of irrigation water. This, coupled with prompt repair or replacement of damaged structures will complement efficient irrigation water deliveries on farms. Also, the study recommends a shift from pumped to gravity irrigation to eliminate the inconveniences and losses by power blackouts.

ii. The study recommends further research using more indicators such as the groundwater ratio, Standardized Gross Value of Production (SGVP) and Farmer's Participation for performance assessment and a practical model design to improve the performances within the recommended ranges. These extra performance indicators will provide better understanding of the critical groundwater depths, the economic output of the irrigation scheme by considering the gross value of production per cropped area and per unit of irrigation supply, and the effectiveness of farmers' involvement in the operation and maintenance of the irrigation system, which can impact its overall performance. Also, the relationship between adequacy and biomass from remote sensing data is recommended for further study.

iii. Under limited resources, a prioritization of parameters to be fixed in the scheme is necessary. Based on the overall AHP analysis, the hydraulic parameter (51%) should be given more priority followed by the socio-economic (32%), management (11%) and the environmental parameters (6%) respectively. Policy formulations should be made to addressing hydraulic and managerial performance in Kenya's public Irrigation schemes as this will have a trickling effect on both the socio-economic and environmental performances and will boost the overall yields in the schemes at reduced operational costs.

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APPENDICES

Appendix I: Questionnaire

This simple survey is part of a Masters Research work to enable collection of substantive information that shall guide the improvement of the performance of Ahero Irrigation Scheme. We guarantee confidentiality on the information provided and therefore encourage respondents to freely share their honest feedback. Feel free also, to skip a question that is unfamiliar. Thank you in advance.

Water Requirements:

1. Rate your satisfaction level with the listed services by ticking appropriately in the boxes.

   (a) Irrigation water amounts delivered on your farm:

- [ ] Strongly dissatisfied
- [ ] Dissatisfied
- [ ] Neutral
- [ ] Satisfied
- [ ] Strongly Satisfied

   (b) Delivery time of irrigation water to farms:

- [ ] Strongly dissatisfied
- [ ] Dissatisfied
- [ ] Neutral
- [ ] Satisfied
- [ ] Strongly Satisfied

2. Apart from Nyando river water, what are the other sources of irrigation water?

- [ ] Boreholes
- [ ] Harvested rainwater
- [ ] Other(s) (specify)……………………………………………

Yields and Income:

Rate your satisfaction levels in the following areas by ticking appropriately:

(a) Seasonal crop yields:

- [ ] Strongly dissatisfied
- [ ] Dissatisfied
- [ ] Neutral
- [ ] Satisfied
- [ ] Strongly Satisfied

(b) Annual incomes:

- [ ] Strongly dissatisfied
- [ ] Dissatisfied
- [ ] Neutral
- [ ] Satisfied
- [ ] Strongly Satisfied

Scheme Management:

1. What is your credit requirement?

- [ ] 1,000 – 5,000

☐ 5,001 – 10,000

☐ 10,001 – 20,000

☐ Over 20,000

2. How much credit are you given?

☐ Equivalent to requirement

☐ Less than requirement

☐ No credits available

General

What improvement area(s) would you suggest for the scheme?

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

I affirm that the information I have provided above is to the best of my knowledge.

………………….. (Signature).

Once again, we thank you for your feedback and pledge to maintain your anonymity.

Appendix II: Equity of Water Delivered in the Farms

Farm No.	Amt delivered "d" (mm)	Amt req "r" (mm)	d/r	CVa*(d/r)	Farm No.	Amt delivered "d" (mm)	Amt req. "r" (mm)	d/r	CVa*(d/r)
1	50.80	72.90	0.70	**0.52**	43	15.01	72.90	0.21	**0.15**
2	19.96	72.90	0.27	**0.20**	44	27.94	72.90	0.38	**0.28**
3	127.00	72.90	1.74	**1.29**	45	18.34	72.90	0.25	**0.19**
4	76.20	72.90	1.05	**0.77**	46	38.10	72.90	0.52	**0.39**
5	124.46	72.90	1.71	**1.27**	47	36.29	72.90	0.50	**0.37**
6	74.08	72.90	1.02	**0.75**	48	38.10	72.90	0.52	**0.39**
7	49.21	72.90	0.68	**0.50**	49	50.80	72.90	0.70	**0.52**
8	23.59	72.90	0.32	**0.24**	50	19.96	72.90	0.27	**0.20**
9	29.03	72.90	0.40	**0.30**	51	21.77	72.90	0.30	**0.22**
10	50.80	72.90	0.70	**0.52**	52	103.41	72.90	1.42	**1.05**
11	43.18	72.90	0.59	**0.44**	53	139.70	72.90	1.92	**1.42**
12	23.28	72.90	0.32	**0.24**	54	45.16	72.90	0.62	**0.46**
13	136.53	72.90	1.87	**1.39**	55	43.54	72.90	0.60	**0.44**
14	50.80	72.90	0.70	**0.52**	56	12.70	72.90	0.17	**0.13**
15	147.32	72.90	2.02	**1.50**	57	43.18	72.90	0.59	**0.44**
16	63.50	72.90	0.87	**0.65**	58	12.70	72.90	0.17	**0.13**
17	82.55	72.90	1.13	**0.84**	59	101.60	72.90	1.39	**1.03**
18	49.21	72.90	0.68	**0.50**	60	197.76	72.90	2.71	**2.01**
19	97.37	72.90	1.34	**0.99**	61	163.29	72.90	2.24	**1.66**
20	10.89	72.90	0.15	**0.11**	62	67.13	72.90	0.92	**0.68**
21	18.14	72.90	0.25	**0.18**	63	38.10	72.90	0.52	**0.39**
22	58.74	72.90	0.81	**0.60**	64	41.73	72.90	0.57	**0.42**
23	4.76	72.90	0.07	**0.05**	65	29.03	72.90	0.40	**0.30**
24	31.04	72.90	0.43	**0.32**	66	43.54	72.90	0.60	**0.44**
25	62.35	72.90	0.86	**0.63**	67	95.25	72.90	1.31	**0.97**
26	40.41	72.90	0.55	**0.41**	68	88.90	72.90	1.22	**0.90**
27	66.04	72.90	0.91	**0.67**	69	117.93	72.90	1.62	**1.20**
28	25.40	72.90	0.35	**0.26**	70	67.13	72.90	0.92	**0.68**
29	28.58	72.90	0.39	**0.29**	71	81.64	72.90	1.12	**0.83**
30	23.28	72.90	0.32	**0.24**	72	91.02	72.90	1.25	**0.93**
31	30.84	72.90	0.42	**0.31**	73	90.49	72.90	1.24	**0.92**
32	4.23	72.90	0.06	**0.04**	74	53.34	72.90	0.73	**0.54**
33	33.87	72.90	0.46	**0.34**	75	30.84	72.90	0.42	**0.31**
34	35.28	72.90	0.48	**0.36**	76	73.66	72.90	1.01	**0.75**
35	24.25	72.90	0.33	**0.25**	77	27.21	72.90	0.37	**0.28**
36	10.16	72.90	0.14	**0.10**	78	137.58	72.90	1.89	**1.40**
37	25.40	72.90	0.35	**0.26**	79	88.90	72.90	1.22	**0.90**
38	7.62	72.90	0.10	**0.08**	80	122.77	72.90	1.68	**1.25**
39	2.54	72.90	0.03	**0.03**	81	61.69	72.90	0.85	**0.63**

40	33.87	72.90	0.46	**0.34**	82	81.28	72.90	1.11	**0.83**
41	6.35	72.90	0.09	**0.06**	83	55.03	72.90	0.75	**0.56**
42	16.93	72.90	0.23	**0.17**		**Average**			**0.57**

Appendi III: Correlation Coefficients

		Adequacy	Efficiency	Dependability	Equity	Effectiveness of Infrastructure	Land Renovation Ratio	Drainage Ratio
Adequacy	Pearson Correlation	1	.972*	-.992**	.265	1.000**	.112	-1.000**
	Sig. (2-tailed)		.028	.008	.667	.	.928	.
	N	5	4	4	5	2	3	2
Efficiency	Pearson Correlation	.972*	1	-.978*	-.145	1.000**	-.243	-1.000**
	Sig. (2-tailed)	.028		.022	.855	.	.844	.
	N	4	4	4	4	2	3	2
Dependability	Pearson Correlation	-.992**	-.978*	1	-.046	1.000**	.772	-1.000**
	Sig. (2-tailed)	.008	.022		.954	.	.439	.
	N	4	4	4	4	2	3	2
Equity	Pearson Correlation	.265	-.145	-.046	1	-1.000**	.264	1.000**
	Sig. (2-tailed)	.667	.855	.954		.	.830	.
	N	5	4	4	5	2	3	2
Effectiveness of Infrastructure	Pearson Correlation	1.000**	1.000**	1.000**	-1.000**	1	1.000**	-1.000**
	Sig. (2-tailed)	.	.	.	.		.	.
	N	2	2	2	2	2	2	2
Land Renovation Ratio	Pearson Correlation	.112	-.243	.772	.264	1.000**	1	-1.000**
	Sig. (2-tailed)	.928	.844	.439	.830	.		.
	N	3	3	3	3	2	3	2
Drainage Ratio	Pearson Correlation	-1.000**	-1.000**	-1.000**	1.000**	-1.000**	-1.000**	1
	Sig. (2-tailed)	.	.	.	.	.	.	
	N	2	2	2	2	2	2	2

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).