PERFORMANCE EVALUATION OF THE BILATE AND FURFURO IRRIGATION SCHEMES IN SILTI ZONE, SOUTHERN ETHIOPIA

M.Sc. THESIS

MULUGETA ABEBO ABO

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

JUNE, 2022

PERFORMANCE EVALUATION OF THE BILATE AND FURFURO IRRIGATION SCHEMES IN SILTI ZONE, SOUTHERN ETHIOPIA

MULUGETA ABEBO ABO

A THESIS SUBMITTED TO THE

DEPARTMENT OF WATER RESOURCES AND IRRIGATION ENGINEERING,

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES,

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILMENT OF THE

REQUIREMENTS FOR THE

DEGREE OF

MASTERS OF SCIENCE IN IRRIGATION AND DRAINAGE ENGINEERING

JUNE, 2022

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled" Performance Evaluation of the Bilate and Furfuro Irrigation Schemes in Silti Zone, Southern Ethiopia", submitted in partial fulfillment of the requirements for the degree of Masters of Science in Irrigation and Drainage Engineering, the Graduate Program of the Department of Water Resources and Irrigation Engineering, and has been carried out by Mulugeta Abebo Abo ID. No. GPIrDrR/015/12, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

______________________	______________________	______________
Name of major advisor	Signature	Date
______________________	______________________	______________
Name of co-advisor	Signature	Date

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

EXAMINERS' APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by Mulugeta Abebo Abo have read and evaluated his thesis entitled "Performance Evaluation of the Bilate and Furfuro Irrigation Schemes in Silti Zone, Southern Ethiopia", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Irrigation and Drainage Engineering.

______________________	________________	_________
Name of Major Advisor	Signature	Date
______________________	________________	_________
Name of Co-Advisor	Signature	Date
______________________	________________	_________
Name of Internal Examiner-I	Signature	Date
______________________	________________	_________
Name of Internal Examiner-II	Signature	Date
______________________	________________	_________
Name of External Examiner	Signature	Date
______________________	________________	_________
SGS Approval	Signature	Date

Final approval and acceptance of the thesis are contingent upon the submission of the final copy of the thesis to the School of Graduate Studies (SGS) through the Department Graduate Committee (DGC) of the candidate's department.

Stamp of SGS Date: ______________________________

ACKNOWLEDGMENTS

In my sincere, I must thank the Almighty God for his tireless help in my life, bad conditions and every work of this study. Thanks, my God!!!

I would like to give my confidential praise to my advisors Dr. Shemelies Asseffa and Dr. Abraham Woldemichael, who gave valuable comments, encouragement, and excellent advice during the whole period from proposal writing up to completing the thesis write-up.

My particular gratitude goes to Southern Agricultural Research Institute for funding this research work and Worabe Agricultural Research Center for giving me a leave of absence.

I would express my sincere thanks to Areka Agricultural research center and Ethiopia Construction Corporation and Research and Soil Laboratory, for their support and help with laboratory tests and field materials during my fieldwork in the study area.

Next, I would express my appreciation to all who assists my fieldwork during data collection and gave me guidance for the activity of the work.

I would like to thank Silti Zone Water, Irrigation and Energy Burea, Sankura and Wulberag woreda Agricultural and Revenue offices, and Kebeles Administration for their support and provision of the necessary information and documents.

Finally, I would like to thank all staff members of the Hawassa University, School of Water Resources Engineering who gave me basic theoretical knowledge during my study period for my Masters' program as well as my Undergraduate degree.

TABLE OF CONTENTS

DEDICATION

I dedicate this thesis manuscript to all my beloved families for their support throughout the day-to-day activity and love and their dedicated partnership in the success of my life.

STATEMENT OF AUTHOR

I hereby declare that this MSc specialty is my original work and has not been presented for a degree in any other university, and all sources of materials used for this thesis have been duly acknowledged.

Name: ___________________________________

Signature: ________________________________

This MSc Specialty has been submitted for examination with my approval as Thesis advisors'.

Name: ___________________________________

Signature: ________________________________

Name: ___________________________________

Signature: ________________________________

LIST OF ABBREVIATIONS AND ACRONYMS

BCM	Billion cubic meter
BD	Bulk density
^0C	Degree celicious
cm	Centimeter
CWR	Crop water requirement
DAs	Development Agents
DU	Distribution uniformity
Dz	Effective root depth
Ea	Application efficiency
Ec	Conveyance efficiency
Eo	Overall irrigation efficiency
Es	Water storage efficiency
ETB	Ethiopian Birr
ET_c	Crop evapotranspiration
ET_o	Reference evapotranspiration
FAO	Food and Agricultural organization
FC	Field capacity
GPS	Geographic Positioning System
ha	Hectare
IR	Irrigation ratio
IWMI	International Water Management Institute
MoA	Ministry of Agriculture
MoWR	Ministry of Water Resources

MoAFS	Ministry of Agriculture and Food Security
NGOs	Non-Government Organizations
NMSA	National Meteorological Service Agency
OPUCA	Output per unit command area
OPUIA	Output per unit irrigated area
OPUIS	Output per unit irrigation supply
OPUWC	Output per unit of water consumed
PWP	Permanent wilting point
RAW	Readily available water
RIS	Relative irrigation supply
RWS	Relative water supply
SIA	Sustainability of irrigated area
SNNPRS	Southern nation nationalities and peoples of regional state
TAW	Total available water
US$	United State America Dollar
USDA	United State Department of Agriculture

LIST OF TABLES

LIST OF FIGURES

LIST OF TABLES IN APPENDICES

ABSTRACT

This study attempts to evaluate the performance of the Bilate and Furfuro irrigation schemes in Silti Zone, Southern Ethiopia using internal and external performance indicators. To achieve the aim the primary and secondary data were gathered. Two schemes were evaluated by their own merits using internal performance indicators and a comparison was also made using external performance indicators. For field data measurements three farmers' fields were selected at the head, middle, and tail-end of each scheme. The results of analyses revealed that average field application, water storage and overall irrigation efficiencies were 55.9 & 58%, 53 & 46.5% and 28 & 32% for Bilate and Furfuro schemes respectively. This implied that the two schemes were performing inefficiently and inadequately, but, water distributed uniformly. The results obtained for conveyance efficiencies implied that most canal sections had unreasonable losses of water in two schemes. The results of external indicators show that, RWS, RIS, WDC, OPUIA, OPUCA, OPUIS, OPUWC, SIA and IR were 0.68 & 0.79, 0.61 & 0.77, 0.66 & 0.53, 4140.4 & 1781.5 \$/ha, *4510.3 & 1968.5* \$/ha, *0.94 & 0.28* \$/m^3, *0.99 & 0.39* \$/m^3, *1.05 & 1.02, 1.11 & 1.09 for Bilate and Furfuro schemes respectively. This revealed that the applied water was not satisfied the crop water demand, but their irrigated lands were expanded for two irrigation schemes. Furfuro scheme was better than Bilate in terms of relative water supply and relative irrigation supply, but their results obtained were below acceptable values. However, Bilate scheme had significantly better land and water productivity than Furfuro scheme due to used high value crops, better agricultural inputs and removal of grass cover and sedimentation from canal systems. Hence, Bilate irrigation scheme was better performing than Furfuro scheme. Therefore, adopt the best practices learned from Bilate irrigation scheme for the Furfuro scheme. Moreover, properly maintain malfunctioned infrastructures, create WUAs and agricultural experts, and create awareness for farmers and WUAs on irrigation water management in two schemes.*

Keywords: performance, land and water productivity, irrigation efficiency and adequacy

1. INTRODUCTION

1.1. Background and Justification

For many people, agriculture is the foundation of their economic growth in developing countries (FAO, 2014). Despite this, the food competition is a major challenge for many years in Ethiopia, because of food insecurity (Endalew *et al*., 2015). One of the reasons for this is population pressure, poor and erratic rainfall, poor farming technologies, drought, famine, etc. However, there is sufficient water resource potentials availability in a country (Berhanu *et al*., 2014). But, irrigation policy is the utmost safeguard against the effects of drought. The proper utilization and effective use of available water resources in the agricultural sector has a major role in food security and economic development, it might contribute up to 140 billion ETB to the country's economic development and up to 6 million households' moves into food security (Awulachew *et al*., 2010). Even so, agricultural production was dependent only on rain-fed agriculture for many years in most parts of the country.

The expansion of irrigated agriculture on various scales (small, medium, and large) and options (diversion, storage, gravity, and pumping), particularly small-scale irrigation schemes are suggested as the best alternative to provide a positive and significant impact to ensure sustainable agricultural crop production and household income, enhance reliable household food security, social needs fulfillment and social poverty reduction (FAO, 1997; Tesfaye *et al.*, 2008; Tizita, 2017; Ahmed, 2019; Wondimagegnhu & Bogale, 2020 and Jambo *et al*., 2021). Accordingly, the Ethiopian government and NGOs designed and constructed many small-scale as well as large-scale irrigation schemes (MoA, 2011). The same source also reported that in some places of the country the traditional small-scale irrigation schemes were also developed by the community members.

Although, as the study outlined in the major part of Ethiopian, irrigated agricultures are served by the surface canal irrigation system, and unfortunately, the majority of operational irrigation schemes are characterized as poor performance level (FAO, 2007; Awulachew *et al*, 2007 and Awulachew & Ayana, 2011). The performance of the existing irrigation schemes in Ethiopia was estimated at an average of 36% below design capacity. This indicated that about 230,000ha of irrigated land was lost due to the underperformance of the existing irrigation systems. Almost 90% of these irrigation performance gaps have happened in small-scale irrigation schemes (Awulachew *et al*., 2010).

The conditions of physical infrastructures, cropping intensity, lack of awareness of farmers as well as irrigation managers, and administration structures affect the performance level of irrigation schemes (Mercoiret *et al*., 2007 & Abdulai, 2006). Moreover, situations such as poor operation, maintenance, and field irrigation water management practices, faults in planning, design, and implementation, absence of continuous improvement initiatives and performance monitoring mechanisms, and lack of managerial and operational rules are causes of the poor performance of irrigation schemes (Awulachew & Merrey, 2007; Cakmak & Beyr, 2004; Lambisso, 2008 and Ulsido & Alemu, 2014).

Any irrigation system must be continuously quantified and monitored concerning crop yield, land, and water productivity as the final goal of the irrigation system (FAO, 1996). Moreover, the current information on irrigation efficiency, uniformity, adequacy, irrigated agricultural outputs, and continuousness inhibits the improvement of the existing irrigation projects. The field-level irrigation schemes' performance evaluation should consider only inputs (i.e water) (Jurriens *et al.*, 2001). But, the comparative performance evaluation mainly focuses further on the water, land, and crop production of the existing irrigation schemes (Molden *et al*., 1998).

1.2. Problem Statement

Many existing irrigation schemes that are managed by the community, particularly in Ethiopia, are characterized by unreasonable losses of irrigation water at field and farm level; unfair distribution of irrigation water within the field; unable to supply adequate water for crop water demand; low level of land and water productivity (Molden *et al.*, 1998; FAO, 2007; Awulachew & Ayana, 2011 and Agide *et al.*, 2016). Thus, most of them fail to achieve the objectives they were planned and implemented. Therefore, it needs continuous evaluation and monitoring of the present situation for operating irrigation schemes to address weak points, identify any performance gap, and causes for the gap, and made improvement measures (FAO, 1996). The same is true for Bilate and Furfuro irrigation schemes.

Bilate and Furfuro irrigation schemes faced various problems like malfunctioned division boxes and flow control gates in canal systems, sedimentation in the main and secondary canal and headwork site, unnecessary grass cover and stagnation of irrigation water in the tertiary canals, poor operation and maintenance practices, lack of awareness of water user and even agricultural experts on crop water demand and irrigation scheduling, high field water competition, lack of irrigation water measurement practice, poor on-farm irrigation water management strategies. Moreover, the interest of farmers in irrigation has intensified in recent years, increasing water demands and so; there has been an increasing pressure to improve two irrigation schemes' performance to ensure the land and water productivity.

Furthermore, clear information has been needed on how well one system is performing relative to another; which system responds better to irrigated agriculture output, and how much the irrigation schemes meet the planned and implemented objectives. Unfortunately, there were not yet any formal and systematic field studies conducted and improvement strategies were recommended for Bilate and Furfuro irrigation schemes.

1.3. Objectives of the Study

1.3.1. General Objective

- The main objective of this study was to evaluate the Bilate and Furfuro irrigation schemes found in Silte Zone, Southern Ethiopia based on internal and external performance indicators

1.3.2. Specific Objectives

- To evaluate the Bilate and Furfuro irrigation schemes using internal performance indicators that help to measure field-level irrigation schemes' performance.
- To evaluate two schemes using the selected external performance indicators.
- To compare the performance of two irrigation schemes that help to provide the lesson from best practices.

1.4. Research Questions

- How much the irrigation efficiencies and uniformities are in the two irrigation schemes?
- What are the performance gaps and where to improve the performance of each irrigation scheme?
- How is the level of land and water productivity in two irrigation schemes?
- Which irrigation scheme is performing relatively better?

1.5. Scope of the Study

This study was done on Bilate and Furfuro irrigation schemes located in the upper Bilate river and Dijjo sub-basin respectively in Silti Zone, Southern Ethiopia. This study particularly focused on the performance evaluation of each irrigation scheme based on quantified internal and selected external performance indicators. The internal performance indicators used in this study were conveyance, field application, water storage, and overall irrigation efficiencies and irrigation uniformities. However, irrigation ratio and deep percolation ratio were not evaluated in this study, because farmers practiced closed end furrow in study areas. While, the evaluated external performance indicators were relative water supply, relative irrigation supply, water delivery capacity, output per unit irrigated area, output per unit command area, output per unit irrigation supply, output per unit of water consumed, sustainability of irrigated area and irrigation ratio. Finally, the comparison was made between two irrigation schemes based on estimated values of the selected external performance indicators and conveyance losses. However, the financial performance indicators and organizational setup were not seen in this study. Because of the absence of design documents, initial investment cost including cost of irrigation structures in each scheme and no cost of irrigation water delivered (i.e no farmers paid irrigation water fees) in study area.

1.6. Significance of the Study

This study is necessary to take possible improvement measures in areas where drawbacks happened that used to improve qualities of irrigation activities, improve management ability of the managers, save water and energy, enhance irrigation efficiency and uniformity, meet irrigation adequacy, ensure land and water productivity of the system, support sustainability of the irrigation agriculture. Hence, it used to guide irrigation managers, agricultural experts and decision makers to prompt improvement measures and assist engineers to design new systems. Moreover, it provides clear information on each irrigation scheme to learn each other and take lesson from best practices for improvement.

2. LITERATURE REVIEW

2.1. Irrigation in Ethiopia

Haile (2015) reported that irrigation practices in Ethiopia were in use starting from 1950 through the use of surface irrigation methods for the production of commercial crops such as sugar cane and cotton. The smallholder farmers' economies were improved through the existence of irrigated agriculture (MoA, 2011). Moreover, the development of irrigation practices also supported the smallholder farmers' agricultural developments (Makombe *et al*., 2011); by enhancing food production in arid and semi-arid regions, promoting economic growth, creating employment opportunities, and improving the living conditions of smallholder farmers (Nata and Asmelash, 2007 and Abraham *et al*., 2011).

Nowadays the irrigation developments, especially small-scale irrigation in Ethiopia are supported by the government, donors, and NGOs, to assure livelihood in the rural area. Essential investments were made in modifying existing irrigation or establishing new irrigation to meet food demand (Morya, 2017). As a result, irrigation infrastructures are increasing year after year, which shows country-wide positive development implications and experiences in small and large-scale irrigation schemes. Ministry of Water Resources of Ethiopia, MoWR (2002), considered that based on the size of the command area irrigation system is classified as small-scale irrigation systems (<200 ha), medium-scale irrigation systems (200-3000 ha), and large-scale irrigation system (>3000 ha). In the Ethiopian case, the small-scale irrigation systems particularly have been provided more positive and significant impacts on land productivity and crop yields, household food security, social needs fulfillment as well as rural poverty reduction (Hagosa *et al*., 2011; FAO, 2007 and Jambo *et al*. 2021).

2.2. Performance Evaluation of Irrigation Schemes

The performance of irrigated agriculture is influenced by variables such as infrastructure design, management practices, climatic conditions, availability of inputs, socioeconomic settings, price of the product, etc. Hence, evaluation of the existing situation of irrigation schemes is very important to identify performance gaps and causes of gaps (Molden *et al*., 1998). Moreover, it helps to diagnose the deviation of actual irrigation performance from the expected performance during the planning of the irrigation system (Gorantiwar & Smout, 2005). The performance evaluation means identifying any weak points, bottlenecks, and/or areas with particular deficiencies in existing irrigation schemes. Furthermore, it is essential to make immediate actions to maintain and improve system operation (FAO, 2007).

The study on performance evaluation of Wosha soyama irrigation scheme located at Wondo Genet, SNNPRS in Ethiopia was conducted by Tesfaye (2020). This study was carried out using field-level performance measures such as conveyance, application, water storage and water distribution efficiencies, and deep percolation ratio. The study reported that the performance of this irrigation scheme was poor due to deep percolation losses, leakage in unlined canals, and seepage losses. Moreover, the overall irrigation efficiency was below the desired performance level which is 26%. This study suggested that the adoption of water-saving practices may improve irrigation schemes' performance.

Dessalew *et al*. (2016) conducted a study on the performance evaluation of Bedene Alemtena small-scale irrigation scheme in Hallaba Special Woreda, Southern Ethiopia. This study concluded that the performance of this irrigation scheme was good, however, to sustain more than this all activities in the irrigation network should be monitored and checked, technical requirements should be met, training and extension should be enhanced, evaluations should be performed on a seasonal basis and the results should be delivered to the relevant individual and institutions with an efficient monitoring and evaluation system.

Tadesse (2017) conducted a study on the performance evaluation of Bobe and Laku small scale irrigation schemes in Awash Kunture Sub-basin by using comparative performance indicators. The study reported that excess irrigation water was delivered to the crop field based on relative water supply and relative irrigation supply indicators. This study revealed that the Bobe irrigation scheme had better performance than Laku irrigation scheme in terms of all evaluated parameters. Moreover, the study also suggested that the external indicators are a very good estimator of the irrigation schemes' performance, used to document reliable and consistent documentation systems and the same study should be adopted and practiced on some other small-scale irrigation projects in the country.

Nuru *et al.* (2020) conducted the study on a comparative performance assessment of Jamis and Homacho Sogido small-scale irrigation schemes in West Harerghe, Oromia Regional State, Ethiopia. This study was carried out in two irrigation seasons (2009 and 2010) using irrigated agriculture output indicators. The study concluded that the Hamacho Sogido irrigation scheme was more productive and had better economic profitability.

Beshir & Bekele (2008) conducted a study on the analysis of irrigation systems using comparative performance indicators on two large irrigation schemes in the upper Awash basin (Nura Era state and Wonji state farm). This study confirms that the availability of water was not a problem in Nura Era irrigation scheme based on high values of relative water and irrigation supply with low values of output per unit consumed water. But, less attention was given to irrigation water management and low water rate was practiced.

Shenkut (2015) conducted the study on the performance assessment of Shina Hamusit and Selamko irrigation schemes in Ethiopia using comparative performance indicators such as irrigated agriculture output, water use (supply), and physical and financial performance indicators. This study reported that water supplied was not met the crop demand based on results of relative water supply and relative irrigation supply. However, the reported results for physical performance indicators show that the irrigated areas were expanded.

This study concluded that the problems causing low productivity originate from poor management and the deterioration of physical infrastructures. Hence, investment for improvements of physical infrastructures, management, and operation of the system at all levels will bring substantial improvement in the performance of any irrigation schemes.

2.3. Performance gaps in irrigation system

The identification of any performance gap in the goal achieving process and amending the situation is necessary for the irrigation performance improvements. Hence, managers at different levels should identify performance gaps, find the causes for the gap and take corrective measures to cure the poor targeted performances. There are four potential kinds of performance gaps in irrigation system performances (Douglas and Juan, 1999).

Technological Performance Gap: This is when the physical infrastructure cannot deliver the amount of a given hydraulic performance standard. The normal solution to amend the technological performance gap is changing the type of irrigation system, proper design, or changing the condition of physical infrastructure and/or maintenance of the non-functional infrastructures.

Implementation Performance Gap: This type of gap is when a difference arises between how management procedures are supposed to be implemented and how they are implemented. This includes such problems as how people adjust gates, maintain canals and report information. To mitigate this kind of problem in irrigation the strategies of implementing operational procedures, consistent supervision or monitoring of the system, and awareness creating techniques should be changed. Training the farmers and developing their capabilities regarding the operation, maintenance, and overviews of system management are vital roles in irrigation systems.

Achievement Performance Gap: This performance gap is the variation among management targets and actual achievements. Such problems are generally addressed either by changing the objectives or increasing the capability of management to achieve intended targets through increasing accessibility to management or reforming organizations' setups in irrigated agriculture.

Impacts of Management: This is the state of varying what people think should be the ultimate effects of the use of irrigation and what results. These are gaps in impact performance and include such measures as agricultural and economic profitability of irrigated agriculture, productivity from the amount of irrigation water, poverty alleviation, and environmental problems. If management procedures are being followed and targets are being achieved, but ultimate impacts are not as intended, then the problem is not that the managing organization has performed badly, since these effects are generally beyond its direct control and so, this is the problem of policy (Douglas and Juan, 1999).

2.4. Performance Indicators for Irrigation Schemes

Any irrigation system performances are evaluated and monitored by either qualitative or quantitative measures of aspects of irrigation standards or targets called performance indicators (Savva & Frenken, 2002 and Bos, 1997). They examined the actual achievement of the final goal based on objectives intended in each stage (Murray-Rust & Snellen, 1993). Performance indicators measure the irrigation performance level with permissible tolerances and are assumed to be unsatisfactory if the value of indicators is descended or beyond a particular range of standard values (Tebeba & Ayana, 2015 and Molden *et al.*, 1998). These performance indicators are either internal or external factors that affect the performance of the irrigated agriculture system (Small and Svendsen, 1992). Furthermore, they identify the main irrigation system constituents (infrastructures, on-farm management, and organizational setups) (Awulachew & Ayana, 2011 and Makombe *et al*., 2007).

2.4.1. Internal Performance Indicators

Internal performance indicators examine the system's internal operations and procedures that relate performance to management targets by analyzing the efficiency, uniformity and adequacy of the irrigation system (Molden *et al*., 1998). Thus, they are used to assess the performance of irrigation schemes following a goal-oriented model approach (Kloezen and Garces-Restrepo, 1998). They help the irrigation managers to monitor every managerial and operational performance (Murray-Rust & Snellen, 1993). But doesn't helps in assessing the importance of irrigation in a given system, at separate system levels, and with separate irrigation water sources relative to other systems.

Moreover, the internal performance indicators address how the input (water) is used, without providing the information on what wider hydrological, agricultural, economic, social, and environmental impacts the inputs have led to. The common irrigation efficiency terms (conveyance, field application, water storage, and overall irrigation efficiency), uniformity, and recently complementary terms (runoff ratio, deep percolation ratio) are used as internal performance indicators for on-field level irrigation system evaluation and also put as the remarkable primary performance indicators (Murray-Rust & Snellen, 1993).

2.4.1.1. Conveyance Efficiency

The main importance of irrigation schemes is delivering water from the diversion point to the field. However, water transporting in the conveyance system, some amount of water is lost. This may be caused by leakage, silt deposit, seepage, evaporation loss, or illegal water turnout. To be said efficient conveyance system, the water should transport with minimum losses. The main useful indicator to check the performance level of the conveyance system is conveyance efficiency.

It measures the effectiveness of the conveyance canals to deliver required irrigation water and shows the loss of irrigation water over a given travel distance and is vigorously affected by the length of the canals and the soil types in the canal banks (Ramulu, 2005). Moreover, the loss of the irrigation water in the conveyance system depends on the quality and experiences of operation and maintenances of conveying canals (Ali, 2011).

FAO (2001) reported that the conveyance efficiency for the lined canal at any length is 95%. While unlined canals in clay soil the conveyance efficiency should be 80%, 85%, and 90% for canal lengths of >2000m, 200-2000m, and <200m respectively. Moreover, the conveyance efficiency is 70% for unlined poorly managed main canals and 85% for the well-managed unlined canals (MoAFS, 2002). The same source also reported that the conveyance efficiency for unlined canals in clay soil with a short length of canal (<200m) is 90%. Also, Brouwer *et al.*, (1989) suggested a conveyance efficiency of 95% for the lined canal at any length.

2.4.1.2. Field Application Efficiency

At the field level, the irrigation water may lose by deep percolation, tail water runoff, evaporation, and seepage losses, especially in surface irrigation systems and that might affect applied irrigation water. Thus, field application efficiency examines the stored water in the root zone relative to the irrigation water applied to the field (FAO, 1989).

The study conducted on-field application efficiency of the irrigation system states that their attainable values vary greatly with irrigation system, type, and management (Solomon, 1988). The same source suggested the field application efficiency for the basin, border, and furrow irrigation were in the ranges of 80- 90%, 70-85%, and 60-75% respectively. Moreover, Irmak *et al*. (2011) explained the potential application efficiency values of (45-65), (55-75), (60-80), (40-60), (65-80), and (60-90) percent for well-designed and well-managed conventional furrow, surge furrow, tail water reuse furrow, paddy basin, precision level basin, and border irrigation system respectively. Irrigation management improves field application efficiency by 5-20% by applying the right depth of water in the right place at the right time (Edkins, 2006).

2.4.1.3. Water Storage Efficiency

In any irrigation scheme, the irrigation practices could satisfy the water requirement of the soil to compensate for the moisture depleted by evapotranspiration. Irrigated fields may have good field application efficiency, yet the irrigation practice may be poor. Such problems may be because of poor water storage efficiency, as the water required before irrigation may not store in the root zone during irrigation (Garg, 2006). The storage efficiency explains how well the system stored water in the plant root zone to meet crop water needs. In another word, it indicates the adequacy of the operating irrigation schemes. High storage efficiency means that the irrigation brings the soil moisture to field capacity (Howell, 2003). It might reduce the crop yield since it reflects the degree of soil moisture stress. The recommended water storage efficiency for furrow irrigation systems is 63% (Raghuwanshi and Wallender, 1998).

Jibril *et al*. (2017) conducted a study on the performance evaluation of Badeggi irrigation scheme in Niger state Nigeria. This study reported that 70% of water storage efficiency was poor and the reason for this was the low water-holding capacity of the soil and excess seepage loss. However, Yemendwosen & Zinabu (2015) conducted a case study on the evaluation of irrigation water management at sugarcane production in Wondo Genet in southern Ethiopia. This study reported a better average water storage efficiency of 94.96%.

2.4.1.4. Irrigation Uniformity

The fair distribution of irrigation in the field is affected by many factors like the method of irrigation, topography, soil infiltration characteristics, furrow types, field length, irrigation system pressure, and flow rate (Irmak *et al*., 2011). Accordingly, for surface irrigation, the fair distribution of irrigation water throughout the field is affected by: (i) differences in opportunity time for irrigation caused by advance and recession, (ii) spatial variability of soil-infiltration properties, and (iii) non-uniform grades of the irrigated fields.

The most commonly used irrigation water uniformity indices considered in surface irrigation systems are distribution uniformity and Christian's uniformity coefficient (Zerihun *et al*., 1997). Most of the time Christian's uniformity coefficient is recommended for stationary sprinklers irrigation systems (Irmak *et al*., 2011). The distribution uniformity more commonly helps to examine the irrigation water distribution over the field in surface irrigation systems, but it is also recommended for micro and sprinkler irrigation systems.

The studies conducted by Eisenhauer (1997) and Irmak *et al.* (2011) reported that the distribution uniformity values of ≥60% indicated the irrigation water is fairly distributed throughout the irrigated field. Moreover, Raghuwanshi and Walender (1998) recommended the irrigation uniformities for advanced furrow system was 70%. Guesh (2017) conducted a study on comparative performance evaluation of Maishawsh and

Midmar irrigation schemes in Meren sub-basin, Ethiopia. This study reported good distribution uniformities for Maishwsh and Midmar irrigation schemes, its values were 94.21 and 93.4% respectively.

2.4.1.5. Overall Irrigation Efficiency

It represents the effectiveness of the entire physical system and operating decision in delivering irrigation water from a water supply source to the target crop demands (Irmak *et al*., 2011). It includes the conveyance efficiency in water delivery and distribution systems, and field application efficiency at the field level (Rai *et al.*, 2017). According to FAO (1989), the overall irrigation efficiency of 50–60% is good; 40% is reasonable, while between 20–30% is considered to be poor. Savva and Frenken (2002) reported that for African irrigation schemes the overall irrigation efficiency is commonly observed in the range of (40-50%). In Ethiopia, various studies reported the overall irrigation efficiencies values less than this range, for example, Muhammedziyad *et al*., (2018); Eticha (2011); Tadesse (2017); Zinabie (2018), and Minchil (2019) reported the overall irrigation efficiencies were 35.9%, 28.6%, 25.89%, 34.97%, and 35.36% respectively.

2.4.2. External Performance Indicators

External performance indicators examine and compare the system's output and bulk impacts of irrigated agriculture among irrigation schemes and/or within the same scheme over time helps to give insight into how productive and efficient land and water resources are used for irrigated agriculture. Moreover, the external performance indicators are used to evaluate outputs and impacts of intervention in individual systems and compare the performance of a system over time, and at different system levels (Molden *et al.*, 1998).

2.4.2.1. Water Delivery Performance Indicators

Molden *et al.* (1998) proposed major water delivery performance indicators such as relative water supply, relative irrigation supply, and water delivery capacity. They are used to measure the irrigation adequacy of the irrigation schemes, meaning they measure whether or not the maximum crop water and irrigation water requirements are satisfied by supplied irrigation water and present canal capacity at the system head.

I. Relative Water Supply

It is the most comprehensive indicator to examine whether or not the applied water from all sources tightly meets the crop demands over a specific period of crop grown in a specific area (Levine, 1982). (Molden *et al*., 1998 and Cornish, 2005) recommended that a unit value for relative water supply is better than higher or lower values. Because, its value of more than one indicates extra water is applied to the root zone beyond plant demands while its value below one indicates the water supplied does not tightly satisfy the crop demands (Raghuwanshi and Wallender, 1998).

Solomon (2016) conducted a study on performance evaluation in Jari and Aloma small-scale irrigation schemes, Tehuledere district, Ethiopia. This study reported that the relative water supply values were almost equal to one. This study concluded that the water supplied was tightly sufficient for the crop water demand. Shenkut (2015) carried out a study on a comparative performance assessment of Shina Hamusit and Selamko irrigation schemes in Ethiopia. This study reported that the results of relative water supply were 1.55 and 1.87 respectively for Shina Hamusit and Selamko irrigation schemes. This means that the water applied was beyond the crop water demand. Adane *et al.* (2020) conducted a study on the performance assessment of upper Blue Nile small-scale irrigation schemes in Ethiopia. The study reported that the values for relative water supply were 6.21, 5.23, 4.11, and 3.56

respectively for Ashar, UpperQuashine, Zuma-1, and Zuma-2 irrigation schemes. This study concluded that excess water was delivered to the field beyond crop water demand causing water logging problems, and then, plant root aeration.

II. Relative irrigation supply

According to Awulachew and Ayana (2011), relative irrigation supply examined the irrigation schemes as to whether or not the total applied irrigation water satisfied the irrigation water demand (i.e net irrigation requirement). The unit value of relative irrigation supply is expected from good performing irrigation schemes and that indicates the applied irrigation water is sufficient tightly to meet crop irrigation demand, i.e. neither surplus nor deficit. If its value is greater than one, the excess irrigation water is applied that is beyond the irrigation water demands while if its value is less than one, the water applied does not satisfy the irrigation demand (Molden *et al*., 1998).

Agide (2012) conducted a study on a comparative performance assessment of community-managed Golgota and Wedecha (Godino sub-system and Gohaworki Sub-system) irrigation schemes in Ethiopia. The study reported that the relative irrigation supply for Golgota, Godino sub-system, and Gohaworki sub-system irrigation schemes were 3.17, 1.90, and 1.20 respectively. This study concluded that irrigation supply at Godino sub-system was well matched to the demand of than Golgota scheme and Gohaworki sub-system. But, excess water was applied in Golgota irrigation scheme and Gohaworki sub-system schemes. The reasons were farmers themselves are responsible for the volume of water diverted from the river and there is no irrigation water fee in Golgota scheme and the absence of water control gates at the headwork of Gohaworki sub-system schemes.

Agide *et al.* (2016) conducted a case study on the analysis of water delivery performance of small-scale irrigation schemes in terms of diversity and lessons across schemes, typologies, and reaches in Ethiopia. This study concluded that the relative irrigation supply for semi-modern irrigation scheme was responded to the highest, but, the traditional scheme replies the lowest value due to disparities in the water supply at irrigation reaches.

III. Water Delivery Capacity

It is an indication of the degree to which irrigation infrastructure constrains the cropping intensities by comparing the canal conveyance capacity to peak consumptive demands (Molden *et al.*, 1998). This indicator addresses the question of whether the system has been designed and constructed in such a way that able to meet the peak water demand of the irrigated crops in a particular growth period (Kloezen and Garces-Restrepo, 1998).

Molden *et al*., (1998) recommended that the water delivery capacity value must be one for good performing irrigation schemes. However, for the conclusion, it should be interpreted in the context of the irrigation system and in conjunction with the other indicators.

Zinabie (2018) conducted a case study on the performance evaluation of Golina small-scale irrigation in North Wollo, Ethiopia. This study reported that the main canal has 82% of design capacity due to maintenance problems and water shortage. According to Samad *et al*. (2000), in a study on water delivery performance in the Doroodzan irrigation scheme in Iraq, the system could not deliver water according to the real crop water requirement. Janvier and Blessing (2020) conducted a case study on the performance evaluation of Rugeramigozi 1 and Rugeramigozi 2 irrigation schemes in Rugeramigozi Marshland in Rwanda. This study reported that the existing irrigation canals' capacities were sufficient to meet the irrigation water requirements at the peak demand period.

2.4.2.2. Irrigated Agriculture Output Indicators

According to Molden *et al*. (1998), the irrigated agriculture performance indicators are evaluators of land and water productivity of irrigated agriculture. Where water is a constraining resource, output per unit of water may be more important, while if the land is a constraint relative to water, output per unit of land may be more important. The land productivity shows the response of each cropped area to generating gross return within the available water and is the effectiveness of land productivity. While the water productivity describes the outcome gained through using a meter cube of applied water and it is the effectiveness of water productivity.

Agide (2012) conducted a study on a comparative performance assessment of Golgota and Wedecha irrigation schemes in Ethiopia. This study reported that in terms of land productivity Golgota irrigation scheme could be considered the benchmark in the region due to more intensive irrigation and better investment; however, it had poor water productivity due to uncontrolled water diversion and the absence of irrigation fees. While Godino sub-system of Wedecha irrigation scheme could be benchmarked in the region for water productivity. Mintesinot *et al.* (2004) conducted a study on the performance evaluation of community-managed irrigation schemes in Tekeze basin in Ethiopia during two cropping seasons. This study reported that the higher values of land productivity were obtained during the first season than in the rest of the seasons, because, in the first season most of the irrigated land was cultivated by high-value crops (Tomato, Onion, and Papers).

Janvier and Blessing (2020) conducted a study on the performance evaluation of Rugeramigozi 1 and Rugeramigozi 2 irrigation schemes in Rwanda. This study reported that low land productivity was obtained for two irrigation schemes. However, the water productivity was superior for Rugeramigozi 2 than Rugeramigozi 1 scheme due to the adoption of deficit irrigation strategies in Rugeramigozi 2 scheme.

2.4.2.3. Physical Performance Indicators

Molden *et al.* (1998) and Bos (1997) proposed two physical performance indicators (such as irrigation ratio and sustainability of irrigated area) for the evaluation of the expansion or contraction of irrigated land in irrigation schemes. Irrigation ratio is the expansion or contraction of the currently irrigated area relative to the designed command area that is attributed to water management responsibilities and reliability of irrigation water supply. This indicator empowered to investigate the alterations or changes in the area irrigated and provide valid reasons for such variation (Raghava *et al*., 2011).

The sustainability of irrigated areas is an indication of currently irrigable areas relative to the initially irrigated area that is used to check the condition of the irrigation system either expanding or contracting (Bos, 1997). Zinabie (2018) conducted a study on the performance evaluation of Golina irrigation in North Wollo, Ethiopia. This study reported that the sustainability of irrigated areas was decreased by 35.14% due to water shortage and water utilization conflict among water users.

Awulachew & Ayana (2011) conducted a study on the performance assessment of irrigation schemes at the national, regional, and scheme levels in Ethiopia. This study reported that 86.5% of irrigation schemes were operating, 74.1% of the command area is under cultivation and only 46.8% of the planned beneficiaries have benefited from implemented irrigation schemes during the period of this study. This study sets the reasons for these problems as lacking sustainable funding, gaps in the extension of agronomic practice, poor farming, and post-harvest technologies.

2.5. Comparison of Existing Irrigation Schemes

The means of comparing the performance across the irrigation schemes helps to assess the spatial variation of irrigation performance and also a variation in various irrigation seasons (Kloezen and Garces-Restrepo, 1998). Then, evaluate its effectiveness in terms of the performance of agricultural production. For this purpose international water management institute proposed various comparative indicators, which relate outputs from irrigated agriculture to the major inputs of water, land, and finance (Molden *et al.*, 1998). The same source has standardized the external/comparative indicators to cross-system comparison for an approach to relate output from the system derived from the inputs into that system. Several studies were conducted on performance evaluation across irrigation systems (Agide, 2012; Beshir and Bekele, 2008; Degirmenci *et al*., 2003; Gorantiwar and Smout, 2005; Guesh, 2017 and Nuru *et al.*, 2020).

Tesfaye *et al*. (2019) conducted the study on a comparative performance evaluation of Wosha and Werka irrigation schemes located at Wondo Genet in southern Ethiopia. This study justified that, the irrigated agricultural output indicators were relatively better at Werka irrigation scheme. Whereas, Wosha irrigation scheme had responses to better water supply and water delivery capacity. However, the crop water demands were not tightly met by diverted irrigation water in these irrigation schemes' and so; the performance was poor in terms of relative water supply and relative irrigation supply.

Mekonen and Seleshi (2005) conducted a study on comparative performance evaluation of Hare, Sille, Bilate, Metahara, and Wonji irrigation schemes based on management and cropping types. This study revealed that in a Hare irrigation scheme more than 50% of irrigation water loss was seen over a 5 km canal distance and its conveyance efficiency was poor due to bad physical infrastructures, seepage, and leakage canals, and unofficial points of water turnouts. However, there was no constraint on water availability and supply at the irrigation scheme level. But, wide variations in the amount of productivity were seen among these irrigation schemes with the same cropping and management types.

3. MATERIAL AND METHODS

3.1. Description of the Study Areas

The study was conducted at Sankura and Wulberag Woredas, Silti Zone, Southern Ethiopia at a distance of about 208 km and 183 km to the South West of Addis Ababa respectively. The study areas are located geographically in the range of 7º27'13'' to 7º40'10''N Latitude, 38º5'17'' to 38º43'8''E Longitude, and 1837 to 1897m Altitude. The area in Bilate and Furfuro irrigation schemes receives a mean annual rainfall of 953.3mm and 1006.1mm respectively (NMSA). About 10.5-11.2% of rainfall is received from November to March which is considered the minor rainy season. The main rainfall season is from June up to September. For detailed information, see appendix-B, tables 1 and 2.

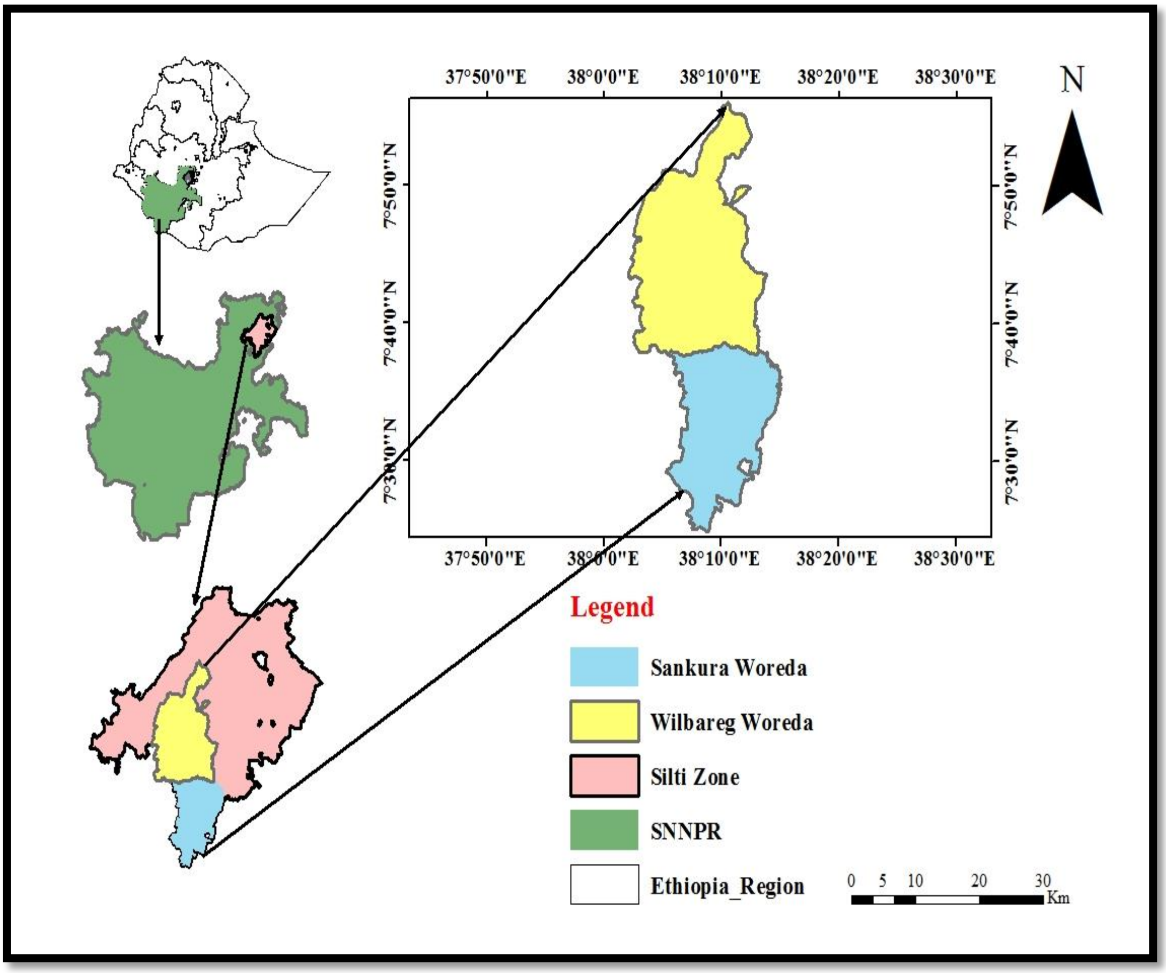

Figure 3.1: Location Map of the Study Areas

As indicated in figures 3.2 and 3.3 below, the monthly rainfall is higher than the monthly reference evapotranspiration between the end of May and the beginning of October. This indicated that, no need for irrigation application during this season. Since the monthly reference evapotranspiration is higher than monthly rainfall, the irrigation is critically significant during January; February, March, November, and December. However, in April, May, and October supplementary irrigation may support rainfall shortage.

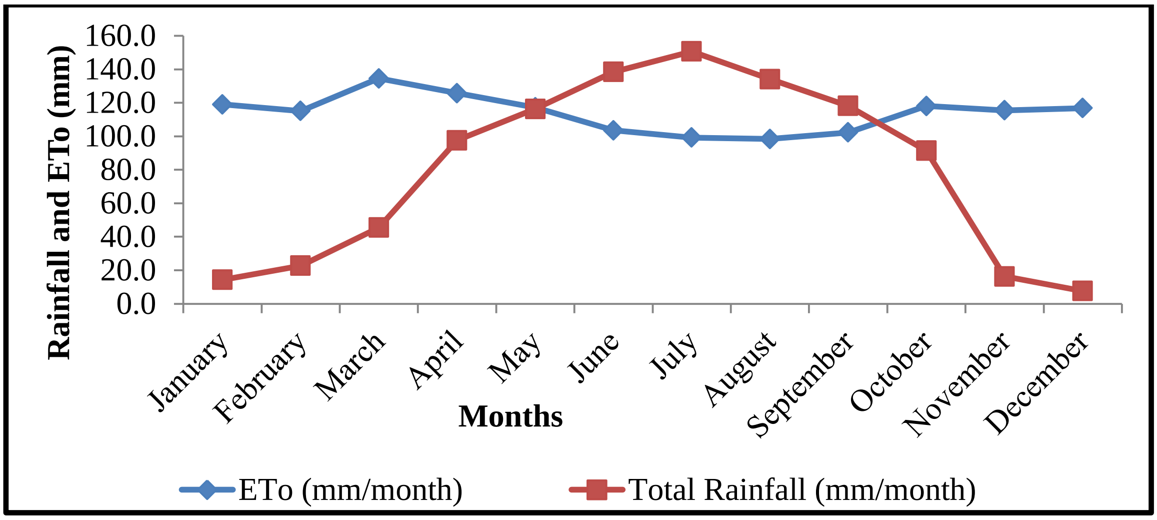

Figure 3.2: Climatic Water Balance in Bilate Irrigation Scheme

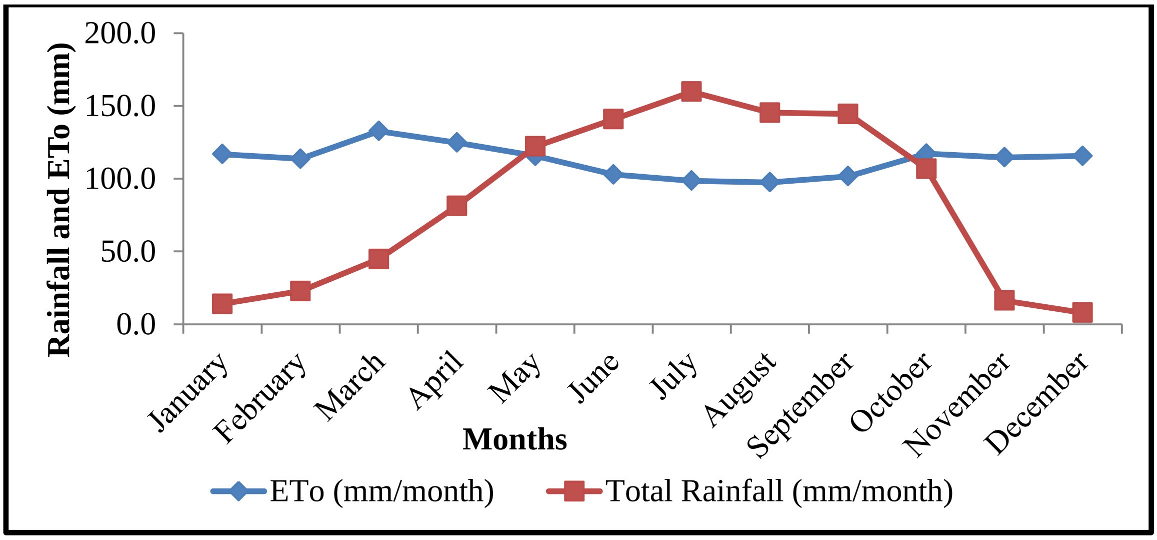

Figure 3.3: Climatic Water Balance in Furfuro Irrigation Scheme

3.2. Description of Two Irrigation Schemes

The distance between the Bilate and Furfuro irrigation schemes is approximately 22 kilometers and they have similar climatic conditions, soil types, and farmland management as described in the following sections.

3.2.1. Bilate Irrigation Scheme

The Bilate irrigation scheme is located in the upper Bilate river basin, Sankura woreda having the geographic location of its headwork at 7°29'23"N Latitude, 38°5'17"E Longitude, and 1897m Altitude. It was established in 2004 E.C by the Federal Government of Ethiopia. The initially designed area was 305 ha. Its source of water is Bilate River diverted by constructed diversion weir having about 7.2 km length of the fully lined main canal. The command area is located on the left side of the River. Bilate irrigation scheme operates only once a year (December to May) with the other seasons being rain-fed and/or the farmers have no interest to grow irrigated crops (Sankura Woreda Agricultural Office). All water users in the irrigation districts are smallholder farmers. The water users practice rotational irrigation based on their field location relative to the main canal. Farmers at the head and near the main canal receive irrigation water first as it is diverted downstream.

The dominant soil texture in the command area is clay loam for soil profiles up to the depth of about 60cm and clay for soil profiles below this depth (Soil Laboratory results in table 4.1). The major crops grown in the command area are Maize, Potato, Onion, Tomato, Green pepper, and Cabbage (Sankura Woreda Agricultural Office). Based on field observations the division boxes and control gates currently malfunctioned except at headwork as indicated in figure 3.5 below. But, the water division and flow controlling were done by local materials such as stones and soils. The cross-sections of some unlined canals are very wide which may lead to water stagnation as indicated in figure 3.5 below.

Figure 3.4: Headwork and Head Regulator in Bilate Irrigation Scheme

Figure 3.5: Current Conditions for Physical Infrastructures in Bilate Irrigation Scheme

3.2.2. Furfuro Irrigation Scheme

The Furfuro irrigation scheme is located in the sub-basin of Dijjo watershed, in Wulberag woreda having the geographic location of its headwork at 7°40'21"N Latitude, 38°10'48"E Longitude, and 1875m Altitude. It was established in 1999 E.C by the Regional Government of SNNPRS. The initially designed area was 200 ha. Its source of water is Furfuro River diverted by constructed diversion weir to the fully lined main canals found on the left and right sides of the river. The command areas are located on both sides of the

River. Furfuro irrigation scheme also operates once a year (December to May) with the other seasons being rain-fed and/or the farmers have no interest in irrigation (Wulberag Woreda Agricultural Office). All water users in the irrigation districts are small private growers. They receive irrigation water on a rotational basis depending on their field location relative to the main canal. Farmers at the head and near the main canal also receive water first.

The dominant soil texture in the command areas is clay loam at soil profiles up to the depth of about 60cm, and clay at soil profiles below this depth (Soil Laboratory result in table 4.2). In its command area, major crops grown are Maize, Potato, Onion, Tomato, Green pepper, Cabbage, and Carrot (Wulberag Worada Agricultural office). Based on field observations the division boxes and flow control gates are currently malfunctioned except at headwork as indicated in figure 3.7 below. The water division and control were done by local materials such as stones and soils. Most unlined tertiary canals have an unnecessarily cross-sectional size and their waterway is covered by grass as indicated in figure 3.7. These may cause irrigation water stagnation and water exposed to evaporation losses.

Figure 3.6: Headwork in Furfuro Irrigation Scheme

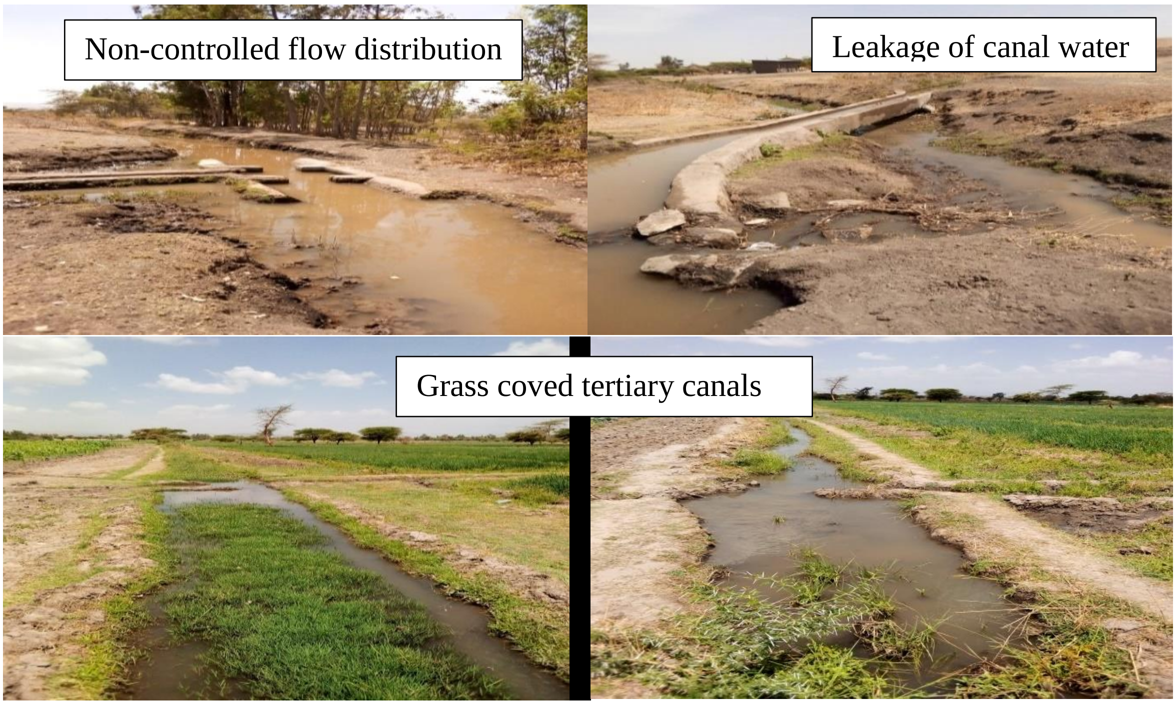

Figure 3.7: Current Conditions for Physical Infrastructures in Furfuro Irrigation Scheme

3.3. Materials Used

The materials and equipment used during data collection and measurements were Core samplers, Augers, Oven, Measuring Tapes, Stopwatch, Analytical balance, Plastic bags, Parshall flumes, GPS, Double ring infltrometer, Staff gauges, Hammer, Digital camera, floating objects, and others. Furthermore, an Excel spreadsheet was used for data analysis, New_LocClim 1.10 was used for climatic data generation, and CROPWAT 8.0 was used for determining crop water requirement, irrigation water requirement, and irrigation scheduling. And also, ArcGIS, and Google Earth were used for study area delineation.

3.4. Field Experimental Layout

To collect and measure the relevant data at the field level, the representative three farmers' fields were selected at the head, middle and tail end water users in each irrigation scheme based on land tenure arrangements, water management practices, the willingness of the farmers, and main canal reach that utilize the irrigation water.

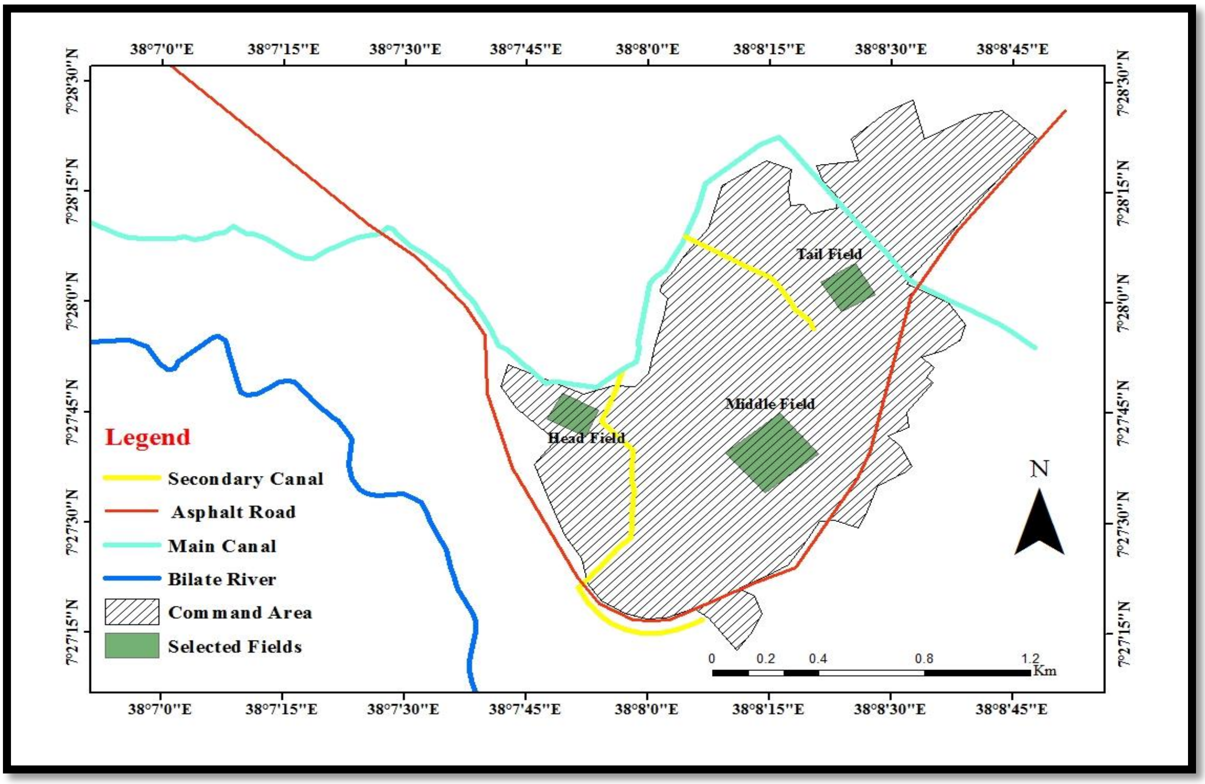

Figure 3.8: Field Layout of Bilate Irrigation Scheme

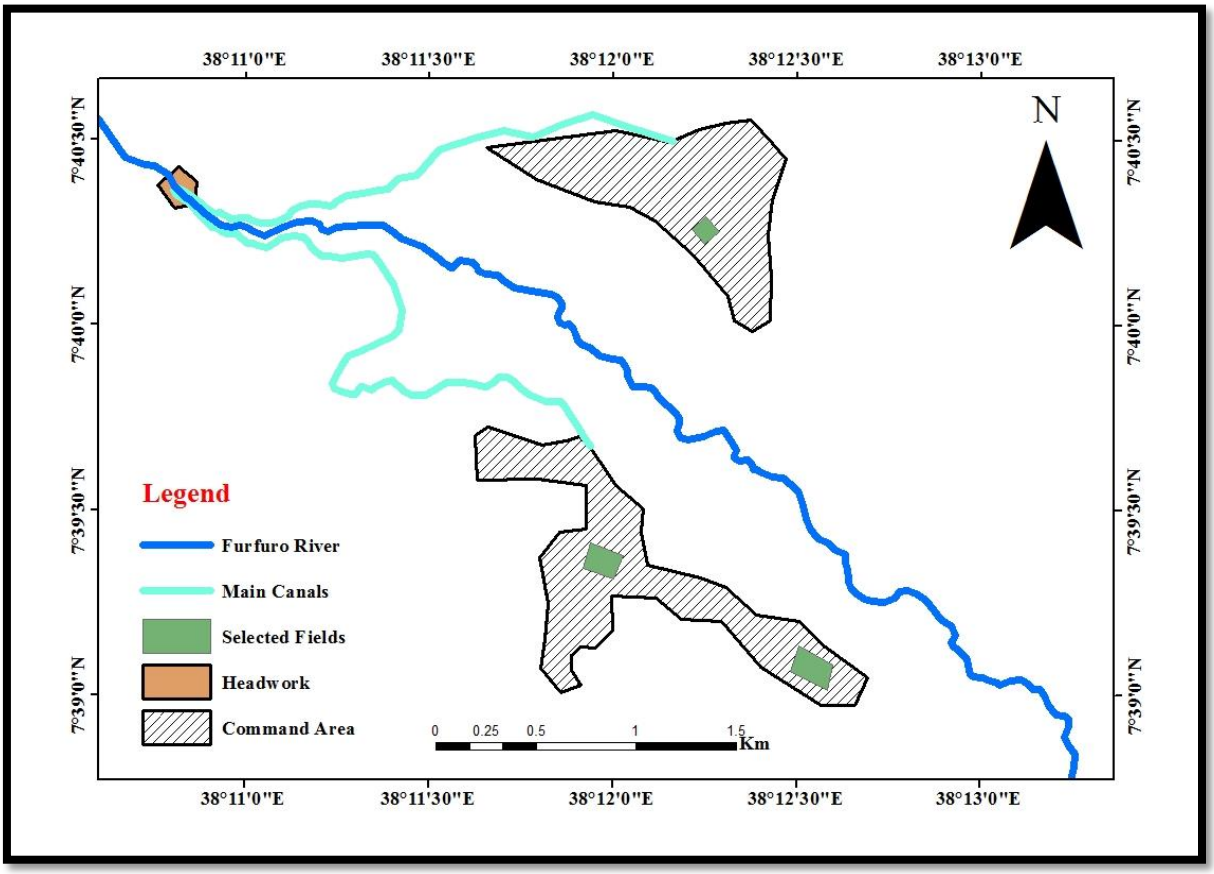

Figure 3.9: Field Layout of Furfuro Irrigation Scheme

3.5. Data Collection and Analysis

3.5.1. Data Collection

A. Primary Data Collection

The irrigation data (like flow discharges in main, secondary, and tertiary canals sections; present discharge capacity of the main canal at its head, and depth of irrigation water applied) were measured at field level for two irrigation schemes. The soil data (bulk density, texture classes, field capacity, permanent wilting point, and soil moisture contents before and two days after irrigation) were analyzed in the soil laboratory, whereas the infiltration rate was measured at the field level for two irrigation schemes.

Moreover, the sources of irrigation water and way of irrigation water supply, size of irrigated field; the current status of physical infrastructures (diversion headwork, water conveyance, and distribution systems, flow division, and flow control structures), conditions of irrigation scheduling, on-field irrigation water operation, management and maintenance practices, dimensions of canal systems, irrigated crop types, crop planting date and length of crop growing period were collected through field observation, informal field survey and field measurements in two irrigation schemes.

B. Secondary Data Collection

The daily grid climatic data for rainfall, maximum and minimum temperature for 37 years (1981-2018) were collected from National Meteorological Service Agency. Since the grid data were collected by satellite, there were no missed data. Due to the absence of either grid or manually collected station data in two study scheme areas, average monthly data for relative humidity, wind speed, and sunshine hour were loaded using New_LocClim 1.10 software. The monthly rainfall for each month was computed by adding all daily rainfall data in that month. Afterward, the average monthly rainfall for each month was computed as the average monthly data for 37 years of that month. The average monthly maximum and minimum temperatures for each month were computed as the average daily temperature data for 37 years of that month. The detailed information on average monthly climatic data was indicated in appendix-B, tables 1 and 2.

The crop data (development stages, crop coefficient, rooting depth, critical depletion level, and yield response factor) were adopted from FAO (1992, 1996 & 1998) published papers. Moreover, production and market price data (crop yield and local prices of the yield) and area size data (command area, initially irrigated area, and area irrigated during the study period) were collected from Silti Zone Water Resources Bureau, Sankura and Wulberag Woreda Agricultural and Revenue Offices as indicated in appendix-F.

3.5.2. Data Analysis

3.5.2.1. Estimation of Internal Performance Indicators

The internal performance indicators (field application, water storage, conveyance, and overall irrigation efficiencies, and irrigation uniformity) were determined for each selected field in two irrigation schemes. These internal performance indicators were used to evaluate on-field irrigation water management practices and day-to-day operations. To determine these internal performance indicators the relevant data were collected, measured and analyzed: - i) soil physical properties (at field and soil laboratory); ii) depth of irrigation water applied (using Parshall flume); iii) depth of stored water at the effective root zone (from soil moisture analysis); iv) total available soil water and readily available water and v) canal flow discharges (area-velocity method using floating objects). However, recently complementary terms (runoff ratio and deep percolation ratio) were not evaluated, since the farmers used close-end furrow, hence, no runoff loss.

- **Soil Physical Properties Analysis**

The soil's physical properties (bulk density, textural class, field capacity, permanent wilting point, and soil moisture content before and two days after irrigation) were analyzed in the soil laboratory and the infiltration rate was measured at the field level for each selected field of two irrigation schemes.

I. Methods of Soil Samples Collection

The soil samples were collected from each selected field at the head, middle and tail end of each irrigation scheme. The soil samples were collected at three intervals of the soil horizon (0-30, 30-60 and 60-100 cm) since the soil profile variation is at 30cm intervals in the study areas. These soil parameters were determined for soil depth within the cultivated crop effective root zones because different crops have various root depths. The selected fields at the head, middle and tail end of Bilate irrigation scheme were cultivated with maize and potato. While the selected fields at the head, middle and tail end of Furfuro irrigation scheme were cultivated with onion, tomato and cabbage.

Canadell *et al.*, (1996) categorized crops as shallow rooting crops (30-60cm), medium rooting crops (50-100cm), and deep rooting crops (90-150cm). The crops like potato, onion, and cabbage are categorized as shallow rooting crops and so, the soil parameters were considered up to 60cm soil depth for fields cultivated by these crops. While, maize and tomato are categorized as medium rooting crops and so, the soil parameters were considered up to 100cm soil depth for fields cultivated by these crops.

II. Soil Textural Class and Bulk Density

To determine the soil textures the composite soil samples were collected diagonally from each selected field by using Auger. Then, the soil textural classes were analyzed in the Areka Agricultural Research Center Laboratory. The proportions of sand, clay, and silt in each soil sample were computed by following the procedures of the hydrometer analysis procedures. Then, the soil textural classes were estimated based on the United States Department of Agriculture (USDA) soil texture classification triangle.

Whereas to determine the bulk density, undisturbed soil samples were collected from each selected field by using the volumetric ring from the pit excavated in each selected field. Afterward, the collected soil samples were placed in an oven and dried at 105°C for 24 hours in Areka Agricultural Research Center Laboratory. Then, dried samples were withdrawn from the oven and their dry weight was measured. Finally, the bulk density of the soil was computed by equation (3.1) (McKenzie *et al.*, 2004).

$$\mathrm{BD} = \frac{\text{Weight of dry soil (gm)}}{\text{The volume of the same soil (cm}^3\text{)}} \tag{3.1}$$

Where BD is the soil bulk density (gm/cm^3)

III. Soil Field Capacity and Permanent Wilting Point

Undisturbed soil samples were collected with a Core sampler from each selected field of two irrigation schemes. Then, soil field capacity and permanent wilting points were analyzed in Ethiopia Construction Corporation and Research Soil Laboratory. The soil samples were air-dried and then, prepared soil samples were saturated up to all the soil pore spaces filled with water. Then, the prepared soil samples were entered into a pressure plate of 1/3 and 15 bars were applied for field capacity and permanent wilting points respectively (Kirkham, 2005). The weight of water retained in a known volume of soil after pressure plates of 1/3 and 15 bars were measured for field capacity and permanent wilting points respectively. Moreover, the weight of the same volume of dry soil was also determined. Finally, the gravimetric soil moisture contents at field capacity and permanent wilting points were determined using equations (3.2) and (3.3) respectively.

$$FC = \frac{\text{Weight of water retained in a known volume of soil}}{\text{Weight of the same volume of dry soil}} * 100 \quad (3.2)$$

$$PWP = \frac{\text{Weight of water retained in a known volume of soil}}{\text{Weight of the same volume of dry soil}} * 100 \quad (3.3)$$

Where FC is field capacity at 1/3 bars pressure, PWP is permanent wilting point at 15 bars

IV. Measurement of the Infiltration Rate

Johnson (1991) concluded that the soil texture is the major inherent factor that affects the infiltration rate in crop fields. As mentioned before, the dominant soil textures are clay loam and clay for all selected fields of two irrigation schemes. Thus, the numbers of infiltration test points were mostly chosen based on soil texture variations. Therefore, in this study, one infiltration test was taken in each selected field of two irrigation schemes.

The infiltration rates were measured at the field level using a Double ring infiltrometer having 30 and 60 cm diameters of the inner and outer ring respectively. These rings were driven into the soil to a depth of 15 cm by the hammer. Then, two rings were filled with a certain amount of water at the same level as the known initial water level. The water level declined over time was recorded frequently. The measurement was continued until the declined water level tends to approach constant values in a certain interval of time.

Figure 3.10: Infiltration Rate Measurements at Field Level

- **Measurement of the Depth of Irrigation Water Applied**

The depths of irrigation water applied into each selected field were measured by 7.7cm (3-inch) throat width Parshall flume. This type of Parshall flume was selected based on the size of field distributary canals. The Parshall flume was installed in the field canals at 10 m apart from the field inlets. The applied irrigation water was diverted through the installed Parshall flume. Then, the head of passing water through the Parshall flume was followed carefully and was measured regularly until farmers stopped their irrigation. Because the irrigation water level may increase or decrease in its sources and/or transport systems. Additionally, the time consumed when the farmers irrigated their fields until they stopped irrigating the field was also recorded. Furthermore, the areas of the irrigated field were measured. According to FAO (1981), the Parshall flume flow rate was taken directly from the table according to the Parshall flume manufactured specifications that do not need calibration as indicated in appendix-D, table 1.

Then, the gross depth of irrigation water that farmers' applied to their field was determined by equation (3.5) which is derived from equation (3.4) (FAO, 2001). The equation (3.4) was recommended to determine the time required to apply the desired depth of irrigation water. Finally, the gross depth of irrigation water applied was determined from the recorded application time, Parshall flume flow rate, and area of the irrigated field by equation (3.5) below.

$$T = \frac{A*d}{6q} \tag{3.4}$$

$$d = \frac{(6*T*q)}{A} \tag{3.5}$$

Where, T is time (minute); d is gross irrigation water depth applied (cm); A is an area of the field (m^2) and q is the flow rate of Parshall flume (l/s)

Figure 3.11: Measurement of Field Applied Irrigation Water using Parshall Flume

- **Measurement of the Depth of Irrigation Water Stored at Effective Root Zones**

The depth of irrigation water stored at the effective root zone was determined from soil moisture contents which were measured before and two days after irrigation. The field application method was furrow irrigation method in two irrigation scheme. Accordingly, for each selected field three furrows at the beginning, middle, and bottom of the field and three test points in each furrow were selected (i.e total of nine test points were selected) by arranging in grid manner of that field. At each test point, the soil samples were collected and then the depth soil moisture contents were analyzed before and after irrigation.

The fresh weights of each collected soil sample were measured at the field level. Then, these collected soil samples were placed in an oven and dried at 105°C for 24 hours at Areka and Worabe Agricultural Research Center. After 24 hours the samples were withdrawn from the oven and their dry weights were measured using an analytical balance.

Afterward, the gravimetric soil moisture contents (%weight bases) were determined by equation (3.6) (George *et al*., 2014) for each collected soil sample. Then, volumetric soil moisture contents (%) were determined by equation (3.7). The depth of soil moisture contents at the root zone was computed by multiplying volumetric soil moisture content (fraction bases) with the effective root depth by equation (3.8) (Depeweg, 2002). Finally, the depth of irrigation water stored in the root zone was estimated by the depth of soil moisture content after irrigation minus the depth of soil moisture content before irrigation.

$$\%\mathrm{Wt} = \left(\frac{\text{Weight of wet soil (gm)} - \text{Weight of dry soil (gm)}}{\text{Weight of dry soil (gm)}}\right) * 100 \quad (3.6)$$

$$\theta\mathrm{v} = \%\mathrm{Wt} * \mathrm{BD} \quad (3.7)$$

$$D_m = \theta v(\text{fraction bases}) * D_z \quad (3.8)$$

Where %Wt is gravimetric soil moisture content (%weight bases), θv is the volumetric soil moisture content (%), D_m is the depth of soil moisture contents at the effective root zone (mm) and D_z is the depth of the effective root zone (mm)

- **The Depth of Irrigation Water needed before Irrigation (RAW)**

The readily available water at the effective root zone was computed from the total available water and depletion levels of each irrigated crop by equation (3.10). But, the total available water at the effective root zone was computed by equation (3.9) (FAO, 1998).

$$TAW = 1000(FC - PWP)*BD*Dz \quad (3.9)$$

$$RAW = TAW*p \quad (3.10)$$

Where; TAW is total available water (mm); FC is the gravimetric soil moisture content at field capacity (fraction), PWP is the gravimetric soil moisture content at permanent wilting point (fraction), Dz is the effective root zone of a crop (m), BD is bulk density (gm/cm^3), RAW is readily available water (mm); p is critical depletion level for each crop (fraction)

- **Canal Flow Discharge Measurement**

The flow discharges were measured at main, secondary, and tertiary canals sections in Bilate irrigation scheme, while at sections of main canals and tertiary canals in the Furfuro irrigation scheme because there are no secondary canals in the Furfuro irrigation scheme. Then, the flow discharges in canal sections were computed by equations (3.11) (Reginald, 2009). The main and secondary canals are lined and rectangular, while the tertiary canals are unlined in two irrigation schemes. In Bilate irrigation scheme the measurement of the flow discharges was done at about twelve points in the lined main and secondary canal sections. While in unlined tertiary canal sections the measurements were done at about eight points. In Furfuro irrigation scheme the measurement of discharges was done at about four points in the lined main as well as unlined tertiary canal sections.

$$Q = V_{mean} * A_w \tag{3.11}$$

Where V_{mean} is average flow velocity (m/s), A_w is canal wetted cross-section area (m^2) and Q is flowing discharges (m^3/s)

The velocity of the flowing water was measured by area-velocity methods using a floating object, because this method is simple, low cost, and it is preferable where other techniques become impracticable (i.e very low velocities and shallow streams) (Reginald, 2009; Canyon and Wolker, 2012 and John, 1978). For a floating object, a straight canal section was selected based on the slope of the canal. Then, the floating object was dropped on the flowing water. The floating objects used were one liter empty bottle and the measurements were taken three times in each section to improve measurement accuracy. Then, the time consumed by the floating object to move from the start point to downstream until it reached the marked length of the canal was recorded as indicated in figure 3.12 below.

The surface velocity was determined by equation (3.12) below. The surface velocity is multiplied by a correction coefficient for the fact that the surface velocity of the water is greater than the average velocity according to Reginald (2009). Hence, John, (1978) suggested the correction coefficient ranges from 0.8 for rough beds to 0.9 for smooth beds of the canal sections (average values of 0.85 were used for this study). Then, the average velocity was computed by equation (3.13).

$$V_s = \frac{L}{t} \tag{3.12}$$

$$V_{mean} = k * V_s \tag{3.13}$$

Where, L is the length of canal that the floating object traveled (m); t is the time taken by the floating object from started point to the marked point (seconds); V_s is the surface velocity of the flow (m/s) and k is correction coefficient

- **Computation of the Canal Conveyance Losses**

The canal conveyance losses were computed from inflow-outflow discharges measured in canal sections by equation (3.14) (Mohammadi *et.al*, 2019).

$$Q_L = \frac{Q_I - Q_O}{L} \tag{3.14}$$

Where Q_L is water loss rates (l/s/m), Q_O is outflow at the outlet of canal sections (l/s), Q_I is inflow at the inlet of canal sections (l/s) and L is canal length between inlet and outlet (m)

Field Application Efficiency

It indicates the amount of losses of irrigation water in field level. To compute the field application efficiency, the measured values of actually applied irrigation water and soil water stored at the effective root zone of the irrigated crops were used. The field application efficiency was computed for each selected field at the head, middle, and tail-end of each irrigation scheme. Then, field application efficiency was estimated as the ratio of the depth of irrigation water stored at the effective root zone to the depth of irrigation water applied to the field using equation (3.15) (Ramulu, 2005).

$$E_a = \frac{\text{Depth of irrigation water stored in the root zone}}{\text{Depth of irrigation water supplied to the field}} * 100 \quad (3.15)$$

Where E_a is field application efficiency

Water Storage Efficiency

It refers to how completely the water needed prior to irrigation has been stored in the root zone during irrigation water application. To estimate water storage efficiency, the measured values of the depth of irrigation water stored at the effective root zone and the irrigation water needed before irrigation were used. The water storage efficiency was estimated for each selected field at the head, middle and tail-end of each irrigation scheme. Then, water storage efficiency was estimated as the ratio of the depth of irrigation water stored during irrigation to the depth of water needed before irrigation at the effective root zone by equation (3.16) (Garg, 2006).

$$E_s = \frac{\text{Depth of irrigation water stored during irrigation}}{\text{Depth of irrigation water needed before irrigation}} * 100 \quad (3.16)$$

Where the depth of irrigation water needed before irrigation is the readily available water (RAW) of the soil in the effective root zone and E_s is `storage efficiency (%)

Irrigation Uniformity

To evaluate the distribution of applied irrigation water within the field level Christian's uniformity coefficient were analyzed in each selected furrows. To estimate the Christian's uniformity coefficient, the depth of irrigation water stored at the effective root zone at three equally spaced points of the selected furrows on a grid arrangement for each selected field was used. The moisture stored in each test points was done by soil moisture contents analysis using gravimetric methods for that test points as discussed previous section. Christian's uniformity coefficient was computed for three selected furrow at head, middle and tail-end selected fields for each irrigation scheme. Then, for each selected field the Christian's uniformity coefficient was the average values of the Christian's uniformity coefficient of the three selected furrow of that selected field. The Christian's uniformity coefficient was computed following suggestion made by Ramulu, (1998):

$$CU = \left(1 - \frac{d}{D}\right) * 100 \quad (3.17)$$

Where CU is Christian's uniformity coefficient (%), D is average depth of water stored (mm); d is average of absolute deviation depth of stored water from the mean (mm)

Conveyance Efficiency

It estimates the amount of water that is lost or mismanaged in the conveyance system. To estimate the conveyance efficiency and conveyance loss in the canal systems, the inflow and outflow discharges were used. The conveyance efficiency was computed as the ratio of outflow to inflow discharges by equation (3. 18) (Ramulu, 2005).

$$E_c = \frac{\text{Outflow rate from the canal sections}}{\text{Inflow rate into the same canal sections}} * 100 \quad (3.18)$$

Where Ec is conveyance efficiency

Overall Irrigation Efficiency

It stands for the efficiency of the entire physical system and irrigation water delivery system that convey irrigation water from the sources to the field crops, but, does not include the efficiency related to root zone storage capacity (Irmak *et al.,* 2011). The overall irrigation efficiency was computed by equation (3.19) (Rai *et al.,* 2017):

$$E_o = (E_c * E_a)*100 \quad (3.19)$$

Where E_o is the overall irrigation efficiency (%); E_c is conveyance efficiency (fraction); and E_a is the field application efficiency (fraction)

3.5.2.2. Estimation of External Performance Indicators

Three groups of the selected external performance indicators were evaluated for two irrigation schemes. These three groups of external performance indicators were water delivery performance indicators (relative water supply, relative irrigation supply and water delivery capacity); irrigated agriculture performance indicators (output per unit irrigated area, output per unit command area, output per unit irrigation supply and output per unit water consumed) and physical performance indicators (sustainability of irrigated area and irrigation ratio).

3.5.2.2.1. Water Delivery Performance Indicators

To evaluate water delivery performance indicators, the relevant data like total net irrigation water applied (seasonal irrigation water applied); total net water applied (the sum of seasonal irrigation water applied and effective rainfall); total net crop water requirement (seasonal crop water requirement); total net irrigation water requirement (seasonal crop water demand less effective rainfall); discharge capacity of the main canal at the system head and peak irrigation flow demands were determined for each irrigation scheme.

- **Determination of the Total Net Irrigation Water Applied**

Total irrigation water applied for a season was estimated from the measured depths of irrigation water applied. The depth of irrigation water applied per interval for the known plot of the irrigated area was measured as mentioned in section 3.5.2.1. The number of irrigation was estimated as the ratio of the total crop growing period to the fixed irrigation interval that farmers practiced. The seasonal depths of irrigation water applied were equal to the product of the depth of irrigation water applied per interval and the number of irrigation (Garg, 2006).

Finally, the volume of seasonal irrigation water applied for each crop was computed as the product of the depth of seasonal irrigation water applied and irrigated area of that crop by (3.20). Therefore, the volume of seasonal irrigation water applied in the whole irrigated area was the sum of the volume of seasonal irrigation water applied to each irrigated crop field. Since field measured depth of irrigation water applied is the gross amount, hence, the total net irrigation water was computed by considering field application efficiency. And so, the total net water applied was determined from total irrigation water and effective rainfall.

$$V_a = 10*D_a*A_c \tag{3.20}$$

Where V_a is volume of seasonal irrigation water applied for each crop (m^3); D_a is the depth of seasonal irrigation water applied for that crop (mm) and A_c is irrigated area by that crop. N.B. number "10" is unit conversion based on principles of 1mm = 1litre/m^2 =10m^3/ha

- **Crop Water Requirement and Irrigation Water Requirement**

The crop water and irrigation water requirements were determined in CROPWAT 8.0 model (FAO, 1977). This model adopted the FAO Penman-Monteith equation to determine the reference and crop evapotranspiration. The effective rainfall was also computed using CROPWAT 8.0 model keeping in mind that this study considered the losses due to runoff and deep percolation for reasonable effective rainfall (Depeweg, 2002). Hence dependable rainfall (FAO/AGLW) formula was adopted, because the rainfall for each period will vary from year to year and therefore, rather than using mean rainfall data (FAO, 1992).

Then, the total net crop water requirement was computed from the crop water requirement of each cultivated crop by equation (3.21). While the total net irrigation water requirement was computed from the irrigation requirements of each cultivated crop by equation (3.22).

Then, the volume of seasonal crop water demand in the whole irrigated area of each irrigation scheme was computed by equation (3.23). But, the volume of seasonal irrigation water demand in the whole irrigated area was computed by equation (3.24).

$$\mathrm{CWR}_{total} = \sum_{\mathrm{i=1}}^{6} \frac{\mathrm{CWR}_{i} * \mathrm{Area\ of\ crop(i)}}{\mathrm{Total\ Area}} \tag{3.21}$$

$$\mathrm{IR}_{total} = \sum_{\mathrm{i=1}}^{7} \frac{\mathrm{IR}_{i} * \mathrm{Area\ of\ crop(i)}}{\mathrm{Total\ Area}} \tag{3.22}$$

$$\mathrm{CWR_v} = 10 * \mathrm{CWR_{total}} * \mathrm{A_{total}} \tag{3.23}$$

$$\mathrm{IR_v} = 10 * \mathrm{IR_{total}} * \mathrm{A_{total}} \tag{3.24}$$

Where, $CWR_{(i)}$ and $IR_{(i)}$ are the depth of crop and irrigation requirements for each crop (mm) respectively, CWR_{total} is the depth of seasonal crop water demand for whole scheme irrigated area (mm), IR_{total} is the depth of seasonal irrigation water demand for whole scheme irrigated area (mm); CWR_v is the volume of seasonal crop water demand (m^3); IR_v is the volume of seasonal irrigation water demand (m^3) and A_{total} is total irrigated area (ha)

- **Peak Irrigation Flow Demand of the Irrigation Schemes**

First total crop growing days, net irrigation requirement and the area being irrigated were collected for each irrigated crop. The total irrigated area (A_{total}) and maximum growing period (B_{max}) were chosen. The maximum net irrigation requirement of the irrigated crops was converted into gross irrigation requirement using equation (3.25). Afterward, peak scheme irrigation water demand for unit hectare area was computed using equations (3.26).

Then, the peak scheme irrigation water demand for the whole scheme's irrigated area was computed using equations (3.27). The reason for using project irrigation efficiency is that the scheme irrigation requirement includes net irrigation water requirement as well as irrigation water losses at conveyance and field canals system and field level.

$$\mathrm{GIR}_{\mathrm{max}} = \frac{\mathrm{IRn}_{\mathrm{max}}}{\mathrm{E}_{\mathrm{P}}} \tag{3.25}$$

$$q\ \left(\frac{l/s}{ha}\right) = \frac{(0.001*GIR_{max}*10{,}000*1000)}{B_{max}*24*60*60} \tag{3.26}$$

$$q\ (l/s) = q\ (l/s/ha) * A_{total} \tag{3.27}$$

Where B_{max} is the maximum total growing period; GIR_{max} is the maximum gross irrigation requirement; IRn_{max} is the maximum net irrigation requirement and E_p is project efficiency

The results of peak irrigation flow demand obtained by these procedures were also verified by computing the duty for each irrigated crop. Accordingly, the duty for each irrigated crop was determined based on equation (3.28). Afterward, the irrigation flow demand for each crop was determined using equation (3.29). Therefore, the peak irrigation flow demand that is needed in the whole irrigated area was computed using equation (3.30).

$$D = \frac{864B}{\Delta} \tag{3.28}$$

$$q = \frac{A}{D} \tag{3.29}$$

$$Q_{max} = \sum_{i=1}^{n} q_i \tag{3.30}$$

Where D is the duty (ha/cumecs); B is the total growing season (day); Δ is seasonal gross irrigation requirement (cm) and q is irrigation flow demand for the irrigated crop (cumecs); A is irrigated area by that crop (ha); Q_{max} is irrigation flow demand that needed in a whole irrigated area (cumecs); n is the number of irrigated crops and q_i is irrigation flow demand

I. Relative Water Supply

To estimate the relative water supply, the values for total net water applied and total net crop water demand was used. According to Raghuwanshi and Wallender (1998), the relative water supply was computed as the ratio of total net water applied (irrigation water plus effective rainfall) to the total net crop water demand in volume by equation (3.31):

$$\text{Relative water supply (RWS)} = \frac{\text{Total net water applied (m}^3\text{)}}{\text{Total net crop water demand (m}^3\text{)}} \qquad (3.31)$$

II. Relative Irrigation Supply

The relative irrigation supply was determined as the ratio of total net irrigation water applied to the total net irrigation water demand in volume, (i.e. crop evapotranspiration minus effective rainfall) using equation (3.32) (Perry, 1996).

$$\text{Relative irrigation supply (RIS)} = \frac{\text{Total net Irrigation applied (m}^3\text{)}}{\text{Total net irrigation water demand (m}^3\text{)}} \qquad (3.32)$$

III. Water Delivery Capacity (WDC)

To estimate the water delivery capacity at the main canal head the relevant data (i.e discharge capacity of the main canal at the system head and peak irrigation demands) were used. Then, the water delivery capacity at the head of the main canal was computed as the ratio of the present canal capacity at the system head to peak consumptive demand by equation (3.33) (Molden *et al*., 1998). It evaluates whether or not the current capacity of the irrigation scheme satisfied the peak demand of whole irrigated crops.

$$\text{WDC} = \frac{\text{Canal capacity to deliver water at system head}}{\text{Peak consumptive demand}} \qquad (3.33)$$

Where WDC is water delivery capacity

3.5.2.2.2. Irrigated Agriculture Output Performance Indicators

To estimate irrigated agriculture performance indicators, the relevant data regarding total irrigated area during the period of analysis, the output of the irrigated area, production value in local price, and size of command areas were collected from Sankura and Wulberag Agricultural and Revenue offices as indicated in appendix-E, tables 1 and 2 and appendix-F, tables 1 and 2. Since different crops were grown in two irrigation schemes; it was difficult to compare two irrigation schemes using crop production directly. Hence, the crop production values were converted to money values based on local market prices and finally converted to US$ to standardize and to compare the results with other findings worldwide. Additionally, the total volume of irrigation water applied and the total volume of crop water demand for two irrigation schemes was estimated as mentioned in sections 3.5.2.2.1.

Then, four basic irrigated agriculture performance indicators (output per unit irrigated area, output per unit command area, output per unit irrigation supply, and output per unit water consumed) were computed by equations (3.34 up to 3.37) (Molden *et al*., 1998).

$$\text{Output per unit irrigated area } \left(\frac{\text{US\$}}{\text{ha}}\right) = \frac{\text{Production}}{\text{Currently irrigated area}} \quad (3.34)$$

$$\text{Output per unit command area } \left(\frac{\text{US\$}}{\text{ha}}\right) = \frac{\text{Production}}{\text{Command area}} \quad (3.35)$$

$$\text{Output per unit irrigation supply } \left(\frac{\text{US\$}}{\text{m}^3}\right) = \frac{\text{Production}}{\text{Diverted irrigation supply}} \quad (3.36)$$

$$\text{Output per unit water consumed } \left(\frac{\text{US\$}}{\text{m}^3}\right) = \frac{\text{Production}}{\text{The volume of water consumed by ET}} \quad (3.37)$$

Where Production is the output of the irrigated area measured at the local market; Irrigated area is the sum of the areas irrigated during the period of analysis; Command area is the designed area; Diverted irrigation supply is the volume of irrigation water diverted throughout the crop growing period and Volume of water consumed by ET is the actual evapotranspiration of the whole cultivated crops.

3.5.2.2.3. Physical Performance Indicators

Two physical performance indicators (i.e irrigation ratio and sustainability of irrigated area) were analyzed by equations (3.38 and 3.39) (Molden *et al*., 1998 and Bos, 1997).

$$\text{Sustainability of Iirrigated Area} = \frac{\text{Currently Irrigated area}}{\text{Initially Irrigated area}} \qquad (3.38)$$

$$\text{Irrigation Ratio} = \frac{\text{Currently Irrigated area}}{\text{Command area}} \qquad (3.39)$$

3.5.2.3. Comparison between Two Irrigation Schemes

In this study, the comparison between Bilate and Furfuro irrigation schemes was made based on estimated values of the external performance indicators (such as relative water supply, relative irrigation supply, water delivery capacity, output per unit irrigated area, output per unit command area, output per unit irrigation supply, output per unit water consumed, sustainability of irrigated area and irrigation ratio) and conveyance losses.

3.5.2.4. Estimation of Irrigation Duration and Irrigation Scheduling

The acceptable duration of irrigation was determined from the depth of irrigation water applied and the basic infiltration rate of the soil measured using equation (3.40). The reasonable irrigation water demand and irrigation interval for each development stage were computed based on the daily water balance of the field. Daily water balance calculation considered the soil water holding capacity, daily crop water demand, available effective rainfall, and soil moisture deficit for every day of the growing season.

$$\text{Duration of Irrigation} = \frac{\text{Applied depth of irrigation water}}{\text{Basic infiltration rate of the soil}} \qquad (3.40)$$

4. RESULTS AND DISCUSSION

4.1. Internal Performance Indicators

➢ **Soil Physical Properties Analysis**

The analyzed soil laboratory result indicated that the dominant soil texture is clay loam in the upper two soil profiles up to 60cm soil depth in all selected fields of two irrigation schemes. But, below 60cm soil depth the dominant soil texture is clay in each selected field of two irrigation schemes, except in the header field of Furfuro irrigation scheme which had clay loam texture in whole tested soil depths as indicated in tables 4.1 and 4.2.

The result obtained show that the bulk density values of clay loam textured soils are found in the range of (1.19 to 1.39 g/cm^3) and clay textured soils are found in the range of (1.19 to 1.31 g/cm^3) in each selected field of two irrigation schemes as indicated in the tables 4.1and 4.2. USDA/NRCS (2008) recommended the ideal bulk density value for better plant root growth is less than 1.10 g/cm^3 for clay loam and clay textured soils.

Table 4.1: Soil Textural Class and Bulk Density for Bilate Irrigation Scheme

Field Location	Soil depth (cm)	Particles size distribution (%) %Clay	%Silt	%Sand	Textural classes	Bulk density (g/cm^3)
Head	0-30	28	28	44	clay loam	1.30
	30-60	30	27	43	clay loam	1.39
	60-100	42	24	34	clay	1.31
Middle	0-30	30	30	40	clay loam	1.28
	30-60	38	25	37	clay loam	1.29
	60-100	50	22	28	clay	1.23
Tail	0-30	32	30	38	clay loam	1.35
	30-60	30	30	40	clay loam	1.19
	60-100	35	30	35	clay	1.19

Table 4.2: Soil Textural Class and Bulk Density for Furfuro Irrigation Scheme

Field Location	Soil depth (cm)	Particles size distribution (%) %Clay	%Silt	%Sand	Textural classes	Bulk density (g/cm^3)
Head	0-30	35	38	27	clay loam	1.28
	30-60	33	37	24	clay loam	1.24
	60-100	37	37	26	clay loam	1.26
Middle	0-30	35	40	23	clay loam	1.30
	30-60	38	39	25	clay loam	1.25
	60-100	50	18	32	clay	1.21
Tail	0-30	38	28	34	clay loam	1.22
	30-60	28	30	42	clay loam	1.32
	60-100	56	16	28	clay	1.21

However, the same source proposed the bulk densities that affect root growth is (1.10-1.49 g/cm^3) and (1.10-1.39 g/cm^3) for clay loam and clay soils respectively. The results obtained in this study show that the bulk densities may affect the root growth according to mentioned author above. This implied that the soil might be highly compacted and this compaction of soil reduces pore space and high resistance to root penetration.

The results obtained for field capacity, permanent wilting point, and total available water at effective root depth were indicated in appendix-A, tables 2 and 3. The result obtained shows that the total available water was between (167.7 - 192.7mm/m) in each selected field of the two irrigation schemes. The average values of total available water obtained from selected fields of each irrigation scheme were used as input data for CROPWAT 8.0 model. The average values for each irrigation scheme were obtained as the average of the total available water measured from the selected fields at the head, middle, and tail-end of each irrigation scheme. The average total available water obtained in this study was (179.5 and 180.1 mm/m) for Bilate and Furfuro irrigation schemes respectively.

- **Soil Infiltration Rates**

The field measured values for basic infiltration rates were 8 and 9mm/hr in Bilate and Furfuro irrigation schemes respectively as indicated in appendix-A, table 1. Since the dominant soil texture was clay loam, especially upper two soil profile depths (i.e up to 60cm soil depth) in two irrigation schemes, the obtained values for basic infiltration rates were in agreement with FAO (1996) recommended value for the same soil types. The obtained values for basic infiltration rates were used for evaluation of farmer application rate of the irrigation water and also used as input data for CROPWAT 8.0 model to determine the irrigation scheduling.

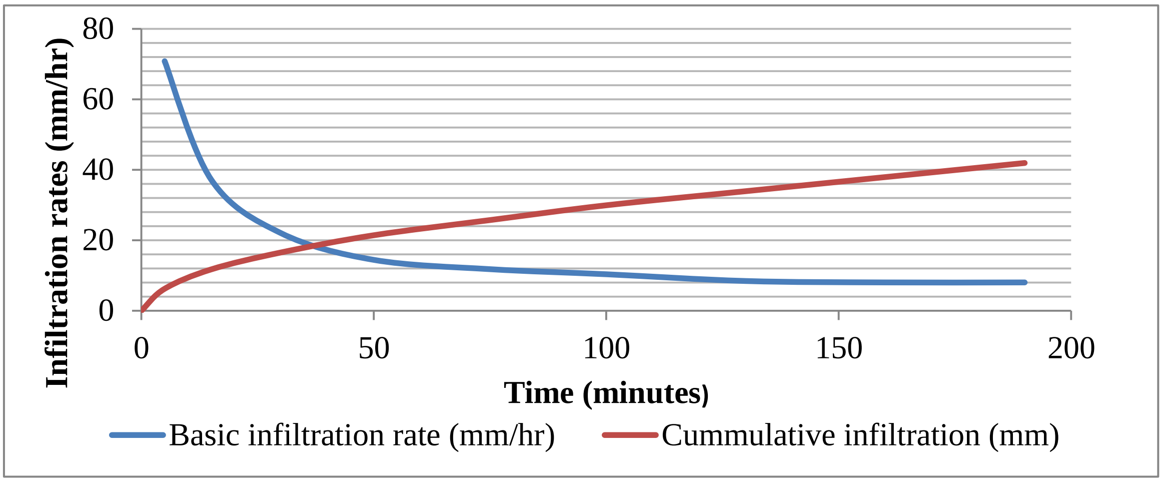

Figure 4.1: Cumulative and Basic Infiltration Rate for Bilate Irrigation Scheme

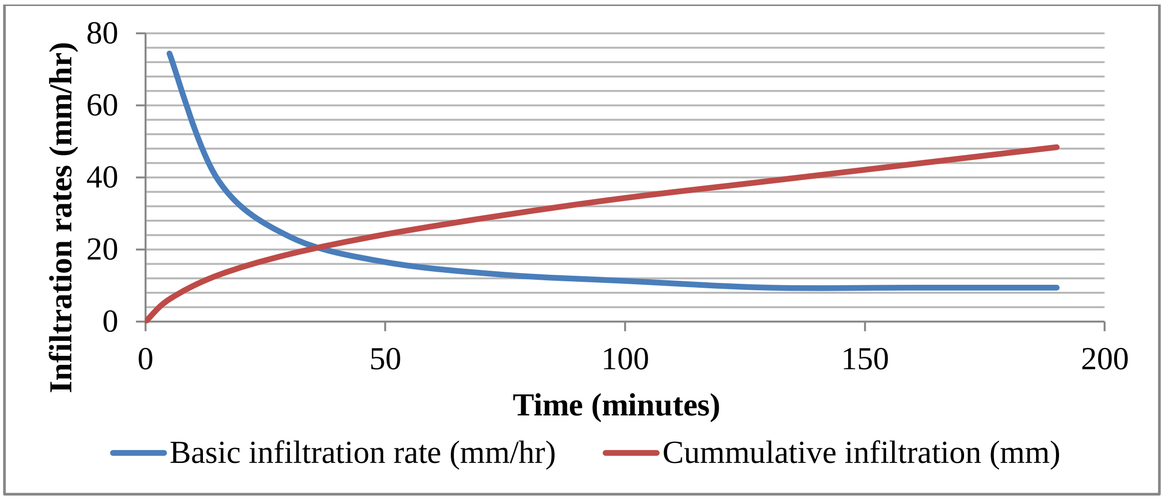

Figure 4.2: Cumulative and Basic Infiltration Rate for Furfuro Irrigation Scheme

4.1.1. Field Application Efficiency

The field application efficiency was calculated from the measured values of the amount of irrigation water applied and water stored at effective root zone. The results of the measured values for irrigation water applied were indicated in appendix-D, tables 2, and 3 for two irrigation schemes. Furthermore, the results of the measured values for soil moisture stored at effective root zones were indicated in appendix-A, table 4 for two irrigation schemes.

As the selected fields were irrigated by different crops i.e fields selected at head and middle irrigated by maize, while at tail-ends was irrigated by potato in Bilate irrigation scheme. The fields selected at head, middle and tail-ends were irrigated by onion, tomato and cabbage respectively in Furfuro irrigation scheme. Hence, the depth of applied water and water stored at effective root zone were different in each fields as the root depth of different crops were different for different crops.

As indicated in table 4.3, the result obtained for field application efficiencies at the head, middle, and tail-end fields were 61.1%, 52.8%, and 53.7% respectively with an average application efficiency of 55.9% in Bilate irrigation scheme. While, the results obtained for application efficiencies at the head, middle, and tail-end fields were 51.9%, 64.9%, and 57.3% respectively with the average application efficiency of 58% in Furfuro irrigation scheme as indicated in table 4.3. This indicated that the field application efficiency varies from field to field in the similar farming system, methods of irrigation water application, and field operation strategies, but the difference may be the on-field water management.

Table 4.3: Field Application Efficiency for Bilate and Furfuro Irrigation Schemes

Field Location	**Bilate Irrigation Scheme**			**Furfuro Irrigation Scheme**		
	WAD (mm)	SMS (mm)	Ea (%)	WAD (mm)	SMS (mm)	Ea (%)
Head	61.2	37.4	61.1	32.2	16.7	51.9
Middle	65.5	34.6	52.8	40.4	26.2	64.9
Tail end	38.6	20.7	53.7	28.9	16.5	57.3
Average			55.9			58.0

WAD is the depth of applied irrigation water and SMS is soil moisture stored

FAO (1989) reported that the maximum attainable application efficiency for surface irrigation systems is 55%-70%. The average field application efficiencies obtained in this study were within the recommended standard mentioned above for two irrigation schemes. The main reason might be the applied water is less than the soil moisture deficit, farmers used closed-end furrow (which may minimize runoff losses), the type of soil texture is clayey, and the compactness of the soil in the study area (which may reduce deep percolation losses). In conclusion, the obtained application efficiencies of this study imply the need to take the improvement measures of on-field water management and day-to-day operations.

4.1.2. Water Storage Efficiency

The water storage efficiency was calculated from soil moisture stored and readily available water that was needed before irrigation at the effective root zone. The result measured for soil moisture stored in each selected field of two irrigation was indicated in appendix-A, table 4. While readily available water of each irrigated crop was indicated in appendix-A, tables 2 and 3. The result obtained in this study for water storage efficiencies was indicated in table 4.4 below for two irrigation schemes.

Table 4.4: Water Storage Efficiency for Bilate and Furfuro Irrigation Schemes

Field Location	**Bilate Irrigation Scheme**			**Furfuro Irrigation Scheme**		
	SMS (mm)	RAW (mm)	Es (%)	SMS (mm)	RAW (mm)	Es (%)
Head	37.4	94.8	39.4	16.72	28.9	57.9
Middle	34.6	83.6	41.4	26.21	66.6	39.3
Tail end	20.7	26.5	78.1	16.54	39.1	42.3
Average			53.0			46.5

SMS is soil moisture stored and RAW is readily available water

The result obtained for water storage efficiencies of the selected fields at the head, middle and tail end were 39.4%, 41.1%, and 78.1% respectively with an average value of 53.0% in Bilate irrigation scheme. While, the result obtained for water storage efficiencies of the selected fields at the head, middle, and tail end were 57.9%, 39.3%, and 42.3% respectively with an average value of 46.5% in Furfuro irrigation scheme. Raghuwanshi and Wallender (1998) and Levine (1982) recommended that the water storage efficiency for furrow irrigation systems is 63%. Thus, the water storage efficiencies obtained in this study were very poor in the two irrigation schemes. This indicated that may the applied irrigation water was not satisfied the soil moisture deficit in the two irrigation schemes. This reflects directly soil moisture stress and inadequacy of irrigation water applied. The main reasons might be the applied irrigation water was below an intended water demand, farmers practicing fast application rates of irrigation water than soil infiltration rate, and/or farmers lacking awareness of different crop needs a different amount of water.

4.1.3. Irrigation Uniformity

The results of the measured values of soil moisture stored at test points were indicated in tables 4.5 and 4.6 below. Then, the results obtained in this study for Christian's uniformity coefficients were indicated in table 4.7 for two irrigation schemes. Thus, the average Christian's uniformity coefficients were (92.3, 92.6 and 88.2%) and (91.0, 93.6 and 94.3%) for selected fields at head, middle and tail-end in Bilate and Furfuro irrigation schemes respectively. The irrigation uniformities values obtained in present study for all selected furrows as well as all selected fields in each irrigation schemes were much higher than the advanced furrow irrigation systems, which is 70% as reported by Raghuwanshi and Walender (1998). Therefore, the irrigation uniformities of the two irrigation schemes were very good, the reason for this might be the farmers used short-length at most 20 metere furrow length; closed-end furrow practices and good land grading practices in the study area.

Table 4.5: Depth of moisture stored in each test points in Bilate irrigation scheme

Field Location	Furrow one			Furrow two			Furrow three		
Head	39.0	38.8	41.0	43.6	32.5	36.0	35.3	34.3	35.8
Middle	41.0	36.1	34.7	37.9	34.1	33.6	32.8	30.5	30.7
Tail	16.1	18.3	24.3	18.3	22.0	22.7	19.4	22.3	23.1

Table 4.6: Depth of moisture stored in each test points in Furfuro irrigation scheme

Field Location	Furrow one			Furrow two			Furrow three		
Head	14.7	16.9	19.0	14.6	16.5	19.1	14.3	16.7	18.6
Middle	22.4	26.9	26.3	25.0	27.2	26.7	23.8	31.1	26.5
Tail	17.0	17.8	17.0	16.1	16.8	14.3	17.1	15.0	17.9

Table 4.7: Christian's Coefficient Uniformity for Bilate Irrigation Schemes

Head Selected Field		Moisture stored			Mean	CU (%)
Beginning Furrow	Total moisture stored	39.0	38.8	41.0	39.6	94.3
	Absolute deviation from mean	1.6	1.5	3.6	2.2	
Middle Furrow	Total moisture stored	43.6	32.5	36.0	37.4	88.9
	Absolute deviation from mean	6.2	4.9	1.4	4.1	
Bottom Furrow	Total moisture stored	35.3	34.3	35.8	35.1	93.6
	Absolute deviation from mean	2.1	3.1	1.5	2.2	
Average for field						**92.3**
Middle Selected Field						
Beginning Furrow	Total moisture stored	41.0	36.1	34.7	37.3	92.8
	Absolute deviation from mean	6.4	1.5	0.2	2.7	
Middle Furrow	Total moisture stored	37.9	34.1	33.6	35.2	95.4
	Absolute deviation from mean	3.3	0.5	1.0	1.6	
Bottom Furrow	Total moisture stored	32.8	30.5	30.7	31.3	89.6
	Absolute deviation from mean	1.8	4.1	3.9	3.3	
Average for field						**92.6**
Tail Selected Field						
Beginning Furrow	Total moisture stored	16.1	18.3	24.3	19.6	81.8
	Absolute deviation from mean	4.6	2.4	3.6	3.6	
Middle Furrow	Total moisture stored	18.3	22.0	22.7	21.0	91.0
	Absolute deviation from mean	2.5	1.2	2.0	1.9	
Bottom Furrow	Total moisture stored	19.4	22.3	23.1	21.6	91.9
	Absolute deviation from mean	1.3	1.6	2.4	1.8	
Average for field						**88.2**

Table 4.8: Christian's Coefficient Uniformity for Furfuro Irrigation Schemes

Head Selected Field		Moisture stored			Mean	CU (%)
Beginning	Total moisture stored	14.7	16.9	19.0	16.9	91.1
Furrow	Absolute deviation from mean	2.0	0.2	2.3	1.5	
Middle Furrow	Total moisture stored	14.6	16.5	19.1	16.7	90.6
	Absolute deviation from mean	2.2	0.2	2.4	1.6	
Bottom Furrow	Total moisture stored	14.3	16.7	18.6	16.5	91.3
	Absolute deviation from mean	2.4	0.0	1.9	1.4	
Average for field						**91.0**
Middle Selected Field						
Beginning	Total moisture stored	22.4	26.9	26.3	25.2	93.8
Furrow	Absolute deviation from mean	3.8	0.7	0.1	1.6	
Middle Furrow	Total moisture stored	25.0	27.2	26.7	26.3	96.5
	Absolute deviation from mean	1.3	1.0	0.5	0.9	
Bottom Furrow	Total moisture stored	23.8	31.1	26.5	27.1	90.6
	Absolute deviation from mean	2.5	4.9	0.3	2.6	
Average for field						**93.6**
Tail Selected Field						
Beginning	Total moisture stored	17.0	17.8	17.0	17.2	96.0
Furrow	Absolute deviation from mean	0.4	1.2	0.4	0.7	
Middle Furrow	Total moisture stored	16.1	16.8	14.3	15.7	93.9
	Absolute deviation from mean	0.4	0.2	2.2	1.0	
Bottom Furrow	Total moisture stored	17.1	15.0	17.9	16.7	93.2
	Absolute deviation from mean	0.5	1.5	1.4	1.1	
Average for field						**94.3**

4.1.4. Conveyance Efficiency

The conveyance efficiency and loss were estimated from the inflow and outflow discharges measured in main, secondary, and tertiary canal sections as indicated in tables 4.9 and 4.10 for two irrigation schemes. The FAO (2001) recommended that the conveyance efficiency for lined canals of any length is 95%. For earthen canals with clay soil could be 80%, 85%, and 90% for canal lengths of >2000m, 200-2000m, and <200m respectively.

Thus, except at 900m lined main canal section of Bilate irrigation scheme and 5300m lined main canal section of Furfuro irrigation scheme, the results of conveyance efficiencies at lined canals were below recommended value. Moreover, estimated values of conveyance efficiencies for unlined tertiary canals sections were below the recommended values in two irrigation schemes. The main reason might be evaporation losses, malfunctioning of control gates, high sedimentation, illegal water turnouts in main and secondary canals, water stagnation, grass covers of the canals' waterway, and canal size widening.

As indicated in table 4.9, the results for average conveyance losses were 0.5, 1.4, and 6.0 (l/s) per 100m for lined main and secondary, and unlined tertiary canals in Bilate irrigation scheme. While in Furfuro irrigation scheme the average conveyance losses in lined main and unlined tertiary canals were 0.067 and 2.36 (l/s) per 100m respectively as indicated in table 4.10. Thus, more water was lost in unlined canal sections, because of seepage and/or leakage losses and their cross-section was widened and stagnation of water was common, which exposed to evaporation losses. In conclusion, the results obtained in this study for conveyance efficiencies and losses indicated high losses of irrigation water in conveyance systems of two irrigation schemes that may influence the irrigation adequacy.

Table 4.9: Canal Conveyance Efficiency and Loss for Bilate Irrigation Scheme

Canal Types	L_c (m)	Q (l/s)	Conveyance Efficiencies (%)	Conveyance loses (l/s)/100m
Main canal	7200	282.60 257.09	91	0.4
	900	168.18 160.79	96	0.8
	1500	82.64 77.24	93	0.4
Average				0.5
Secondary canal	400	78.86 68.48	87	2.6
	210	20.66 18.32	89	1.1
	106	5.22 4.60	88	0.6
Average				1.4
Tertiary-1	115	26.58 15.20	57	9.90
Tertiary-2	96	20.18 13.51	67	6.94
Tertiary-3	120	8.63 4.92	57	3.09
Tertiary-4	105	10.83 6.59	61	4.03
Average				6.0

Table 4.10: Canal Conveyance Efficiency and Loss for Furfuro Irrigation Scheme

Canal Types	Lc (m)	Q (l/s)	Conveyance Efficiencies (%)	Conveyance loses (l/s)/m
Main Canal -1	5300	88.443 84.766	96	0.069
Main Canal -2	6100	43.184 39.200	91	0.065
Average				0.067
Tertiary-1	380	18.087	57	2.06

		10.267		
Tertiary-2	210	15.108 9.562	63	2.64
Average			76.7	2.35

L_c is canal length and Q is flow discharge

4.1.5. Overall Irrigation Efficiency

According to table 4.11, the overall irrigation efficiencies obtained in this study were 28 and 32% for Bilate and Furfuro irrigation schemes respectively. Rai *et al.* (2017) suggested that the overall irrigation efficiency values between 50 and 60% are good, 40% are reasonable, while 20-30% are poor. Thus, the overall irrigation efficiencies recorded in this study were poor; the reason might be losses of water in conveyance systems.

Table 4.11: Overall Irrigation Efficiency for Bilate and Furfuro Irrigation Schemes

Efficiencies %	Bilate Irrigation Scheme	Furfuro Irrigation Scheme
Overall conveyance efficiency	78.6	76.7
Average application efficiency	55.9	58
Overall irrigation efficiency	28	32

4.2. External Performance Indicators

4.2.1. Water Delivery Performance Indicators

The results obtained on water delivery indicators (relative water supply, relative irrigation supply, and water delivery capacity) were discussed in this section as indicated in table 4.12. Thus, the relative water supply and relative irrigation supply were calculated from the total volume of water applied, the total volume of irrigation water applied, the total volume of crop water demand, and total volume of irrigation water demand. The determined values for total crop water demand and irrigation water demand for two irrigation schemes were indicated in appendix-C, tables 1and 2. Whereas, the measured values for total irrigation water applied in two irrigation schemes were indicated in appendix-D, tables 2 and 3.

Table 4.12: Relative Water Supply and Relative Irrigation Supply for Two Schemes

Scheme	Total water applied/season (m^3)	Total net irrigation water applied/season (m^3)	Total CWR/season (m^3)	Total IR/season (m^3)	RWS	RIS
Bilate	945968	701115	1392385	1147532	0.68	0.61
Furfuro	801699	685073	1,009,465	892839	0.79	0.77

The result in table 4.12 indicated that the relative irrigation supplies were 0.61 and 0.77 for Bilate and Furfuro irrigation schemes respectively. Molden *et al.* (1998) suggested that the relative irrigation supply value of one is better than the higher or lower values for any irrigation scheme. The results obtained in this study show that the relative irrigation supplies were below one for the two irrigation schemes. This indicated that applied water is not tightly matched to irrigation water demand in the two irrigation schemes. The reason might be the losses of irrigation water in the conveyance system, lack of awareness of crop water demand, and expansion of the irrigated area. The results obtained for relative water supplies were 0.68 and 0.79 for Bilate and Furfuro irrigation schemes. These results implied that the sum of irrigation water applied and effective rainfall was not satisfied the crop water demands in the two irrigation schemes.

As indicated in table 4.13, the results obtained for water delivery capacities were 0.66 and 0.53 for Bilate and Furfuro irrigation schemes respectively. According to Molden *et al.* (1998), the value of water delivery capacity below one implied that the designed and constructed canal conveyance capacity does not meet peak consumptive demands in a particular period and constrains the cropping intensities. Thus, the results obtained in this study indicated that the present discharge capacity of the canal at the system head was much lower than the peak crop demand in the two irrigation schemes. Because, during the study period, the main canal did not deliver its full capacity due to high water competition in its water sources in Bilate irrigation scheme and there was no assigned body to adjust the flow controlling gate and leakage losses in main canals in Furfuro irrigation scheme.

Table 4.13: Water Delivery Capacity for Bilate and Furfuro Irrigation Schemes

Schemes	Canal discharge (cumecs)	Canal discharge (l/s)	Peak consumptive demand (cumecs)	Peak consumptive demand (l/s)	WDC
Bilate	0.282	282	0.425	425.4	0.66
Furfuro	0.132	132	0.251	250.5	0.53

4.2.2. Irrigated Agricultural Output Performance Indicators

The relevant data were collected for the estimation of the irrigated agriculture performance indicators. The data collected for irrigated area per crop, irrigated crop yields, local market price, total irrigated areas and total productions were indicated in appendix-E and F for two irrigation schemes during the study season. Then, the results obtained in this study for irrigated agriculture performance indicators those evaluated as land productivity (output per unit irrigated area and output per unit command area) and water productivity (output per unit irrigation supply and output per unit water consumed) were indicated in table 4.13.

Table 4.14: Land and Water Productivity for Bilate and Furfuro Irrigation Schemes

Irrigation Schemes	Bilate	Furfuro
Irrigated area during this study (ha)	332.25	221
Production from total irrigated area (US$)	1375651.8	393,701.6
Designed area (ha)	305	200
Total Irrigation Water Applied (m^3/season)	1,460,656	1,427,236
CWR (m^3/season)	1,392,385	1,009,465
Output per unit irrigated area (US$/ha)	4140.4	1,781.5
Output per unit command area (US$/ha)	4510.3	1,968.5
Output per unit irrigation Supply (US$/$m^3$)	0.94	0.28
Output per unit water consumed (US$/$m^3$)	0.99	0.39

4.2.2.1. Output per unit Irrigated Area

According to table 4.14, the results obtained on output per unit irrigated area were 4,140.4 and 1,781.5 US$/ha in Bilate and Furfuro irrigation schemes respectively. The variation between the results of output per unit irrigated area among two irrigation schemes was 2358.9 US$/ha. The study conducted by Degirmenci *et al*. (2003) in 12 irrigation schemes in the Southeastern Anatolia project suggested that the variation between output per irrigated area among various irrigation schemes is in the range of (308-5771 US$/ha). Thus, the result obtained in this study indicated that the variation of output per irrigated area in two irrigation schemes was in the recommended range of this mentioned author.

4.2.2.2. Output per unit Command Area

According to table 4.14, the results of output per unit command area were 4510.3 US$/ha and 1,968.5 US$/ha for Bilate and Furfuro irrigation schemes respectively. The variation between the results of output per unit command area among two irrigation schemes was 2541.8 US$/ha. Degirmenci *et al*. (2003) suggested that the variation between the output per unit command area could be in the range of (1223 - 9436 US$/ha) among various irrigation schemes. Thus, the results obtained in this study showed that the variation between the output per unit command area among Bilate and Furfuro irrigation schemes was in the recommended range of the mentioned author.

The result of this study indicated that the output per unit command area is better than output per unit irrigated area in two irrigation schemes. This is evidence that there is an effect thereby expansion of the irrigated area by 27.25ha in Bilate and 21ha in Furfuro irrigation schemes relative to the designed command area without delivering additional irrigation water.

4.2.2.3. Output per unit Irrigation Supply

The result obtained in this study on output per unit irrigation supply was 0.94 US$/m^3 and 0.28 US$/m^3 for Bilate and Furfuro irrigation schemes respectively. Cakmak *et al*. (2004) conducted a study on sixty irrigation schemes found in Kizilimak Basin, Turkey, and suggested the values for output per unit of irrigation supply could be in the range of (0.03 - 2.21 US$/m^3). Thus, the result of output per irrigation supply was in the recommended range of mentioned author for two irrigation scheme.

4.2.2.4. Output per unit of Water Consumed

The results obtained in this study on output per unit of water consumed were 0.99 US$/m^3 and 0.39 US$/m^3 in Bilate and Furfuro irrigation schemes respectively. Molden *et al.* (1998) suggested that the output per unit of water consumed for irrigation schemes could be in the range of (0.03 - 0.91 US$/m^3). Thus, the result of output per water consumed for Furfuro irrigation scheme was in the recommended range of mentioned author. While the result of output per water consumed for Bilate irrigation scheme was beyond recommended range, the reason might be farmers use a high level of agricultural inputs, and the command area may have better soil fertility.

The output per unit irrigated area and output per unit command area are termed land productivity. While output per unit irrigation supply and output per unit water consumed is termed water productivity. Therefore, Bilate irrigation scheme had better land and water productivity than Furfuro irrigation scheme.

4.2.3. Physical Performance Indicators

4.2.3.1. Sustainability of Irrigated Area

According to table 4.15, the result of sustainability of irrigated area for Bilate and Furfuro irrigation schemes were 1.02 and 1.05 respectively. This indicates that actual irrigated areas during the study season were 102% and 105% of the initially irrigated area in Bilate and Furfuro irrigation schemes respectively. Therefore, irrigated areas of the schemes were expanded compared with the initially irrigated area. Similarly, various studies reported the values indicating the expansion of the initially irrigated area in existing irrigation schemes, for example, Agide (2012); Kassa and Ayana (2019), and Tadesse (2017) reported the values of 1.22 for Golgota irrigation scheme, 1.08 for Tahtay Tsalit irrigation scheme, and 1.2 for Bobe irrigation scheme respectively, who conducted their studies in Ethiopia.

4.2.3.2. Irrigation Ratio

According to table 4.15, the results of irrigation ratio in Bilate and Furfuro irrigation schemes were 1.09 and 1.11 respectively. This means that actual irrigated areas during the study season were 109 and 111% of the designed command in Bilate and Furfuro irrigation schemes. This means that the irrigated lands were expanded in these irrigation schemes areas. The reasons might be the self-initiation and interest of farmers within the schemes command areas to irrigate their land due to good land productivity as better soil fertilities of the areas and interest coming from neighboring farmers to irrigate extra land in addition to the designed area. Minichil (2019) reported similarly greater than one value for irrigation ratio in Kulech irrigation schemes evaluated in four consecutive years.

Table 4.15: Irrigation Ratio and Sustainability of Irrigated Area for Two Schemes

Schemes	Currently Irrigated area (ha)	Actual irrigated land in any season (ha)	Designed area (ha)	Sustainability of Irrigated Area	Irrigation Ratio
Bilate	332.25	325.5	305	1.02	1.09
Furfuro	221	209.5	200	1.05	1.11

4.3. Comparison made between Bilate and Furfuro Irrigation Schemes

As indicated in tables 4.9 and 4.10, more irrigation water was lost in the conveyance systems of Bilate irrigation scheme than Furfuro irrigation scheme. The reason might be higher canal sedimentation, illegal water turnouts, and malfunctioned division boxes and flow control canals in Bilate irrigation scheme than Furfuro irrigation scheme.

As indicated in table 4.12 above, the relative water supply and relative irrigation supply values obtained were low in two irrigation schemes, depicting that, disregarding the distribution of the supply, the scarcity of irrigation water was being supplied much less than the demand. Moreover, the water delivery capacity values obtained were also low in two irrigation schemes, implying that the present main canal capacity at the system head was not meet the peak irrigation demand of the system. Since the result obtained for RWS, RIS and WDC were below acceptable values for two irrigation schemes. But, Furfuro irrigation scheme had relatively better values of RWS and RIS than Bilate scheme. In Furfuro irrigation scheme there is no competition to irrigation water, hence, farmers applied the irrigation water as much as amount of their interest. However, in Bilate irrigation scheme there were high competition of water in its source and field.

As indicated in table 4.15 above, the result obtained in this study for the sustainability of the irrigated area and irrigation ratio was within an acceptable range of (Molden *et al*., 1998 and Cornish, 2005) recommendation. This indicated that the irrigated areas were equally expanding for the two irrigation schemes. Thus, in terms of physical performance indicators, there was no difference between these two schemes' performance, hence, the irrigated land is currently expanded. This implied that the shortage of delivered irrigation water never reduces the farmers’ motivation to irrigate their fields and neighboring farmers' intensification for irrigation, however, it may affect irrigation water adequacy.

As indicated in figure 4.3 below, the land productivity (output per unit irrigated area and output per unit command area) of Bilate irrigation scheme was much higher than Furfuro irrigation scheme. This might be happened due to differences in irrigated field productivity during the study season because of the variation in cropping pattern, soil fertility, and willingness of farmers to invest more agricultural inputs such as fertilizers, pesticides and herbicides, which means higher yield per unit of land at Bilate irrigation scheme. Moreover, highly productive and marketable crops such as potato and Maize were dominant crops in Bilate scheme. From this evidence, therefore, the Bilate irrigation scheme had better land productivity than Furfuro irrigation scheme.

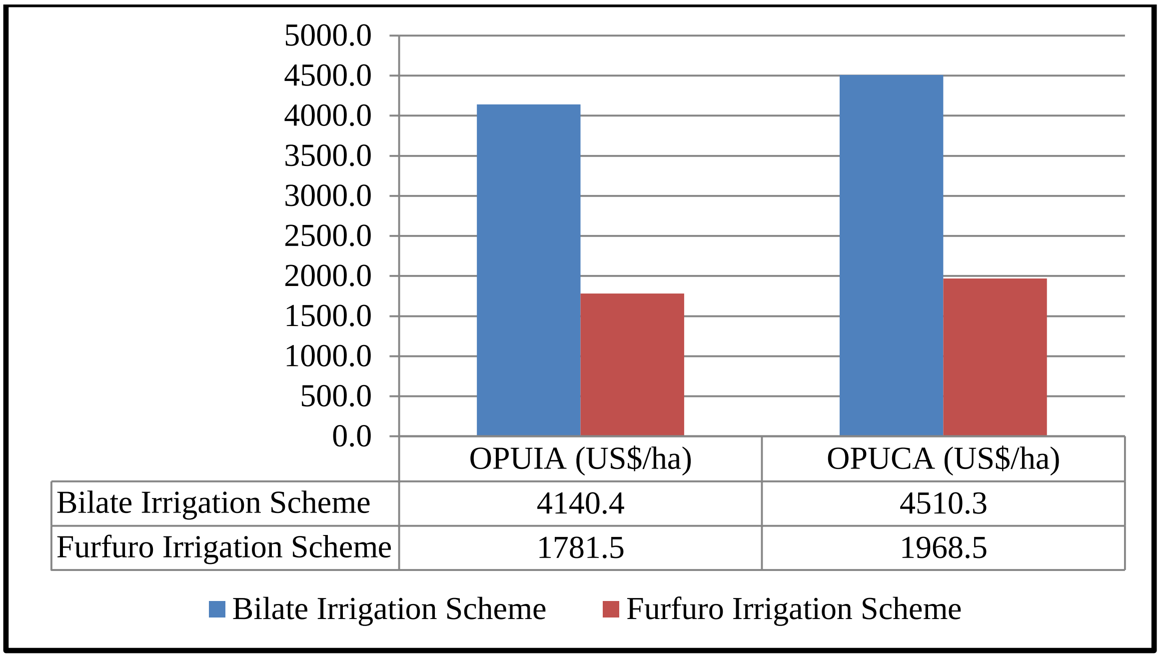

Figure 4.3: Comparison of Bilate and Furfuro Schemes based on Land Productivity

According to figure 4.4, the result obtained for output per unit of irrigation supply and output per unit of water consumed were better in Bilate irrigation scheme than Furfuro irrigation scheme. This implied that more outputs were returned from unit irrigation water applied and water consumed from Bilate irrigation scheme than Furfuro irrigation scheme. The reason might be the irrigated crops were high value crops in Bilate irrigation scheme; better soil fertility; farmers' awareness and motivation for irrigation. Therefore, Bilate irrigation scheme had better water productivity than Furfuro irrigation scheme.

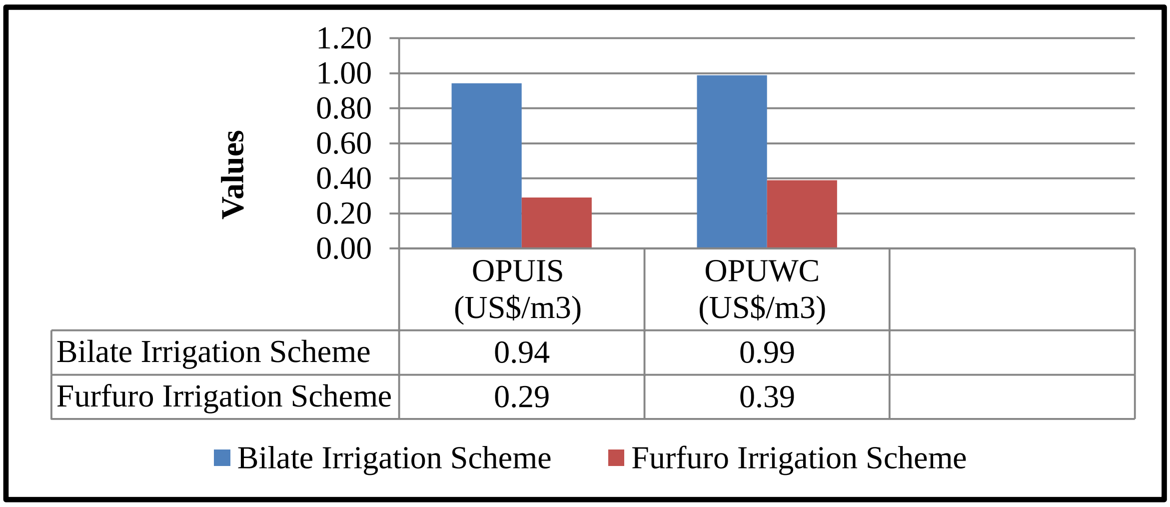

Figure 4.4: Comparison of Bilate and Furfuro schemes based on Water Productivity

Bilate irrigation scheme had significantly better land and water productivity than Furfuro scheme due to use of high value crops, better agricultural inputs and removal of grass cover and sedimentation from canal systems. Hence, Bilate irrigation scheme was better performing than Furfuro irrigation scheme. Therefore, adopt the best practices learned from Bilate irrigation scheme for the Furfuro scheme. Moreover, properly maintain malfunctioned infrastructures, create WUAs and agricultural experts, and create awareness for farmers and WUAs on irrigation water management in two irrigation schemes.

4.4. Irrigation Duration and Irrigation Scheduling

The acceptable duration of the irrigation was determined from the depth of irrigation water applied and the basic infiltration rate of the soil as indicated in table 4.16 below. The soil types of the study areas were clay loam and clay and the bulk density shows the soil is highly compacted. Hence, a long duration of irrigation and slow flow rate application is preferable. But, the duration of irrigation that farmers practiced in each selected field at the head, middle, and tail end of each irrigation scheme was much lower than the acceptable duration of irrigation. This indicated that farmers' application rate was faster than the basic infiltration rate of the soil. This might cause overflow of irrigation water.

The measured depth of the irrigation water that farmers had applied to each selected field at the head, middle, and tail end was 61.17mm, 65.49mm, and 38.60mm per interval and they used fixed irrigation intervals of 13, 14, and 15 days respectively in Bilate irrigation scheme. Whereas, in the Furfuro irrigation scheme the measured depth of the irrigation water that farmers applied to selected fields at the head, middle, and tail end was 32.2mm, 40.38mm, and 28.88mm per interval and used fixed irrigation intervals of 5, 6, and 6 days respectively. The farmers practiced fixed irrigation intervals for all crops because they are free to irrigate till they have received enough water and continue until the furrows store some amount of water by thinking that it can help until the next irrigation.

The acceptable net irrigation application depths and irrigation intervals for major irrigated crops were computed and their results are indicated in appendix-C, tables 4 up to 8. Hence, the depth of irrigation water and irrigation intervals that farmers practiced was not proportional to the acceptable depth of irrigation water and irrigation intervals in two irrigation schemes. The reason might be the farmers get the irrigation water on rotational bases; they also lack the awareness of irrigation scheduling and the absence of water management and day-to-day operational rules in the study schemes areas.

Table 4.16: Comparison of Farmers' Irrigation Duration with Acceptable Duration

Scheme	Field Location	Depth of water applied (mm)	Acceptable duration (hours)	Farmers' duration (hours)
Bilate	Head	61.2	7.6	4.2
	Middle	65.5	8.2	4.0
	Tail	38.6	4.8	4.2
Furfuro	Head	32.2	3.6	1.7
	Middle	40.4	4.5	2.4
	Tail	28.9	3.2	2.3

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

Performance evaluation of the irrigation schemes is a vital activity to pinpoint and locate the problem areas and so that prompt improvement options and then, assists engineers to design new systems. Moreover, the comparative performance evaluation provides clear information on performance level of the schemes that enables to transfer best practices to take improvement measures. Therefore, the objective of this study was to evaluate the performance of the Bilate and Furfuro schemes in Silti Zone, Southern Ethiopia. Two irrigation schemes were evaluated by their own merits using internal performance indicators and a comparison was also made using external performance indicators. Three representative farmers' fields were selected at the head, middle and tail end of each irrigation scheme.

The results of application efficiencies for two irrigation schemes indicated the need for improvements in on-field water management. The water storage efficiency results of the two schemes show that the applied water had not satisfied the soil moisture deficit, therefore, indicating the inadequacy of the irrigation. Moreover, the results of conveyance efficiencies and losses show that the two schemes had an unreasonable loss of irrigation water in their conveyance systems. The overall irrigation efficiencies were poor in two irrigation schemes. Generally, the results of internal performance indicators indicated that two irrigation schemes were performing inefficiently and inadequately. The main reason might be the applied irrigation water was below the crop water demand or farmers lack awareness of different crops need different amounts of water, high sedimentation and illegal water turnout in main and secondary canals and water stagnation, grass cover in canals waterway, and widening of tertiary canals size and unreasonable losses of water in conveyance systems. But, the irrigation water was distributed uniformly within the field in two schemes. The reason might be the farmers use short-length and closed-end furrows.

The results obtained for external performance indicators revealed that the applied irrigation water is not tightly satisfied the crop water demands and peak consumptive use. The reason might be poor field water management; failure in infrastructures (division boxes and flow control gates); unacceptable losses of irrigation water in conveyance systems; irrigation intensification from neighboring farmers and illegal water turnout in main and secondary canals; high water competition among farmers and at the source of Bilate irrigation scheme and lack of awareness on water demand of crops. However, the irrigated lands were expanded in two irrigation schemes. Moreover, the results of output per unit command area were better than output per unit irrigated area in two irrigation schemes; this is evidence that there is an effect thereby expansion of the irrigated area by 27.25ha in Bilate and 21ha in Furfuro schemes relative to the designed area without delivering additional irrigation water. Moreover, the result of output per unit of water consumed was better than output per unit of irrigation water supply for two irrigation schemes, this is evidence that the lack of awareness to apply the crop water demand may affect the irrigated agriculture outputs.

The Furfuro irrigation scheme was better performing than Bilate irrigation scheme in terms of conveyance losses, relative water supply, and relative irrigation supply. Whereas the Bilate irrigation scheme was meaningfully better performing than Furfuro irrigation schemes in terms of irrigated agriculture output and water delivery capacity. So, Bilate irrigation scheme had better performance than Furfuro irrigation scheme. The reason might be productive use of irrigation water; had better soil fertility, higher value crops were irrigated dominantly, more intensive irrigation, better agricultural inputs in Bilate irrigation scheme. Hence, the irrigation managers in Furfuro irrigation scheme adopt the best practices learned from Bilate irrigation scheme. But, two irrigation schemes need improvement measures. This study was conducted only in one irrigation season and performance evaluation of two irrigation schemes was not seen regarding financial performance indicators and organizational setups.

5.2. Recommendations

- The two irrigation schemes need proper maintenance of the division boxes and flow control gates; continuously removing sediment from the main and secondary canals and prevention of grass cover in unlined canals waterways, water stagnation in-field distribution canals, and widening of unlined canal sections.
- Encourage water users association and local agricultural experts who share water and ensure equity among users, especially during periods of water shortage.
- Create awareness to beneficiary farmers and water users' associations about field irrigation water measurements, irrigation water management strategies, scheme operation, and maintenance practices through continuous training.
- Wereda experts and DAs with water users association must plan seasonal water demand, irrigation duration, and scheduling for farmers and water association users according to the crop pattern in the scheme area and do not irrigate an area that exceeds the planned area. Thus, decisions concerning flow rate, duration, and frequency should be placed in the hands of DAs and WUAs.
- Adopt the best practices learned from Bilate irrigation scheme for the Bilate irrigation scheme; for example, use more productive crops, better agricultural inputs, removal of grass cover and sedimentation from canal systems, etc.

6. REFERENCES

Abdulai, R. 2006. Is land title registration the answer to insecure and uncertain property rights in sub-Saharan Africa. RICS Research Paper Series, 6(6). http://hdl.handle.net/2436/28832

Abraham Bairu Gebrehiwot, Nata Tadesse, Bheemalingeswara, and Mokennen Haileselasse. 2011. Suitability of Groundwater Quality for Irrigation: Journal of American Science 7(8):191-199.

Abrha, F. A. 2017. Performance Evaluation of Small Scale Irrigation Scheme in Addis-Alem, Seharti Samre Woreda. MSc Thesis. Hawassa University. Hawassa, Ethiopia. 72p.

Adane, B. 2020. Performance Assessment of Small-Scale Irrigation Schemes : A Case Study of Upper Blue Nile, East Dangila. Irrigation and Drainage Systems Engineering, 9(4), 7–10. https://doi.org/10.37421/idse.2020.9.247

Adugnaw A.N. 2017. Performance Evaluation of Furrow Irrigation in Belles Sugar Development Project Sugarcane Farm Level. MSc Thesis. Hawassa University. Hawassa, Ethiopia. 68p.

Agide Dejen. 2012. Comparative irrigation performance assessment in community-managed schemes in Ethiopia. African Journal of Agricultural Research, 7(35), 4956–4970. https://doi.org/10.5897/ajar11.2135

Agide, Z., Haileslassie, A., Sally, H., Erkossa, T., Schmitter, P., Langan, S. and Hoekstra, D. 2016. Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia : Diversity and lessons across schemes, typologies and reaches. Lives Working Paper 15, 15, 38. https://cgspace.cgiar.org/handle/10568/73684

Ahmed, J. 2019. The Role of Small Scale Irrigation to Household Food Security in Ethiopia: A Review Paper. Journal of Resources Development and Management, 60, 20–25. https://doi.org/10.7176/jrdm/60-03.

Ali, M.H., 2011. Water conveyance loss and designing conveyance system. In Practices of Irrigation & On-farm Water Management: 2 (pp. 1-34). Springer, New York, NY.

Andales, AA, ChC!vez, JL, and Bauder, TA. 2011. Irrigation scheduling: The water balance approach. Service in action; no. 4.707

Awulachew SB, Yilma AD, Loulseged M, Loiskandl W, Ayana M and Alamirew T. 2007. Water resources and irrigation development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute.

Awulachew, SB., Erkossa, T. and Namara, R. 2010. Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. Research Report, International Water Management Institute, Addis Ababa. International Water Management Institute, July, 1–59.

Awulachew, S. B., and Ayana, M. 2011. Performance OF irrigation: An assessment at different scales in Ethiopia. Experimental Agriculture, *47*(S1), 57–69. https://doi.org/10.1017/S0014479710000955

Awulachew, S. B. and Merrey, D. J. 2007. Assessment of Small Scale Irrigation and Water Harvesting in Ethiopian Agricultural Development. Agriculture, January 2014, 1–11.

Beshir, A., and Bekele, S. 2008. Analysis of irrigation systems using comparative performance indicators: a case study of two large scale irrigation systems in the upper Awash Basin. Impact of Irrigation on Poverty, 77–92.

Bos, M.G. 1978. Discharge measurement structures. 2nd ed., Publication No. 20, Int. Inst. For Land Reclamation and Improvement/ILRI, Wageningen, the Netherlands.

Bos, M.G. 1997. Performance indicators for irrigation and drainage. Irrigation and Drainage Systems 11, 119–137. https://doi.org/10.1023/A:1005826407118

Brouwer, C., Prins, K. and Heibloem, M. 1989. Irrigation water management: irrigation scheduling. Training manual 4

Cakmak, B. and Beyr, I. 2004. Benchmarking Performance of Irrigation Schemes : Irrigation and Drainage, 163, 155–163.

Canadell, J., Jackson, R.B. and Ehleringer, J.B. 1996. Maximum rooting depth of vegetation types at the global scale. Oecologia 108, 583–595. https://doi.org/10.1007/BF00329030

Canyon Hydro and Wolkers Dorfer. 2012. Flow Measurement Devices, Laboratory Evaluation of Open Channel Area-Velocity Flow Meters, Hydraulics Laboratory Report HL, Wikipedia, ISCO Flow Measurement Handbook

Cornish, G. A. 2005. Performance Benchmarking in the Irrigation and Drainage Sector abcd Document Information. February.

Değirmencİ, H., Büyükcangaz, H., and Kuşcu, H. 2003. Assessment of Irrigation Schemes with Comparative Indicators in the Southeastern Anatolia Project. 27, 293–303.

Demeke Tamene Mitku, Asfaw Kebede kassa and Ashebir Haile Tefera. 2021. Determination of water requirements for onion in Ethiopia. British Journal of Earth Sciences Research. Vol.8, No.1, pp.1-24.

Depeweg Ir. H.W.Th. 2002. Revised Edition. Field Irrigation and Drainage Principles.

Dessalew, T., Ayalew, A., Desalegn, T., Mathewos, M., and Alemu, G. 2016. Performance Evaluation of Bedene Alemtena Small Scale Irrigation Scheme in Hallaba Special Woreda, Southern Ethiopia. OALib, *03*(02), 1–6. https://doi.org/10.4236/oalib.1102021

Dires Tewabe, Amare Tsige, Alebachew Enyew and Mulugeta Worku. 2021. Determination of crop water requirements and irrigation scheduling of wheat using CROPWAT at Koga and Rib irrigation scheme, Ethiopia. Research Square. 717969 (1). doi.org/10.21203/rs.3

Douglas, L.V., and A. S. Juan. 1999. Transfer of Irrigation Management Services. Guideline. Irrigation and Drainage Paper. No. 58. FAO, Rome.

Ebsa, M.H. (2017). Comparative Performance Assessment of Mojo Asha and Adano Small-Scale Irrigation Schemes in East Hararghe Zone. MSc Thesis. Hawassa University. Hawassa, Ethiopia. 109p.

Edkins, R. 2006. Irrigation efficiency gaps–review and stock take. Prepared for Sustainable Farming Fund and Irrigation New Zealand.

Eisenhauer, D.E. 1997. Irrigation Performance Measures: Efficiency and Uniformity. Journal of Irrigation and Drainage Engineering 123, 423-442.

Endalew, B. Muche, M. and Tadesse, S. 2015. Assessment of food security situation in ethiopia: A Review. In Asian Journal of Agricultural Research (Vol. 9, Issue 2, pp. 55–68). https://doi.org/10.3923/ajar.2015.55.68

Eticha, Shiberu. 2011. Performance Evaluation of Small Scale Irrigation Schemes in Adami Tullu Jido Kombolcha Woreda, Central Rift Valley of Ethiopia. MSc Thesis. Haramaya University.

Ewaid, S. H. and Abed, S. A. 2019. Crop Water Requirements and Irrigation Schedules for Some Major Crops in Southern Iraq. 11, 756; doi:10.3390/w11040756.

FAO (Food and Agricultural Organization). 1977. Irrigation and Drainage Paper No. 24. Guidelines for predicting crop water requirements by J. Doorenbos & W.O. Pruitt. Rome, Italy.

FAO (Food and Agricultural Organization). 1981. Guide for Measurement of Irrigation Water using Partial Flumes and Siphons. Technical Bulletin No.1. A. Kandriah. Addis Ababa, Ethiopia.

FAO (Food and Agricultural Organization). 1989. Irrigation and Drainage Paper. No. 45. Guideline for Designing and Evaluating Surface Irrigation Systems. Rome

FAO (Food and Agricultural Organization). 1992. Irrigation and Drainage Paper No. 24. Crop water requirements. J. Doorenbos, W.O. Pruitt, A. Aboukhaled, J.Damagnez, N.G. Dastane, C.Van Den Berg, P.E. Rijtema and O.M. Ashford Rome. Italy.

FAO (Food and Agricultural Organization). 1996. Irrigation and Drainage Paper No. 33. Yield Response to Water by J. Doorenbos, A.H. Kassam, C.L.M. Bentvelsen, V. Brainscheid, J.M.G.A. Pluisje, M.Smith, G.O. Vittenbogoard and H.K. Van Der Wal. 00100-Rome, Italy

FAO (Food and Agricultural Organization). 1997. Bulletin No. 4. Irrigation Potential in Africa, A-Basin Approach, Land, and Water. Rome, Italy

FAO (Food and Agricultural Organization). 1998. Irrigation and drainage paper No. 56. Crop evapotranspiration - Guidelines for computing crop water requirements. Richard G., Allen, Luis S. Pereira, Dirk Raes and Martin Smith. Rome, Italy.

FAO (Food and Agricultural Organization). Training manual no 5. 2001. Irrigation Water Management: Irrigation Methods. C. Brouwer, K. Prins, M. Kay and M. Heibloem. Wageningen, Netherlands

FAO (Food and Agricultural Organization). 2007. Irrigation and Drainage Paper. No. 63. Modernizing irrigation management: Mapping System and Services for Canal Operation Techniques. Daniel Renault, Thierry Facon and Robina Wahaj. Rome, Italy

FAO (Food and Agriculture Organization). 2014. State of Food Insecurity in the world: Strengthening the Enabling Environment for Food Security and Nutrition. Rome.

GARG, S. K. 2006. Irrigation Engineering & Hydraulic Structures - Garg.pdf (p. 1572).

George, P. Petropoulos, Hywel, M., Griffiths, Wouter Dorigo, Angelika Xaver, and Alexander Gruber. 2014. Surface soil moisture estimation.

Gorantiwar, S. D., and Smout, I. K. 2005. Performance assessment of irrigation water management of heterogeneous irrigation schemes: A framework for evaluation. Irrigation and Drainage Systems, *19*(1), 1–36. https://doi.org/10.1007/s10795-005-2970-9

Guesh Hagos Asresu. 2017. Comparative performance evaluation of irrigation Schemes: A case study of Maishawsh and Midmar small scale irrigation schemes in Meren sub-basin, northern Ethiopia. MSc thesis. Hawassa University, Hawassa, Ethiopia.

Hagosa, F., Makombe, G., Namara, R., and Awulachew, S. 2011. Importance of Irrigated Agriculture to the Ethiopian Economy: Capturing the direct net benefits of irrigation. In Ethiopian Journal of Development Research (Vol. 32, Issue 1). https://doi.org/10.4314/ejdr.v32i1.68597

Haile, G. G. 2015. Irrigation in Ethiopia, a Review. *5*(15), 141–148.

Howell TA. 2003. Irrigation efficiency. Encyclopedia of water science. Marcel Dekker, New York: 467-472.

Hudson, N., & Food and Agriculture Organization of the United Nations. 1993. Field measurement of soil erosion and runoff. 139. http://books.google.com/books?id=rS1fiFU3rOwC&pg=PA121

Irmak, S., Odhiambo, L., Kranz, W., & Eisenhauer, D. 2011. DigitalCommons@University of Nebraska-Lincoln Irrigation Efficiency and Uniformity, *and* Crop Water Use Efficiency. January. https://digitalcommons.unl.edu/biosysengfacpub

Jambo, Y., Alemu, A., & Tasew, W. 2021. Impact of small-scale irrigation on household food security: evidence from Ethiopia. Agriculture and Food Security, *10*(1), 1–16. https://doi.org/10.1186/s40066-021-00294-w

Janvier Hakuzimanaa and Blessing Masasib. 2020. Performance evaluation irrigation schemes in Rugeramigozi Marshland, Rwanda. Water conservation and management, 4(1):

Jibril, G., Saidu, M. and Yabagi, A., 2017. Performance evaluation of Badeggi irrigation scheme, Niger State Nigeria, using efficiency techniques. *Scholarly J. Sci. Res. and Essay*, *6*(2), pp.42-47.

John PH. 1978. Discharge measurement in lower-order streams. Int Revue Gs Hydrobiol 63(6): 731-755.

Johnson A.I. 1991. A Field Method for Measurement of Infiltration: Geological survey water-supply paper 1544-F. U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225

Jurriens M., Zerihun D., Boonstra J., Feyen J. and Surdev. 2001. Surface Irrigation Software. Publication 59, ILRI, Wageningen, the Netherlands

Kandiah, K. 1981. Evaluation of furrow irrigation system for cotton, MelkaWerer Research Station, IAR, Ethiopia.

Kassa, E. T., Ayana, M., & Science, A. 2019. Comparative performances analysis of two small-scale irrigation schemes : A case of Tahtay Tsalit and Mychew, Tigray, Ethiopia.

Kim, J. and Hogue, T.S. 2008. Evaluation of a MODIS-Based potential evapotranspiration product at the Point Scale. Journal of Hydrometeorology, 9(3), pp.444 - 460.

Kirkham, M.B. 2005. Principles of Soil and Plant Water Relations. The United States of America. 0-12-409751-0.

Kloezen, W.H. and Garces-Restrepo, C. 1998. Assessing of irrigation performance with comparative indicators: The case of the Alto Rio Lerma Irrigation District, Mexico. Research Report 22. Colombo, Sri Lanka: International Water Management Institute.

Lambisso R. 2008. Assessment of design practices and performance of small-scale irrigation structures in the south region.

Lesley, W. 2002. Irrigation Efficiency. Irrigation Efficiency Enhancement Report No. 4452/16A, March 2002. Prepared for Land WISE Hawkes Bay. Lincoln Environment. USA Levin G., Cruz Galvan A. Garcia D.

Levine, G. 1982. Relative Water Supply. An Explanatory Variable for Irrigation Systems. Technical Report No.6. Ithaca, New York, USA: Cornell University.

Makombe, G., Kelemework, D. and Aredo, D. 2007. A comparative analysis of rainfed and irrigated agricultural production in Ethiopia. *Irrig Drainage Syst* 21, 35–44. https://doi.org/10.1007/s10795-007-9018-2.

Makombe, G.; Namara, R.; Hagos, F.; Awulachew, S. B.; Ayana, M.and Bossio, D. 2011. A comparative analysis of the technical efficiency of rain-fed and smallholder irrigation in Ethiopia. Colombo, Sri Lanka: International Water Management Institute. 37p. (IWMI Working Paper 143).

Mamuye, A.Y. 2017. Performance Evaluation of Tsilwe Small Scale Irrigation Scheme in Gaba Catchment Enderta Distinict, Tigray Region. MSc Thesis. Hawassa University. Hawassa, Ethiopia. 86p.

McKenzie NJ, Jacquier DJ, Isbell RF, Brown KL. 2004. Australian Soils and Landscapes An Illustrated Compendium. CSIRO Publishing: Collingwood, Victoria.

McVicar, T.R., Li, L.T., Van Niel, T.G., Hutchinson, M.F., Mu, X.M., and Liu, Z.H. 2005. Spatially distributing 21 years of monthly hydro-meteorological data in China: Spatio-temporal analysis of FAO-56 crop reference evapotranspiration and pan evaporation in the context of climate change. CSIRO Land and Water Technical Report 8/05. Canberra, Australia.

Mehanuddin, H., NGR, Prapthishree, K. S. Praveen, L. B. and Manasa, H. G. 2018. Study on Water Requirement of Selected Crops and Irrigation Scheduling Using CROPWAT 8.0. Agricultural water management: 7 3431-3436.

Mekonen Ayana and Seleshi Bekele Awulachew. 2005. Comparison of irrigation performance based on management and cropping types. International Water Management Institute for Nile Basin and East Africa. Arba Minch University, Arba Minch, Ethiopia. 13 p

Mercoiret, M., Pesche, D., and Bosc, P. 2007. Rural producers' organizations for pro-poor sustainable agricultural development. Conference conducted for contribution to the writing of World Development Report 2008: Agriculture for Development. World Bank.

Merriam, J.L., Shearer, M. N. and Burt, C. M. 1983. Evaluating Irrigation Systems and Practices. In: Design and Operation of Farm Irrigation Systems. An ASAE Monograph No. 3, American Society of Agricultural Engineers Publisher, USA. Pp 721-760.

Miller, W.R. and R.L. Donahue. 1995. Soils in our environment. 7th ed. Prentice Hall Inc, New Jersey. 649p.

Minichil Taye. 2019. Evaluating and Comparing the Performance of Small Scale Irrigation Systems: A Case Study Jedeb and Kulech Small Scale Irrigation Schemes in East Gojam Zone. MSc Thesis. Bahr Dar University. Bahri Dar, Ethiopia. 114p.

Miniebel Fentahun Moges. 2019. Performance Evaluation of Golda Small-Scale Irrigation Scheme in Assosa Woreda. MSc Thesis. Hawassa University. Hawassa, Ethiopia.

Mintesinot Behailu, Nata Tadesse, Abiot Legesse and Dagmawi Teklu. 2004. Community-based irrigation management in the Tekeze basin: performance evaluation of small scale irrigation schemes. A collaborative project between Mekelle University, ILRI, and EARO and funded through the IWMI - comprehensive assessment of water for agriculture program.

MoA (Ministry of Agriculture). 2011. Small-Scale Irrigation Situation Analysis and Capacity Need Assessment. Addis Ababa, Ethiopia.

MoAFS (Ministry of Agriculture and Food Security). 2002. Assessment of Irrigation Efficiency in Traditional Smallholder schemes in Pangani and Rufiji Basins. Tanzania.

Mohammadi, Amir, Atefeh Parvaresh Rizi, and Nader Abbasi. 2019. “Field Measurement and Analysis of Water Losses at the Main and Tertiary Levels of Irrigation Canals: Varamin Irrigation Scheme, Iran.” Global Ecology and Conservation 18:

Molden, D., Sakthivadivel, R., Perry, C., De Fraiture, C., & Kloezen, W. H. (1998). Indicators for comparing the performance of irrigated agricultural systems. In Water Management (Vol. 20).

Morya. 2017. Performance evaluation of Irrigation scheme. Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur.

MoWR (Ministry of Water Resources). 2002. Water Sector Development Program 2002–2016. Irrigation Development Program, Main report. Addis Ababa, Ethiopia. pp. 142

Muhammedziyad Geleto, Mihret Dananto and Demisachew Tadele. 2018. Performance Evaluation of Selected Surface Irrigation Schemes in Kachabira Woreda, SNNPRS, Ethiopia

Murray-Rust, D.H., and Snellen, W. B. 1993. Irrigation system performance assessment and diagnosis. In International Irrigation Management Institute.

Narmilan A. and Sugirtharan M. 2021. Application of FAO-CROPWAT Modelling on Estimation of Irrigation Scheduling for Paddy Cultivation in Batticaloa District, Sri Lanka. Agricultural Reviews.(42):73-79

Nata Tadesse and Asmelash Berhane. 2007. Recharging Practices for the enhancement of hand-dug wells discharge in Debre Kidane watershed, North Ethiopia. 4th International Work Shop on Water Management and Irrigation: Focus on groundwater. Mekelle University, Mekelle, Ethiopia.

Nuru, N., Ayana, M., and Umer, N. 2020. Comparative Performance Assessment of Two Small Scale Irrigation Scheme in West Harerghe, Oromia Regional State, Ethiopia. American Journal of Management Science and Engineering, *5*(3), 24. https://doi.org/10.11648/j.ajmse.20200503.11

Peryy, C.J. 1996. Quantification and measurement of a minimum set of Indicators of the performance of ırrigation systems. Colombo, Sri Lanka: IWMI. Duplicated.

Raghuwanshi, N.S. and Wallender, W.W., 1998. Optimal furrow irrigation scheduling under heterogeneous conditions. Agricultural Systems, *58*(1), pp.39-55.

Raghava Rani, B. Venkateswarao, and S Sreekanth. 2011. Modernization of an existing irrigation project by performance evaluation using performance indicators. International journal of mathematics and Engineering 141 (2011) 1273 – 1292.

Ramulu, U.S., 2005. Management of water resources in agriculture. New Age International.

Rai, R.K., Singh, V.P. and Upadhyay, A., 2017. Planning and evaluation of irrigation projects: methods and implementation. Academic Press.

Reginald, W. Herschy. 2009. Streamflow measurement. Third edition. Chairman British Standards Institution Technical Committee on Hygrometry

Roger, D. H., Lamm F. R., Mahbub A., Trooien T. P., Clark G. A. Barnes P. L. and Kyle M. 1997. Efficiencies and Water Losses of Irrigation System. Irrigation Management Series. Kansas.

Samad Sanaee Jahromi, Herman Depeweg and Jan feyen. 2000. Water delivery performance in the Doroodzan Irrigation Scheme, Iran. Irrigation and Drainage Systems 14:

Savva, A.P. and Frenken, K., 2002. Monitoring the technical and financial performance of an irrigation scheme. Irrigation Manual Module, *14*, p.58.

Shenkut, A. 2015. Performance Assessment Irrigation Schemes According to Comparative Indicators : A Case Study of Shina-Hamusit and Selamko, Ethiopia. International Journal of Scientific and Research Publications, *5*(12).

Skogerboe, G., Hyatt, M., England, J., and Johnson, J. 1966. Measuring Water with Parshall Flumes. January, 55. https://digitalcommons.usu.edu/water_rep

Small, L. E., and M. Svendsen. 1992. A framework for assessing irrigation performance. International Food Policy Research Institute Working Papers on Irrigation Performance No. 1. Washington, D. C.: International Food Policy Research Institute.

Solomon, K.H., 1988. Irrigation systems and water application efficiencies. California State University, Fresno, California, pp.93740-0018. (1988). 93740.

Solomon Wondatir Taye. 2016. Performance Evaluation of Irrigation Schemes: A Case Study of Jari and Aloma Small-Scale Irrigation Schemes, Tehuledere District. MSc Thesis. Arba Minch University. Arba Minch, Ethiopia. 166p.

Sumner, D.M. and Jacobs, J.M. 2005. Utility of Penman-Monteith, Priestley-Taylor, reference evapotranspiration, and pan evaporation methods to estimate pasture evapotranspiration. Journal of Hydrology, 308 (1-4), pp. 81–104.

Tadesse, T. 2017. Performance Evaluation of Bobe and Laku Small Scale Irrigation Scheme in Awash Kunture Sub Basin. Toli Kebe Tadesse Masters of Science Addis Ababa Science and Technology. Nadre.Ethernet.Edu.Et. https://nadre.ethernet.edu.et/record/2583/files/THESESAASTU-2019-228.pdf

Tebeba M and Ayana M. 2015. Hydraulic Performance Evaluation of Hare Community Managed Irrigation Scheme, Southern, Ethiopia.

Tesfaye, A., Bogale, A., Namara, R. E., & Bacha, D. 2008. The impact of small-scale irrigation on household food security: The case of Filtino and Godino irrigation schemes in Ethiopia. Irrigation and Drainage Systems, 22(2), 145–158. https://doi.org/10.1007/s10795-008-9047-5.

Tesfaye, H. 2020. Technical Performance Evaluation of Small-Scale Irrigation Scheme at Wondo Genet, Ethiopia. Journal of Resources Development and Management, *68*, 15–22. https://doi.org/10.7176/jrdm/68-02

Tesfaye, H., Dananto, M., and Woldemichael, A. 2019. Comparative Performance Evaluation of Irrigation Schemes in Southern Ethiopia. Irrigation & Drainage Systems Engineering. 8(2), 8–12.

Tizita Damtew. 2017. Effect of Small Scale Irrigation on Household Food security in Bona-Zuria Woreda, Sidama Zone, Southern Ethiopia. M.Sc Thesis. Hawassa University, Hawassa, Ethiopia. 111p.

Todorovic, M. 2005. Crop Water Requirements. *Water Encyclopedia*, *January 2006*. https://doi.org/10.1002/047147844x.aw59

Ulsido, M., and Alemu, E. 2014. Irrigation Water Management in Small Scale Irrigation Schemes : the Case of the Ethiopian Rift Valley Lake Basin. 1(1), 5–15.

USDA/NRCS (Unites States Department of Agriculture/Natural Resources Conservation Services). 2008. The nature and properties of soils. 10th edition, by Nyle, Brady, Macmillan Publishing Company.

Wondimagegnhu, B. A., & Bogale, B. A. 2020. Small-scale irrigation and its effect on food security of rural households in North-West Ethiopia: A comparative analysis. Ethiopian Journal of Science and Technology, 13(1), 31–51. https://doi.org/10.4314/ejst.v13i1.3

Yewendwosen Mamo and Zinabu Wolde. 2015. Evaluation of water management in irrigated sugarcane production: a case study of Wondogenet, SNNPRS, Ethiopia. Vol.4, p7

Zerihun, D., Wang, Z., Rimal, S. and Feyen, J. 1997. Analysis of surface irrigation performance terms and indices. Agricultural Water Management 34: 25-46.

Zinabie Mekonnen. (2018). Performance Evaluation of Small-Scale Irrigation Scheme: A case Study of Golina Small-Scale Irrigation scheme, North Wollo. MSc Thesis. Addis Ababa University. Addis Ababa, Ethiopia. 95p.

7. APPENDICES

Appendix A: Results of Soil Physical Properties in Study Schemes

Table 1: Cumulative and Basic Infiltration Rates in Bilate Irrigation Schemes

Reading time	Cumulative time	Water level reading (mm)		Intake	Basic infiltration rate	Cumulative infiltration
Minute	minute	Before filling	After filling	mm	mm/hr	mm
0	0		112	0	0	0
5	5	106.1	111	5.9	71	6
10	15	104.8	112	6.2	37	12
15	30	106.5	109	5.5	22	18
20	50	104.2	112	4.8	14	22
25	75	107.1	110	4.9	12	27
25	100	105.7	112	4.3	10	32
30	130	107.8	111	4.2	8	36
30	160	107	109	4	8	40
30	190	105	112	4	8	44

Table 2: Cumulative and Basic Infiltration Rates in Furfuro Irrigation Schemes

Reading time	Cumulative time	Water level reading (mm)		Intake	Basic infiltration rate	Cumulative infiltration
Minute	minute	Before filling	After filling	mm	mm/hr	mm
0	0		105	0	0	0
5	5	98.8	104	6.2	74	6
10	15	97.4	106	6.6	40	13
15	30	100.1	105	5.9	24	19
20	50	99.5	107	5.5	17	24
25	75	101.6	106	5.4	13	30
25	100	101.3	105	4.7	11	34
30	130	100.3	107	4.7	9	39
30	160	102.3	106	4.7	9	44
30	190	101.3	105	4.7	9	48

Table 3: Soil Field Capacity, Wilting Point, TAW, and RAW in Bilate Irrigation Scheme

Field Code	Soil depth (cm)	FC (%)	PWP (%)	TAW (mm/m)	TAW (mm/root depth)	RAW (mm/root depth)
	0-30	38.6	23.7	193.2	58.0	29.0
Head	30-60	37.4	22.1	213.4	64.0	32.0
	60-100	39.1	26.2	169.1	67.6	33.8
Total	100			191.9	189.6	94.8
	0-30	35.7	21.2	185.3	55.6	27.8
Middle	30-60	37.2	24.1	169.2	50.8	25.4
	60-100	40.0	27.6	152.3	60.9	30.5
Total	100			168.9	167.3	83.6
Tail	0-30	37.5	23.5	188.9	56.7	14.2
Reach	30-60	38.8	25.0	164.6	49.4	12.3
Total	60			163.4	106.1	26.5

BD-bulk density

Table 4: Soil Field Capacity, Wilting Point, TAW, and RAW in Furfuro Irrigation Scheme

Field Code	Soil depth (cm)	FC (%)	PWP (%)	TAW (mm/m)	TAW (mm/root depth)	RAW (mm/root depth)
Head	0-30	38.4	22.9	197.7	59.3	14.8
	30-60	36.7	21.6	187.6	56.3	14.1
Total	60			192.5	115.6	28.9
	0-30	37.3	23.4	180.3	54.1	21.6
Middle	30-60	38.1	24.8	166.7	50.0	20.0
	60-100	40.3	27.4	156.0	62.4	25.0
Total	100			167.7	166.5	66.6
Tail	0-30	38.0	23.1	181.6	54.5	19.1
Reach	30-60	36.9	22.5	190.5	57.1	20.0
Total	60			177.1	111.6	39.1

The reason for recorded different values for RAW and soil moisture stored in each selected field is the different for irrigated crops so different root depth; different in soil physical properties such as FC, PWP, BD

Table 5: Soil Moisture Stored in each Selected Field of two Irrigation Schemes

Field Code	Bilate Irrigation Scheme		Furfuro Irrigation Scheme	
	Soil Depth (cm)	Moisture Stored (mm)	Soil Depth (cm)	Moisture Stored (mm)
Head	0-30	10.7	0-30	7.93
	30-60	13.2	30-60	8.79
	60-100	13.5		
Total	100	37.4	60	16.72
Middle	0-30	9.8	0-30	8.00
	30-60	12.3	30-60	10.20
	60-100	12.5	60-100	8.01
Total	100	34.6	100	26.21
Tail	0-30	10.5	0-30	7.44
	30-60	10.2	30-60	9.10
Total	60	20.7	60	16.54

Appendix B: Climatic Data in Study Areas

Table 1: Monthly Climatic Data in Bilate Irrigation Scheme

Month	Avrg. Temp ◦C	Humidity %	Wind Km/day	Sun hours	ET_o mm/month	Total rainfall mm/month	Effective rainfall mm/month
January	20.2	72	69	8.1	119.0	14.3	0
February	19.7	67	69	8.1	115.1	22.7	3.6
March	19.7	73	69	8.3	134.5	45.5	17.3
April	18.9	77	69	8.1	125.7	97.6	54.1
May	18.6	91	69	7.3	117.2	116.4	69.1
June	18.6	90	95	6.3	103.5	138.5	86.8
July	18.8	91	52	5.2	99.2	150.7	96.6
August	18.8	91	35	5.3	102.3	118.2	70.6
September	18.5	93	69	5.1	98.4	134.1	83.3
October	18.7	88	69	8.1	118.1	91.4	49.1
November	19.8	75	86	8.5	115.5	16.3	0
December	20.9	70	86	8.2	116.9	7.6	0
Total						953.3	530.4

Table 2: Monthly Climatic Data in Furfuro Irrigation Scheme

Month	Avrg. Temp ◦C	Humidity %	Wind Km/day	Sun hours	ET_o mm/month	Total rainfall mm/month	Effective rainfall mm/month
January	19.8	72	69	8	116.9	13.9	0
February	19.3	67	69	8.1	113.7	22.8	3.7
March	19.3	73	69	8.3	132.7	44.7	16.8
April	18.5	77	69	8.1	124.8	81.3	41
May	18.2	91	69	7.3	115.6	122.1	73.7
June	18.4	90	95	6.3	102.9	140.9	88.7
July	18.6	91	52	5.2	98.6	159.7	103.8
August	18.4	91	35	5.3	101.7	144.4	91.5
September	18.3	93	69	5.1	97.5	145.3	92.2
October	18.4	88	69	8.1	117.2	106.8	61.4
November	19.4	75	86	8.5	114.6	16.3	0
December	20.5	70	86	8.2	115.6	7.9	0
Total						1006.1	572.9

Appendix C: Crop and Irrigation Water Requirements and Irrigation Scheduling

Table 1: Seasonal Water Demand and Effective Rainfall for Bilate Irrigation Schemes

Crop types	Total growing season (days)	Seasonal CWR (mm)	Seasonal Eff. Rain (mm)	Seasonal IRn (mm)	Seasonal GIR (mm)
Maize	120	457.4	83.7	371.6	774
Potato	110	421.7	73.2	346.5	722
Cabbage	120	404.5	85.9	318.6	664
Onion	100	375.4	49.1	320.5	668
Tomato	110	408.5	41.5	363.2	757
Pepper	125	475.8	88	390	813

Table 2: Seasonal Water Demand and Effective Rainfall for Furfuro Irrigation Schemes

Crop types	Total growing season (days)	Seasonal CWR (mm)	Seasonal Eff. Rain (mm)	Seasonal IRn (mm)	Seasonal GIR (mm)
Maize	120	452.1	64.1	390.1	812.7
Carrot	115	434	61.9	372	775.0
Cabbage	120	399.9	70.5	327.2	681.7
Onion	100	371.3	42.2	326.5	680.2
Tomato	110	406	43.5	361.1	752.3
Pepper	125	470.3	72.7	397.7	828.5

Table 3: FAO Recommended Crop Water Requirements of Different Crops

Crop Types	Recommended seasonal Crop Water Requirements (mm)
Cabbage	380-500
Maize	500-800
Onion	350-550
Potato	500-800
Tomato	400-600

Source: FAO Irrigation and Drainage paper 33 published in 1996 by Doorenbos et.al.

The CWR for potatoes was below FAO No. 33 recommended range. The main reason might be the recommended value is for medium grown varieties with a total growing season of 120 to 150 days. But, the field survey of this study indicated that the total growing days for potatoes was about 110 days which is early grown variety. Moreover, the CWR for maize is also below FAO No. 33 recommended range. The main reason might be the recommended root depth for maize crops is in the range of 1 to 1.7m. But, the field survey of this study indicated that the maximum rooting depth for the maize was 1m.

Table 4: Irrigation Scheduling for Tomato in Furfuro Irrigation Scheme

Date	RAW (mm/root depth)	Net Irrigation application (mm)	Irrigation number	Intervals (days)
1/10/2021	19.3	19.34	First	9
1/19/2021	19.3	18.85	Second	9
1/28/2021	29.8	29.75	Third	9
2/6/2021	45.4	44.72	Fourth	10
2/16/2021	62.7	61.62	Fifth	12
2/28/2021	64.5	59.40	Sixth	12
3/12/2021	64.5	64.16	Seventh	12
3/24/2021	64.5	60.90	Eighth	13
4/6/2021	64.5	62.97	Ninth	14
4/20/2021	64.5	31.12	Tenth	end

Table 5: Irrigation Scheduling for Maize in Bilate Irrigation Scheme

Date	RAW (mm/root depth)	Net Irrigation application (mm)	Irrigation number	Intervals (days)
1/5/2021	26.0	26	First	15
1/20/2021	26.0	24.5	Second	14
2/3/2021	42.0	41.2	Third	13
2/16/2021	65.2	65.2	Fourth	14
3/2/2021	86.5	85.1	Fifth	16
3/18/2021	86.5	83.3	Sixth	16
4/3/2021	86.5	82.8	Seventh	16
4/20/2021	86.5	49.6	Eighth	end

Table 6: Irrigation Scheduling for Potato in Bilate Irrigation Scheme

Date	RAW (mm/root depth)	Net Irrigation application (mm)	Irrigation number	Intervals (days)
1/15/2021	11.8	11.5	First	5
1/21/2021	11.8	11.5	Second	6
1/27/2021	11.8	11.5	Third	6
2/2/2021	11.8	11.8	Fourth	6
2/7/2021	13.4	13.4	Fifth	5
2/11/2021	15.0	12.7	Sixth	4
2/15/2021	16.7	14.4	Seventh	4
2/19/2021	18.3	16.0	Eighth	4
2/23/2021	19.9	17.6	Ninth	4
2/27/2021	21.5	19.1	Tenth	4
3/3/2021	23.1	21.5	Eleventh	4
3/7/2021	23.6	21.3	Twelfth	4
3/11/2021	23.6	20.8	Thirteenth	4
3/15/2021	23.6	20.8	Fourteenth	4
3/19/2021	23.6	20.8	Fifteenth	4
3/23/2021	23.6	20.8	Sixteenth	4
3/27/2021	23.6	20.8	Seventeenth	4
3/31/2021	23.6	20.8	Eighteenth	4
4/4/2021	23.6	20.0	Nineteenth	4
4/8/2021	23.6	19.3	Twenty	4
4/13/2021	23.6	23.2	Twenty first	5
4/18/2021	23.6	22.1	Twenty second	5
4/23/2021	23.6	20.8	Twenty third	5
4/29/2021	23.6	7.23	Twenty fourth	end

Table 7: Irrigation Scheduling for Onion in Furfuro Irrigation Scheme

Date	RAW (mm/root depth)	Net Irrigation application (mm)	Irrigation number	Intervals (days)
1/9/2021	10.1	10.1	First	4
1/13/2021	10.1	9.4	Second	5
1/18/2021	10.1	9.4	Third	5
1/23/2021	10.1	9.4	Fourth	4
1/27/2021	12.3	10.7	Fifth	4
1/31/2021	14.6	12.1	Sixth	4
2/4/2021	16.8	14.5	Seventh	4
2/8/2021	19.1	16.0	Eighth	4
2/12/2021	21.4	17.6	Ninth	5
2/17/2021	24.2	24.2	Tenth	5
2/22/2021	24.2	22.3	Eleventh	5
2/27/2021	24.2	22.3	Twelfth	5
3/4/2021	24.2	23.3	Thirteenth	5
3/9/2021	24.2	23.5	Fourteenth	5
3/14/2021	24.2	23.5	Fifteenth	5
3/19/2021	24.2	23.2	Sixteenth	5
3/24/2021	24.2	22.6	Seventeenth	5
3/29/2021	24.2	22.0	Eighteenth	5
4/3/2021	24.2	21.0	Nineteenth	6
4/9/2021	24.2	24.1	Twenty	6
4/15/2021	24.2	11.3	Twenty first	end

Table 8: Irrigation Scheduling for Cabbage in Furfuro Irrigation Scheme

Date	RAW (mm/root depth)	Net Irrigation application (mm)	Irrigation number	Intervals (days)
1/5/2021	14.1	14.1	First	6
1/11/2021	14.1	13.2	Second	7
1/18/2021	14.1	13.2	Third	7
1/25/2021	14.1	13.2	Fourth	7
2/1/2021	14.1	13.3	Fifth	6
2/7/2021	15.7	14.6	Sixth	6
2/13/2021	17.6	16.7	Seventh	6
2/19/2021	19.6	18.5	Eighth	6
2/25/2021	21.5	20.4	Ninth	6
3/3/2021	23.4	22.7	Tenth	6
3/9/2021	25.4	25.2	Eleventh	6
3/15/2021	27.3	27.1	Twelfth	6
3/21/2021	33.9	33.4	Thirteenth	7
3/28/2021	33.9	31.5	Fourteenth	7
4/4/2021	33.9	31.0	Fifteenth	7
4/11/2021	33.9	30.6	Sixteenth	7
4/18/2021	33.9	30.6	Seventeenth	7
4/25/2021	33.9	30.5	Eighteenth	end

Appendix D: Flow Measurements in Study Schemes

Table 1: Free Flow Discharge Values for Different Size of Parshall Flumes

Head (cm)	Through width (inches)				
	1	2	3	6	9
	Discharge (l/s)				
2	0.140	0.281			
3	0.263	0.526	0.772	1.496	2.504
4	0.411	0.822	1.206	2.357	3.889
5	0.581	1.162	1.705	3.354	5.471
6	0.771	1.541	2.261	4.473	7.232
7	0.979	1.957	2.872	5.707	9.155
8	1.205	2.407	3.532	7.047	11.231
9	1.446	2.889	4.239	8.489	13.448
10	1.702	3.402	4.991	10.027	15.801
11	1.973	3.943	5.786	11.656	18.281
12	2.258	4.513	6.621	13.374	20.885
13	2.557	5.109	7.496	15.177	23.605
14	2.868	5.731	8.408	17.062	26.440
15	3.191	6.377	9.358	19.027	29.383
16	3.527	7.048	10.342	21.070	32.433
17	3.875	7.743	11.361	23.188	35.585
18	4.234	8.460	12.413	25.38	38.837
19	4.604	9.200	13.499	27.643	42.186
20	4.985	9.961	14.616	29.976	45.630
21	5.376	10.744	15.764	32.379	49.167
22		11.547	16.942	34.848	52.794
23			18.151	37.384	56.510
24			19.389	39.984	60.312

Table 2: Depth of Water Applied in each Selected Fields of Bilate Irrigation Scheme

Field measured data							
Field Code	Irrigation events	Intervals (days)	Time (minute)	Head (cm)	Q(l/s)	A(m^2)	Applied depth (mm)
Head	1		251.15	8	3.532	875	60.83
	2	13	260	8	3.532	875	62.97
	3		246.54	8	3.532	875	59.71
Average							61.17
Middle	1		245.43	13	7.496	1640	67.31
	2	14	241	13	7.496	1640	66.09
	3		230	13	7.496	1640	63.08
Average							65.49
Tail	1		255.5	8	3.532	1382	39.18
	2	15	244.6	8	3.532	1382	37.51
	3		255.09	8	3.532	1382	39.12
Average							38.60

Table 3: Depth of Water Applied in each Selected Fields of Furfuro Irrigation Scheme

Field measured data				Head (cm)	Q(l/s)	A(m^2)	Applied depth (mm)
Farm Types	Irrigation events	Interval (days)	Time (minute)				
Head	1		108.7	7	2.872	558	33.57
	2	5	99.8	7	2.872	558	30.82
	3		104.3	7	2.872	558	32.21
Average							32.20
Middle	1		148.7	8	3.532	755	41.74
	2	6	139.9	8	3.532	755	39.27
	3		143	8	3.532	755	40.14
Average							40.38
Tail	1		128.3	8	3.532	1000	27.19
	2	6	138.9	8	3.532	1000	29.44
	3		141.7	8	3.532	1000	30.03
Average							28.88

According to the study area the amount of the farmers applied irrigation water to each selected field were depending on availability of water to that field

Appendix E: Total Production from Irrigated Fields in Study Irrigation Scheme

Table 1: Production of Irrigated Land in Bilate Irrigation Scheme

Irrigated Crops	Irrigated cropped area (ha)	The output of irrigated area (Ql/ha)	Total yield (Ql)	Unit local price (birr)	Production (Birr)	Production $USA
Maize	18.5	42	777	1300	1010100	23019.6
Potato	235	140	32900	1500	49350000	1124658.2
H. Cabbage	19.25	160	3080	1000	3080000	70191.4
Onion	15.5	150	2325	600	1395000	31791.2
Tomato	10.5	170	1785	1400	2499000	56950.8
Green Pepper	3.25	10	32.5	2000	65000	1481.3
L. Cabbage	30.25	140	4235	700	2964500	67559.3
Total	332.25				60363600	1375651.8

H. Cabbage means head cabbage and L. cabbage means local cabbage

Table 2: Production of Irrigated Land in Furfuro Irrigation Scheme

Irrigated Crops	Irrigated cropped area (ha)	The output of irrigated area (Ql/ha)	Total yield (Ql)	Unit local price (birr)	Production (Birr)	Production $USA
Tomato	8	120	960	1400	1344000	30629.0
Onion	126	110	13860	600	8316000	189516.9
L. Cabbage	60	150	9000	700	6300000	143573.4
Carrot	7.75	130	1007.5	750	755625	17220.3
Maize	13	25	325	1300	422500	9628.5
Green Pepper	6.25	11	68.75	2000	137500	3133.5
Total	221				17275625	393701.6

L. cabbage means local cabbage

Appendix F: Crop Raw Data for CROPWAT 8.0 Model

Table 1: Maize Crop Characteristics

	Growth stage				
Maize crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	21	34	39	26	120
Crop coefficient(kc)	0.4		1.2	0.9	
Rooting depth(m)	0.3		1	1	
Depletion level(p)	0.55	0.55	0.55	0.55	
Yield response factor (ky)	0.4	1.5	0.5	0.2	1.25

Source: FAO (1992, 1996 and 1998)

Table 2: Potato Crop Characteristics

	Growth stage				
Potato crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	24	29	29	29	110
Crop coefficient(kc)	0.5		1.2	0.9	
Rooting depth(m)	0.3		0.6	0.6	
Depletion level(p)	0.25	0.25	0.25	0.25	
Yield response factor (ky)	0.8	0.8	0.7	0.2	1.1

Table 3: Onion Crop Characteristics

	Growth stage				
Onion crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	15	25	25	35	100
Crop coefficient(kc)	0.5		1.1	0.9	
Rooting depth(m)	0.25		0.6	0.6	
Depletion level(p)	0.25	0.25	0.25	0.25	
Yield response factor (ky)	0.45		0.8	0.3	1.1

Source: FAO (1992, 1996 and 1998)

Table 4: Tomato Crop Characteristics

	Growth stage				
Tomato crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	13	26	35	35	110
Crop coefficient(kc)	0.5		1.25	0.9	
Rooting depth(m)	0.3		1	1	
Depletion level(p)	0.4	0.4	0.4	0.4	
Yield response factor (ky)	0.4	1.1	0.8	0.4	1.05

Source: FAO (1992, 1996 and 1998)

Table 5: Cabbage Crop Characteristics

	Growth stage				
Cabbage crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	29	44	36	11	120
Crop coefficient(kc)	0.5		1.05	0.95	
Rooting depth(m)	0.25		0.5	0.5	
Depletion level(p)	0.35	0.35	0.35	0.35	
Yield response factor (ky)	0.2		0.45	0.6	0.95

Table 6: Pepper Crop Characteristics

	Growth stage				
Pepper crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	18	24	65	18	125
Crop coefficient(kc)	0.4		1.1	0.9	
Rooting depth(m)	0.3		1	1	
Depletion level(p)	0.3	0.3	0.3	0.3	
Yield response factor (ky)					1.1

Source: FAO (1992, 1996 and 1998)