PERFORMANCE EVALUATION OF MELEWE SMALL SCALE IRRIGATION SCHEME
IN ARBEGONA WOREDA, SIDAMA REGIONAL STATE, ETHIOPIA

MSc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

JUNE, 2022

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ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled "*Performance Evaluation of Melewe Small Scale Irrigation Scheme, in Arbegona Woreda, Sidama Regional State ,of Ethiopia*" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in *Water Resource Engineering and Management*, the graduate program of Department of Water Resource and Irrigation Engineering and has been carried out *by Dagne Daka Magane* with Id. No *GPWREMR/0004/12* under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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EXAMINERS' APPROVAL SHEET

We undersigned, the member of board of examiners of the final MSc open defense by *Dagne Daka Magane* have read and evaluate his thesis entitled "*Performance Evaluation of Melewe Small Scale Irrigation Scheme in Arbegona Woreda, Sidama Regional State, of Ethiopia*", and examined the candidate. This is, therefore to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Water Resource Engineering and Management.

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DEDICATION

I dedicate this thesis manuscript to my families, for their love and full committed cooperation in the success of my life.

STATEMENT OF AUTHOR

I, the undersigned person declare that, this thesis is my own original work and it is not presented and will not be presented to any other University for perusing similar degree award. Moreover, all the source of materials used for the thesis are duly acknowledged.

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Place: Hawassa University, Institutes of Technology, Hawassa, Ethiopia

Date of submission: _________________________

LIST OF ABBREVIATIONS AND ACRONYMS

BD	Bulk Density
CWR	Crop Water Requirement
Du	Distribution Uniformity
Ea	Application Efficiency
Ec	Conveyance Efficiency
ETo	Reference evapotranspiration
Es	Storage Efficiency
FAO	Food and Agricultural Organization
FC	Field Capacity
Kc	crop coefficient
GOs	Governmental Organizations
GPS	Global Positioning System
IAEA	International Atomic Energy Agency
ICSAA	Irrigation Development and Scheme Administration Agency
M.a.s.l	Meter above sea level
Mm	Millimeter
Max	Maximum
Min	Minimum
MOA	Ministry of Agriculture
MOWR	Ministry of Water Resource
NGOs	Non-Governmental Organizations
PET	Potential Evapotranspiration
PWP	Permanent Wilting Point
SSIP	Small Scale Irrigation Project
SNNPR	South Nation Nationalities Peoples Region
SIE	Scheme Irrigation Efficiency
UTM	Universal Transverse Mercator
USDA	United State Department of Agriculture
USBR	United State Bureau of Reclamation

TABLE OF CONTENTS

CONTENTS PAGES

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF FIGURES

LIST OF APPENDIX FIGURES

ABSTRACT

Performance evaluation of irrigation schemes helps to know the present status of the scheme and to apply possible measures for improvement. Efficient operation and management for irrigation system plays an important role in the sustainability of irrigated agriculture. This study was initiated to evaluate the performance of Melewe small-scale irrigation scheme using internal performance indicators. Evaluation was conducted for one irrigation season. Both primary data and secondary data were collected for this study. Primary data include field discharge measurement, soil physical characteristics test in laboratory. Secondary data were collected from different sources. Collected data were analyzed using empirical equations and statistical analysis in percentage basis. Internal performance indicators used to conduct this study were efficiency parameters (conveyance, application, and storage), distribution uniformity, and deep percolation loss. Evaluation were carried out at the head, middle and tail reach of the command area of the scheme. The result of study showed that average conveyance efficiency main, secondary (1 and 2) and tertiary (1 and 2) canals were 86.9, 78.3, 73.3, 77.1, 81.3% respectively. Water distribution uniformity of the head, middle, and tail field were 84.1, 78.5, and 86.5% respectively. Application efficiencies of head, middle and tail end of selected fields were 42.3, 68.9 and 56.1% respectively. Water storage efficiencies of head, middle and tail end of selected fields were 87.1, 90.4 and 83.8% respectively. The result of study showed that average overall conveyance efficiency, average application efficiency, scheme storage efficiency and average deep percolation loss were 79.3, 55.1, 87.1, and 44.2%, respectively. The result of the study also showed that farmer's application depth of irrigation water was lower than depth of irrigation water that would be required to fill root zone to field capacity. As result showed calculated irrigation intervals was greater than farmer practiced. The study shows that over all irrigation efficiency was below desired level which is 44%. Generally, overall performance of the scheme is considered as low. So, it is important to adopt water management practices, frequent training of irrigation water user farmers and maintenance of unlined water conveyance system to achieve good performance of the scheme.

Key words: *Melewe small scale irrigation, Performance evaluation, internal indicators, irrigation efficiency*

1. INTRODUCTION

1.1. Background of the Study

Irrigation is highly expected to play a major role in the realization of Ethiopian food security and poverty alleviation strategy. Irrigation enhances agricultural production and improves the food supply, income of rural population, opening employment opportunities for the poor, supports national economy by producing industrial crops that are used as raw materials for value adding industries and exportable crops. One of the best alternatives to consider for reliable and sustainable food security development is expanding of small scale irrigation development in the country (Awulachew et al., 2008).

Ethiopia has an irrigation potential of 5.3 million hectares of land which 3.7 million hectares can be developed using surface water sources, and 1.6 million hectares using groundwater and rainwater management. Irrigation contributes to rapid transformation of agriculture as present-day agriculture is dominated by rainfed single crops (Awulachew et al., 2011). Despite its enormous potential to boost the country's economy irrigated agriculture is facing a number of problems. One of the major concerns is the generally poor efficiency with which water resources have been used for irrigation. A relatively safe estimate is that 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff (FAO, 1989).

To achieve sustainable production from irrigated agriculture it is obvious that the utilization of the important resources in irrigated agriculture; water and land must be improved. Thus on-farm irrigation systems and operations need to be evaluated against the potential efficiency of the systems. Performance assessment has been an integral part of irrigation since man first started harnessing water to improve crop production. Evaluation involves measuring conditions at one or more points in a field selected to be typical or representative for the irrigation projects (Pereira and Trout, 1999).

Performance evaluation is a practical tool to assess the successes of irrigation management at the scheme to meet growing challenges; increasing demand for irrigation to meet the growing food demands of the population: the competition for water allocation from high priority non-agricultural sectors and technical infeasibility. It is necessary to retrofit new techniques and approaches to existing management practices to improve the performance of the scheme. In recognition to both the promise and hazards associated with irrigation, evaluating irrigation performance has now become of paramount importance not only to point out where the problem exists but also helps to identify alternatives that may be both effective and feasible in improving system performance (Dessalew et al., 2016).

Based on the above background, the efficiencies and the effectiveness of water use at farm-level is very essential to alleviate the current challenges caused due to inefficient operation of irrigation system and poor management of an irrigation water. It is important to study the performance of scheme in order to identify problematic areas, suggest possible recommendations and improvement of the scheme. Starting from its operation, no performance studies had been conducted. Hence, this leads to study the performance evaluation of Melewe small-scale irrigation scheme.

1.2. Statement of Problem

Irrigation is major importance in many countries in terms of agricultural production and food security, However there is wide spread dissatisfaction with the performance of irrigation projects in developing countries (Behailu et al., 2004).

In Ethiopia existing small-scale irrigation schemes face various problems related to operation and maintenance, water management and sustainability. These problems have greatly reduced their benefits and challenged their overall sustainability (Awulachew et al., 2010).

Similarly, in the Melewe small-scale irrigation scheme there are a number of shortcomings to become the scheme below its performance.

To overcome the problems, performance evaluation is a practical tool to assess the successes of irrigation management at the scheme to meet growing challenges; increasing demand for irrigation to meet the growing food demands of the population.

There were no significant studies conducted regarding to performance of the Melewe small-scale irrigation scheme before this study. Therefore, this study was aim to assess the performance level for better water management that can also be used as a point of entry for better irrigation water management options.

1.3. Objective of the Study

1.3.1. General Objective

The general objective of this study is to evaluate the performance of Melewe small-scale irrigation scheme using internal performance indicators.

1.3.2. Specific Objectives

- To evaluate application efficiency, storage efficiency, distribution uniformity and deep percolation ratio of the scheme.
- To evaluate the efficiency of water conveyance system.
- To evaluate irrigation practices of farmers in the scheme.

1.4. Research Questions

- What are the current performance levels of the scheme?
- What are current conveyance efficiencies of the canals in the irrigation scheme?
- What are the irrigation practices in Melewe small scale irrigation scheme?

1.5. Significance of the Study

The performance evaluation of the irrigation scheme, described in this research work has a great role to address the current problems observed in the scheme and to improve future system management in the study area, and then interventions could be made to improve the functioning of the system. The study shall have significant contribution for further improvement and investment approaches for implementing agents (GOs, NGOs, and Research Centers). It also used as a benchmark and entry point for development works and future studies.

1.6. Scope of the Study

The study was intended to evaluate the performance of Melewe small-scale irrigation scheme by focusing on; internal performance indicators of irrigation scheme. The study, finally makes a critical analysis of the issues related to irrigation system performance, and recommends the remedial measures to improve the performance. The study covered from the diversion point (weir) up to the end of the irrigation system layout.

2. LITERATURE REVIEW

2.1. Irrigation Development in Ethiopia

Irrigation in Ethiopia is considered as a basic strategy to alleviate poverty and hence food security (Belete, 2006). It is useful to transform the rain-fed agricultural system which depends on rainfall into the combined rain-fed and irrigation agricultural system. This is believed to be the most prominent way of sustainable development in the country. However, the development of irrigation practices in Ethiopia has to be investigated so as to seriously know the history of irrigation emergence and its subsequent developments (Haile and Kasa, 2015).

Hagos et al., (2009) were noticed that irrigation is one means by which agricultural production can be increased to meet the growing demands in Ethiopia. A study also indicated that one of the best alternatives to consider for reliable and sustainable food security development is expanding irrigation development on various scales, through river diversion, constructing micro dams, water harvesting structures, etc.

2.2. Purpose and Needs of small-scale irrigation in Ethiopia

Tesfaw (2018) in the study conducted to show the countries experience on small irrigation practice and its effects on the farmer's way of life describes that small scale irrigation becomes develop in rural areas of the community agricultural productivity to be enhanced. This helps to minimize the dependence and erratic rainfall by providing suitable supply of water by the system to increase food security for the communities. Irrigation development can also improve the quality of the crops which in turn to maximize the human nutritional aspect. Traditionally farmers have built small scale scheme on inventiveness, from government aid by technical and material support, they manage them with in a collaborative and integrated way through their own user associations.

Small-scale irrigation systems may have advantages over large-scale systems that small-scale technology can be based on farmers existing knowledge, local technical, managerial and entrepreneurial skills can be used; migration or resettlement of labor is not usually required; planning can be more flexible; social infrastructure requirements are reduced; and external input requirements are lower (Belete, 2006).

Awulachew et al.,(2010) in the study conducted to explore the roles, constraints and opportunities of small scale irrigation in Ethiopian agricultural development states that, small-scale systems and technologies are attractive since they put the operation, maintenance and management of systems directly in the hands of the individual farmers, thus eliminating any need for centralized control or management.

2.3. Small scale irrigation scheme

The definition of “small scale irrigation systems” varies, depending on the way that specific country defines it. The description “small-scale” refers not so much to the physical size of the farm plot or the irrigation scheme, but rather to the fact that the plots and the irrigation schemes are managed and owned by the farmers themselves. It is this which distinguishes small scale irrigation from medium and large-scale irrigation, in which a public or private entity is responsible for the management of the irrigation scheme, even if smallholder farmers are the irrigators and producers (Belay, 2013).

According to Ethiopian irrigation scheme classification, small-scale irrigation scheme (SSI) is defined as the area less than 200 ha; which are often community-based and traditional methods. The traditional small scale irrigation uses simple water diversions. It has been practical for decades in the high land where small farms could divert river, spring water seasonally for a limited dry season cropping (Awulachew et al., 2008).

2.4. Irrigation water management

The management of irrigation systems aims to achieve optimal crop production and efficient water use or in other term a reliable, predictable and equitable irrigation water supply to farmers. Inequity of water distribution occurs very often. Farmers are not sure when and how much water they can expect, which leads to very little cooperation and involvement in irrigation management and limited contribution to operation and maintenance costs (Wil and Vander, 1994).

Playan and Mateos (2004) defined that the function of the conveyance and distribution systems and services should provide sufficient water in a timely manner so that it can be used efficiently for crop production. Reliability and efficiency are then keywords for a modernization plan. The reliability of an irrigation service is the degree to which the irrigation system and its water deliveries conform to the expectations of the users. A reliable service allows efficient irrigation management within the constraints of the system.

The ever-increasing water demand compared with the depleting water resources warrants refined water use practices in irrigated agriculture to attain improved socio-economic benefits. In the past years the improvement in the irrigation system concentrated in the hardware component namely the physical aspects like structures but limited on the software part namely water usage for agricultural purpose. A good management, proper and timely application of water may result in better yield and reduction in drainage problems (Vidhya et al., 2002). Irrigation water management has become a central issue in many countries, in particular after recent studies, which revealed the disappointing performance of many irrigation schemes.

2.5. Need for Performance Evaluation of Irrigation Schemes

Performance evaluation is a major activity of proper management, which in turn is the basis for optimal use of land and water resources. Some of the reasons that the need of performance assessment are: to improve system operations, to assess progress against strategic goals, as an integral part of performance oriented management, to assess the general health of the system, to assess impacts of interventions, to diagnose constraints, to better understand determinants of performance, and to compare the performance of the system with others or with the same system over time (Awulachew and Ayana, 2011).

Oad and Sampath (1995), good management is dependent upon appropriate methods and measures by which system performance can be evaluated relative to the management objectives. Hence, reliable measures of system performance are extremely important for improving irrigation policy making and management decisions. The development potential for small-scale irrigation seems attractive in view of cost effectiveness.

Evaluation of performance of irrigation schemes have been undertaken mostly from collective water management experienced diverse problems in different type of systems, which determined the strong role of technical criteria in the development of irrigation schemes (Bos et al, 2005).

The performance of the schemes varied with the quality of the scheme design, experience of the communities in irrigation agriculture, access to reliable markets, the level of institutional support by government institutions and organizational capacity of the respective communities (Tilahun, 2014).

The performance of any irrigation system is defined as the degree of measurements to which it achieves its expected objectivity, therefore it is essential to measure and evaluate their success or failure of objective and identifies specific areas in need of improvement (Cakmak et al., 2004). Performance of a system as encompassing the totality of both its activity inputs and the transformation of the inputs into intermediate and final outputs, and the effect of these activities on the system itself and on its external environment (Murray Rust and Snellen, 1993).

Regarding the different approaches of soliciting evaluation data, it can be collected periodically from the system to refine management practices and identify the changes in the field that occur over the irrigation season or from year to year. The types of performance measures (indicators) to be chosen depend on the purpose of the performance assessment activity (Molden et al., 1998). With these indicators, the amount of deviation between the actual values against the intended are evaluated.

2.6. Performance indicator for small scale irrigation scheme

Several approaches and methodologies have been developed for assessing irrigation performance from different perspectives. With limited water and land resources availability for the required increase in food production, improving the productivity of existing irrigation schemes has got an increasing attention (Dejen, 2015).

Indicators are a way of measuring progress towards the achievement of the goal, i.e. the targets or standards to be met at each stage. They provide an objective basis for monitoring progress and evaluation of final achievements (Savva and Frenken, 2002).

A performance indicator is basically a quantitative measure of an aspect of irrigation standards which helps to evaluate and monitor irrigation efficiency. Performance indicators are therefore relationships between two or more magnitudes of an irrigation zone. In order to calculate these indicators it is necessary to previously define the parameters or variables to be used (Alegre et al., 2004).

Performance indicators are effective management tools and facilitate result based management and effective use of public resources. Monitoring and evaluation becomes more precise and objectives and personal judgment and narrative description can be minimized. Performance indicators provide quick assessment and at much lower cost than in depth analysis. Irrigation performance indicators range from water distribution to agriculture, economic, social and environmental aspects (Tebeba and Ayana, 2015).

2.7. Internal performance Indicator

Internal performance indicators describe the effectiveness of the physical system and operating decisions to deliver irrigation water from a water source to the crop. Internal indicators examine the mechanisms of water control and allocation at all levels of the project and the efficiency with which the water is conveyed through the canal, how irrigation is applied to the field, how adequate the amount is and how the application is uniformly applied to the field (Irmark et al., 2011)

Generally, internal indicators enable a comprehensive understanding of the processes that influence water delivery service and the overall performance of a system. Internal process indicators relate performance to management targets such as timing, duration, and flow rate of water; area irrigated and cropping patterns (IWMI, 2007).

Kloezen et al., (1998) stated that internal indicators are used to assess performance following a goal-oriented model approach. Generally, these process indicators address how the input (water) is used, but do not provide information on to what wider hydrological, agricultural, economic, social, and environmental impacts the inputs have led.

Brouwer et al., (1989) and Howell, (2003) also explain those internal indicators as irrigation system efficiency indicators explained as follows: The efficiency of the system in terms of meeting water demands at field level in quantity and time is determined by both water losses by canal seepage and the way the system is managed and operated.

A set of process indicators developed by Bos and Nugteren, (1990) used for performance evaluation of irrigation system are Conveyance efficiency, application efficiency, distribution efficiency, deep percolation, storage efficiency and overall efficiency.

A. Conveyance efficiency

Water conveyance efficiency is used to measure the efficiency of water conveyance system associated with the canal network, watercourses and field channels; it is also applicable where the water is conveyed in channels from the well to the individual fields. It is one of the several closely related and commonly used output measures of performance that focus on the physical efficiency of the water conveyance by the irrigation system (Bos,1997). Conveyance losses are primarily dependent on the wetted perimeter of the canals and not on the volume of water conveyed. Thus, they are considered to be fixed for all parts of the irrigation system.

Brower and Heibloem (2011) provide indicative values of the conveyance efficiency, considering the length of the canals and the soil type in which the canals are dug. Earthen canals with sand, loam, and clay soil type have 70, 75, and 85% efficiency respectively for 200 -2000 meter length; If the canal is lined it will have 95% efficiency. These values will decrease for longer canals and increase for shorter canals.

According to Brouwer and Prins (1989) the conveyance efficiency for long unlined canal (>2000m), the conveyance efficiency has been reported as 60, 70 and 80% for sand, loam and clay soil respectively. On the other hand for medium length unlined canals (200-2000m), conveyance efficiency is 70, 75 and 85% for sand, loam and clay soil respectively; while for short canals (<200m) the magnitude is nearly 80, 85 and 90% for sand, loam and clay soil respectively. The efficiency of lined canals has been reported in the order of 95% for all canal length.

B. Application efficiency

Water application efficiency provides a general indication of how well an irrigation system performs its primary task of delivering water from the conveyance system to the crop. The objective is to apply the water and to store it in the crop root zone to meet the crop water requirement (Odhiambo and Kranz, 2011). Water application efficiency is a measure of the fraction the total volume of water delivered to the farm or field to that which is stored in the root zone to meet the crop evapotranspiration needs. After the water reaches the field supply channel, it is important to apply the water as efficiently as possible. Losses from the field occur as deep percolation (depths greater than required depth) and as field tail water or runoff and reduce the application efficiency.

According to FAO (1989) application efficiency is the most important in terms of design and management since it reflects the overall beneficial use of irrigation water. It is the ratio of the average depth of irrigation water infiltrated and stored in the plant root zone to the average depth of irrigation water applied, expressed as a percentage.

Kenneth (1988) indicated that attainable water application efficiencies vary greatly with irrigation system, type and management, and suggested that the attainable application efficiency for surface irrigation are 80-90%, 70-85% and 60-75% under basin, Border and furrow type of system respectively.

The field application efficiency mainly depends on the irrigation method and the level of farmer discipline. Some indicative value of the average field application efficiency are 50-60%, 60-80% and more than 80% for surface, sprinkler and drip irrigation methods respectively (FAO, 1989). In general, according to Michael, (1997) water application efficiency decreases as the amount of water applied during each irrigation increases.

C. Water storage efficiency

Storage efficiency is an index used to measure irrigation adequacy. It is the ratio of the quantity of water stored in the root zone during irrigation event to that intended to be stored in the root zone. The value of storage efficiency is important either when the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs. This parameter is the most directly related to the crop yield since it will reflect the degree of soil moisture stress (Eticha, 2011).

The water storage efficiency refers to how completely the water needed prior to irrigation has been stored in the root zone during irrigation water application. Zerihun et al., (1997), also defined storage efficiency as a ratio of the volume of water actually stored in the subject region to the volume of water that can be stored.

D. Distribution uniformity

Distribution uniformity is a measure of how uniformly water is applied during an irrigation event. The uniformity of application can have a considerable effect on crop yield and optimum water application. There are several interpretations of in the literature, but a common measure for surface irrigation systems is to divide the average depth infiltrated from the quarter of the field with the lowest infiltrated depth, by the average infiltrated depth. This is called the 'lower quarter'. When a field with a uniform slope, soil and crop density receives steady flow at its upper end, a waterfront will advance at a monotonically decreasing rate until it reaches the end of the field (FAO, 1989). Roger et al., (1997) explained that water lost to percolation below the root zone due to non-uniform application or over-application water runoff from the field all reduces irrigation efficiencies.

Effective water distribution was obtainable because of good canal layout, each plot in blocks were given adequate time to receive water. Poor management of available water for irrigation both at system and farm levels has led to a range of problems and further aggravated water availability and has reduced the benefit of irrigation investments (Jibril et al., 2017).

E. Deep Percolation Ratio (DPR)

A component of the irrigation applied to a field percolates into the soil below the root zone. Part of the water is intentionally added to the irrigation water to maintain the salt balance of the soil through leaching additional salt brought by the irrigation water itself or through capillary process from saline groundwater (Smedema and Rycroft, 1983). Higher DPR values are indications of over irrigation. The volume of percolated water in excess of the leaching requirement is considered as lost water and is used to define the efficiency of irrigation. DPR expresses the ratio between the percolated water beyond the root zone to the volume of water applied to the field (Feyen and Dawit, 1999).

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted in Sidama Region, Arbegona Woreda, and shemetanto kebele. Arbegona Woreda is one of the 36 woreda of Sidama Region. Melewe small scale irrigation is bounded between Geographical UTM of 6°35'18" to 6°56'37"N latitude and 38°35'60" to 38°53'36"E longitude. It has an area of about $20km^2$. Head work site situated Geographical UTM of zone 37 at $6^0$38.072'N latitude and $38^0$44.081'E longitude at elevation 2396 m.a.s.l. The scheme is situated within the Genale Dawa main drainage and Genale sub-drainage basin specifically within Melewe River catchment. The site is accessible via Arbegona to Bona all weather road. Total distance of the headwork site is 77km and 11km from Hawasa and Yayye Town (Woreda Capital) respectively. Melewe small scale irrigation is a river diversion irrigation scheme studied and designed by Southern, Nation, Nationalities, People Region Bureau of Water & Irrigation; Irrigation Construction and Scheme Administration Agency for the development of net irrigable land of *92.61ha* of land by diverting Melewe River (ICSAA, 2018).

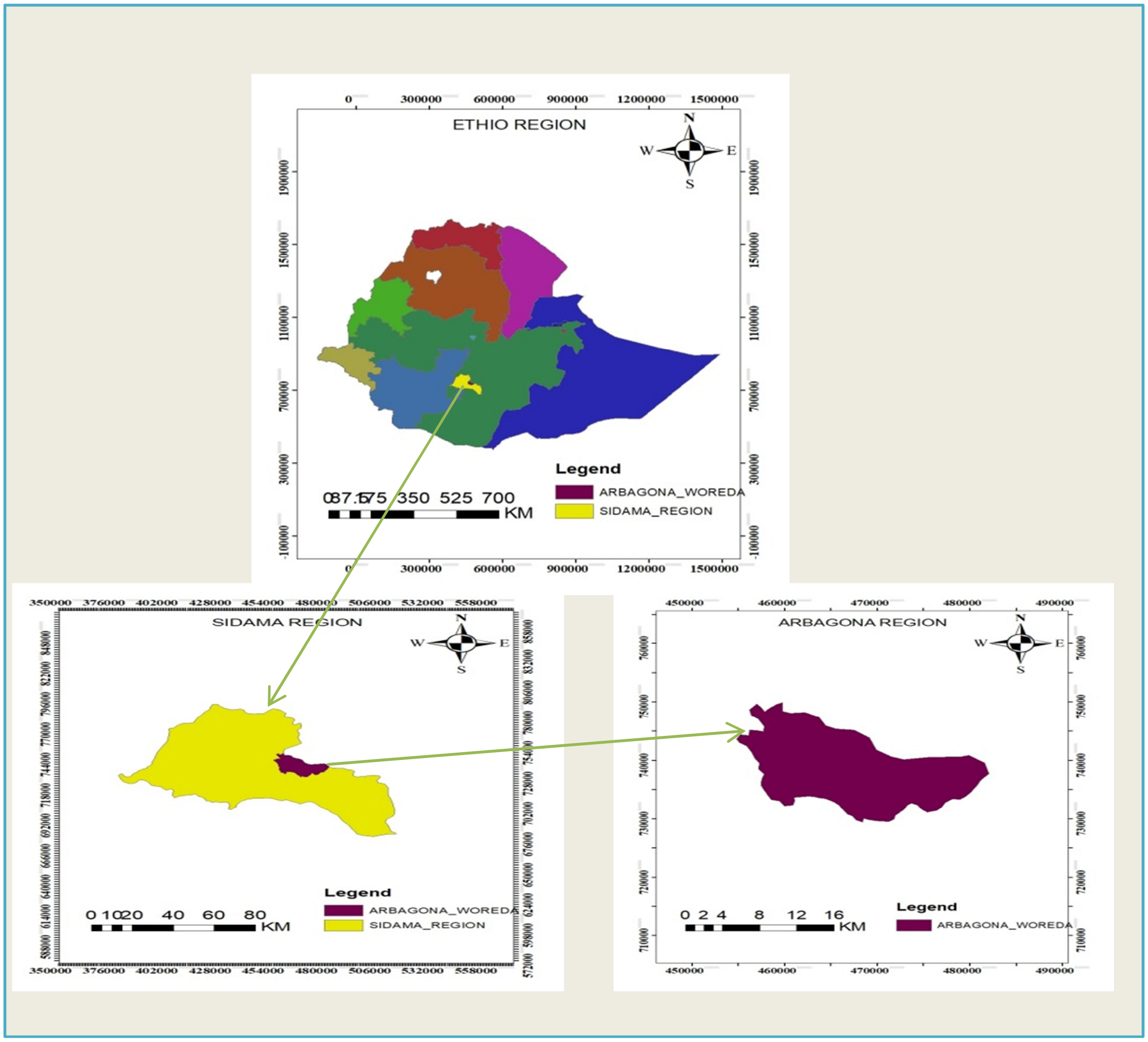

Figure 1: Location map of study area

3.1.2. Climate

According to long term (1993-2018) record Meteorological data mean annual rainfall is 1340.3mm, with mean annual reference evapotranspiration of 1215 mm/annum. The mean monthly maximum temperature varies from 18.4^{0}c to 22.6^{0}c and minimum temperature varies from 6.6^{0}c to 8.7^{0}c respectively. The monthly relative humidity varies between 68 to 92%. The wind speed varies from 69 km/day in October to 138 km/day in June. The sunshine hours varies between 5.3 hr/day in August to 8.6 hr/day in October. Rainy season extends from July to end of October and the small rainy season from middle of March through end of June and there has been high evapotranspiration in the area in the November, December, January, February and March, see Appendix Table 1 and 2

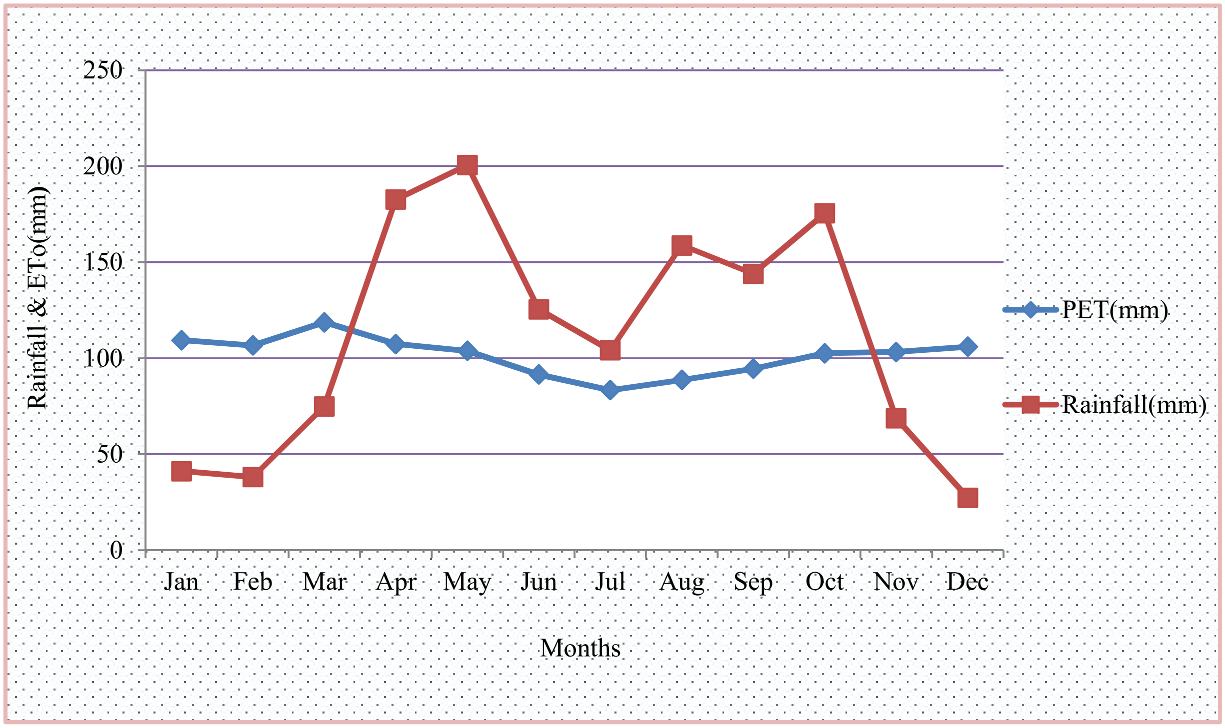

Figure 2: Climatic water balance of study area.

3.2. Material

Materials used to for data collection and analysis purpose are listed in the table below.

Table 1: Materials used for sample collection and analysis

No	Type of material	Purpose
1	Core sampler	To collect undisturbed soil samples for soil moisture test
2	Auger	To dig soil samples for texture analysis
3	Hammer	To hit the core sampler
4	Plastic bag	To take undisturbed soil sample
5	weight balance	To measure weight of soil moisture at wet and dry condition
6	Oven dry	To dry soil sample
7	Measuring tape	To measure the dimension of sample pot, sampling pit and canal
8	Stopwatch	To know the time taken water passing through known distance
9	Parshall flume	To measure the rate of flowing water in the field canal
10	Water level	To check the slope of Parshall flume
11	GPS	To collect different coordinate points

3.3. Method of data collection

3.3.1. Primary data collection

The primary data was collected directly from the field observation irrigation scheme status using transect walk along the scheme. Discharge measurements in the canals and on to the chosen plots as well as duration of each sampled irrigation and amount of water each selected farmer diverted to his plot for a given irrigation event were obtained through measurements. Soil data were also collected from laboratory soil sample measurements. Additionally, data on plot sizes and field irrigation run lengths (furrows) were obtained at the sample plots. All secondary and a data collected were organized and analyzed before evaluation.

A) Lay out of sample field

By physically traveling along the water conveyance canal system, appropriate canal segment lengths were marked at the beginning and end reach of sub canals for water flow velocity measurement. Similarly, to evaluate field irrigation practice of farmers, three sample research plots were chosen purposely. The selection was carried out one from the head (plot 1), middle (plot 2) and tail end (plot 3) water users of the irrigation scheme with taking in to account spatial variations in field irrigation practice.

The sample field plots were selected based on the availability of water reaching from the conveyance system or distance from the water source to the command area. The sizes of the selected fields were measured and field preparations made according to the existing farmers' practices.

Analyze soil moisture content before and after irrigation, three furrows were identified along each research plot (one furrow from the center and two furrows from opposite sides of research plots). Three sampling point locations were marked starting from the beginning to the end of each furrow at regular interval total nine sampling point identified and soil samples were taken from each point by excavating sampling pit.

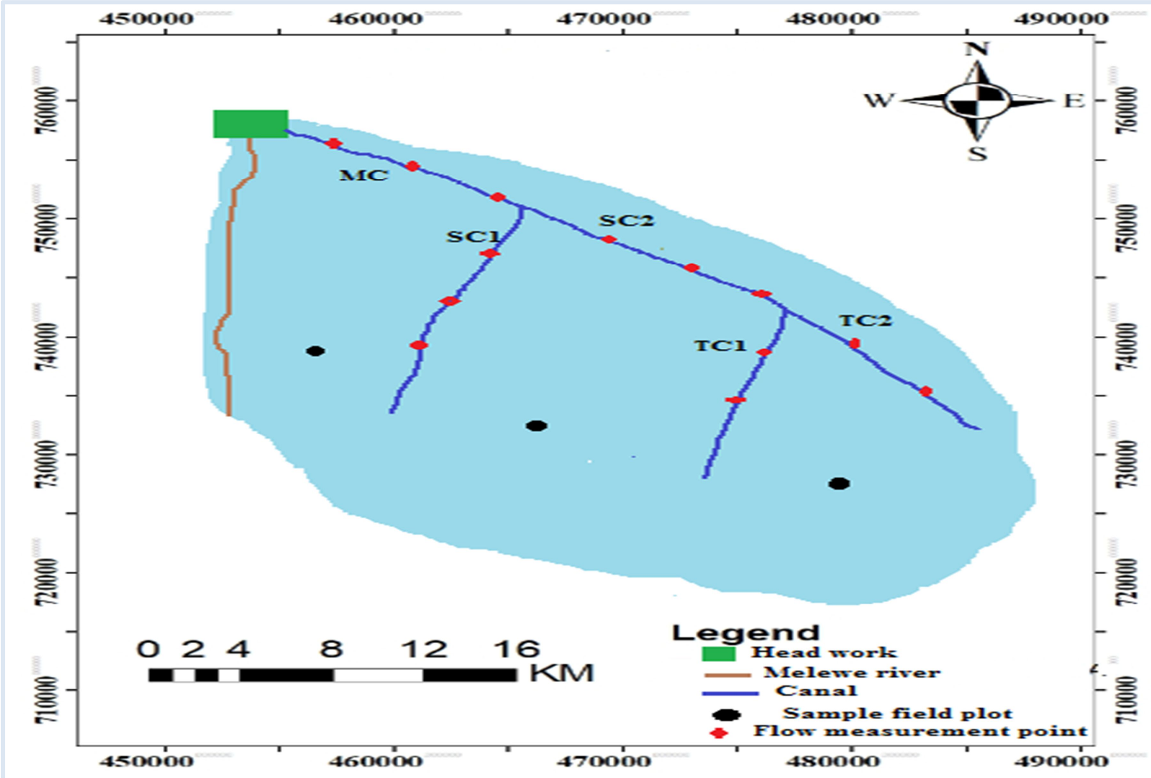

Figure 3: Melewe small scale irrigation scheme layout

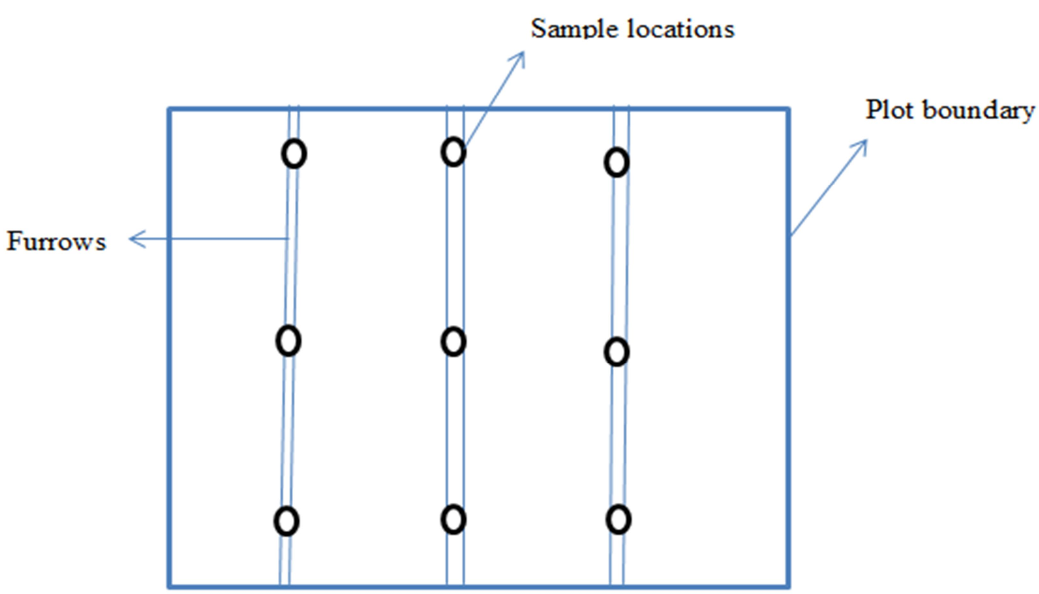

Figure 4: Schematic layout of sample field plot

B) Method of Soil Sample Collection

To collect representative soil samples, two rows were selected along each field and two sampling points were identified from the beginning to the end of each row at regular interval. Then, at each selected points of the rows, soil samples were collected from 0-30 cm and 30-60 cm depth. The depth for different crops was taken based on Brouwer et al. (1989), that categorized those crops as shallow rooting crops (30-60cm), medium rooting crops (50-100cm) and deep rooting crops (90-150cm). In the irrigation site farmers grow mainly Potato, Cabbage and carrot these crops are categorized as shallow rooting crops.

Appling systematic soil survey method soil samples were collected by excavating nine sampling pit (i.e. thee pit from each) along identified three furrows with equal interval.

For each chosen plot, a total of 18 soil samples were collected from point locations along the identified furrows before and after an irrigation event during the growing season mid- crop growth stages. This procedure was repeated in each of the three chosen research plot. Therefore 36 from each field, a total of 108 soil samples were collected during the specified crop growth stages and used to determine moisture kept in the root zone. To achieve a relative accuracy, initial weights of the collected soil samples were immediately measured in the field using digital sensitive balance to determine moisture contents before oven-dry.

To determine soil texture, soil moisture content at field capacity and permanent wilting point twelve disturbed soil sample from each sample plot were taken to Hawasa soil testing laboratory.

3.3.2. Secondary data collection

Secondary data was collected from published and unpublished documents, books, working papers of different institutions. For instance, Sidama Region Water and Energy bureau, Meteorological station, Arbegona Woreda Agriculture Office, and shemetanto Keble development agent experts.

3.4. Soil sample Analysis

The soil parameters measured include moisture content, soil texture, bulk density, field capacity (FC), permanent wilting point (PWP) and as discussed below.

After each pattern of field work had finalized, the soil samples were submitted to to Hawasa soil testing laboratory to analysis the soil parameters (soil texture, bulk density, soil moisture content at filed capacity and permanent welting point) for each research plot.

A. Soil moisture Content

Initial moisture content of the soil before irrigation and moisture content after irrigation has been determined by using gravimetric method.

$$\text{Moisture content}(\%)=\frac{\text{Ww-Wd}}{\text{Wd}}*100\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.1)$$

Where: - Ww is weight of wet soil (gm).

Wd: weight of dry soil (gm)

The water content in the soil was determined in the volume base using the following equation (Jaiswal, 2003)

volumetric moisture content % = intial moisture content*bulk density……………(3.2)

B. Bulk density

The soil bulk density (BD) was determined from undisturbed soil samples using a core sampler of size 5 cm internal diameter and 5 cm height. The soil sample was collected from 0-30 cm and 30-60 cm at three locations along the diagonal of each selected field and oven dried at 105 °C for 24 hours. The bulk density was determined using the following equation (Hillel, 2004).

$$\text{BD}=\frac{\text{Ms}}{\text{VC}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.3)$$

Where: BD: soil bulk-density (g/ cm^3)

Ms: mass of dry soil (gm) and

VC: volume of soil in the core sampler (cm^3) and

Volume of soil in the core sampler calculated as

$$\text{Vc}=\text{A}*\text{H}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

Where: Vc: volume of soil in the core (cm^3)

A: area of core sampler (cm^2)

H: height of core sampler (cm)

The area of the core was calculated as equation

$$A=\frac{\pi D^2}{4} \quad \text{..} (3.5)$$

D: internal diameter of the core (cm)

A: Area of core sampler

C. Soil Texture Determination

Particle size distribution was determined using the Bouyoucos Hydrometer method (Bouyoucos, 1962) and the textural class was assigned using USDA textural triangle (See Appendix figure 2.4).

The percentage of sand, silt and clay of the soil sample were determined by sieve analysis and hydrometer method. After the percentage of sand, silt, and clay was measured, the soil may be assigned a textural class using the USDA textural triangle. The proportions of the separates in classes commonly used in describing soils are given in the textural triangle. In using the diagram, the points corresponding to the percentages of silt and clay present in the soil under consideration are located on the silt and clay lines respectively. Lines are then projected inward, parallel in the first case to the clay side of the triangle and in the second case parallel to the sand side.

D. Soil Field Capacity and Permanent Wilting Point

Field capacity and permanent wilting point of the soil were analyzed through pressure plate apparatus. Soil samples were saturated for one day and a pressure of 1/3 bar (for field capacity) and 15bars (for permanent wilting point) was exerted until no further change in soil moisture content were observed. After getting soil moisture values, available water holding capacity of the soil were calculated.

3.5. Discharge measurement

To achieve sufficient and equitable delivery of water to the fields it is useful to know the discharge. Flow measurement takes place both conveyance and water application area. Canal discharge were measured by floating method and the field application water was measured by Parshall flume which is horizontally constricted vertical throat in an open channel used to measure the discharge entering into the field.

A. Canal Discharge Measurement

Discharge was determined at the inlet and outlet of the considered conveyance section according to the float method in main, secondary and tertiary canals. The method consists of estimating the average flow velocity and measuring the area of the cross-section, called the "wetted cross-section''. Generally, twenty six canal discharge measurements were conducted at inlet/outlet of the main, secondary1, secondary and tertiary1 and tertiary 2 canals during the mid-crop growth irrigation time observations.

The discharge was calculated by continuity equation.

$$Q=V*A \qquad (3.6)$$

Where: - Q: the discharge (m^3/s)

V: the average flow velocity (m/s)

A: the area of the wetted cross-section (m^2).

To estimate the average flow velocity, the flow velocity of the water at the surface, the surface velocity, Vs was first determined. The surface velocity was determined by measuring the time it takes for a floating object along the canal. The floating object (small empty plastic container) was placed in the center of a canal and the time measurement was repeated four times to avoid mistakes. The stretch of canal used for measurement should be straight and uniform, in order to avoid changes in the velocity and in the area of the cross-section, because any such variation reduces the accuracy of the velocity estimation.

To determine the velocity of surface water of the channel, the length of trail section was divided by the average time taken by the float cross it. Since the velocity of the float on the surface of the water was greater than the average velocity of the stream, it was necessary to correct the measurement by multiplying by a constant factor (velocity correction factor) which was usually assumed to be 0.85 (Harrelson, 1994). To obtain the rate of flow, this average velocity (measured velocity * correction factor) was multiplied by the average cross-sectional area of the stream.

To compute the surface velocity, Vs the selected length, L was divided by the travel time,t

$$Vs=\frac{L}{Tav} \qquad (3.7)$$

Where: Vs is the surface velocity (m/s)

L is the trail distance in meters between selected points and

Tav is the average travel time in seconds between selected points

The surface velocity must be reduced in order to obtain the average velocity, because surface water flows faster than subsurface water.

$$V=0.85*Vs \qquad (3.8)$$

Where: V is the average flow velocity (m/s);

Vs is the surface velocity (m/s)

For measuring the flow with the float method, the area of the wetted cross-section (A) was determined for a selected straight and uniform portion of the canal. The area was calculated from measurements of the surface water width and the water depth

$$A=W*H \qquad (3.9)$$

Where: A: area of wetted cross-section (m^2)

W: surface water width (m)

H: water depth (m)

B. Field Discharge Measurement

The discharge which was applied to the field was measured by standardized size 2 inch parshall flume. To determine the amount of water applied by the irrigators to the field, during an irrigation event, two inch parshall flume was installed at the entrance of test field. Frequent readings were taken when the farmers irrigate the test field. Irrigation was continuing until the farmers thought that enough amount of water is applied to the field. When the irrigator completed irrigating the test field, the average depth of irrigation water passing through the flume and the respective time were recorded for the sizes of test field being irrigated.

One irrigation event per plot was considered at each crop- growing stage to estimate flow rate during each selected farmer diverted water to his plot to irrigate. And three field discharge measurements were conducted from the head, middle and tail reaches sampled research plot as follow:

According to (USBR, 2014.), discharge was computed as:

$$Q=C*H^{n} \qquad (3.10)$$

Where: - Q is applied discharge (l/s)

H is water depth measured at one third from in late of converging,

C and n are constants to be determined for flume with two-inch throat

3.6. Evaluation of the Irrigation System Performance

This task was accomplished with deep understanding about the present status of the scheme and agricultural activities in the project. The performance of irrigation system was determined by the efficiency with which the water is conveyed through the canal and how irrigation is applied to the plots through data collected along with identify problems. In other words based on data obtained periodically from measurements of irrigation flow and soil moisture, the irrigation system performance was evaluated using internal performance indicators. The indicators are concerned with performance that directly affect water conveyances and water applied effects. The authors noted that performance of an irrigation system cannot be described with any single efficiency term. Taking this into account, efficiencies such as conveyance efficiency and loss, application efficiency, water storage efficiency and distribution uniformity were considered along with identify problems to evaluate the performance of the irrigation system. The appropriateness of their grand average values is compared to the targets of adequate efficiencies and uniformities which are considered potential achievable values under the ideal conditions.

3.6.1. Conveyance Efficiency

The conveyance system performance of the scheme was evaluated using the prevailing parameters termed as conveyance efficiency and loss. Efficiency of conveying water from the embankment storage to the tail end reaches of the secondary canals was examined. The parameters were assessed through systematic procedure as stated below using inflow-outflow method. The inflow-outflow method is a water balance approach that consists in the direct measurement of the discharge flowing into and out of a reach of sub canal.

To measure the conveyance efficiency of Melewe irrigation scheme three segments on main canal, three segment secondary canals (Sc1 and Sc2) and two segments on tertiary canal (Tc1and Tc2) from head to tail of the canal were selected and discharge was measured at selected segment for each canal. The principle of choosing the segments for discharge measurement was the ease of use of lines segment's rectangular channel shape to measure the flow.

The conveyance efficiency was measured on the canals at Outlet and inlet of each segment using float method. Floater was used and the time taken to travel 10, 9, and 8m at main, secondary and tertiary canal length was recorded using stopwatch. Bantero et al., (2008) used to measure the discharge at intake and the application point to estimate the losses and the method was applied within short interval and projecting the loss per unit length found to be relevant technique to get the desired result.

The first main canal discharge measurement of the initial point was taken at 100m distance from the main intake gate and also the second, and the third measurement initial points were taken at 250 and 370m distances respectively from the first measurement.

The first measurements at secondary canals1 were taken at 150m distances from the main canal. Second and the third measurements also were taken at 250 and 370m distances each canal respectively. In the same way, the first measurements at secondary canals 2 were taken at 100m distances from the main canal. Second and the third measurements also were taken at 250 and 370m distances each canal respectively.

The first measurement at tertiary canals 1 were taken at 60m distances from the secondary canal and Second measurement was taken at 110m distances canal. Similarly, first measurement at tertiary canals 2 was taken at 60m distance from the secondary canal and Second measurement was taken at 100m distance canal. In this way conveyance efficiency and losses were determined in unit length of canal.

According to Irmak et al., (2011) conveyance efficiency is computed as:

$$Ec=\frac{Wf}{Wd}*100 \qquad \text{……………..(3.11)}$$

Where: - Ec is conveyance efficiency (%)

Wf is quantity of water delivered to the canal outlet (m^3/s)

Wd is quantity of water diverted to the canal inlet (m^3/s)

Losses in conveyance system were computed as;

$$Lc=Wd-Wf \qquad \text{……………..(3.13)}$$

Where: - Lc is conveyance loss (m^3/sec)

Wd is outflow discharge in specified canal length (m^3/s)

Wf is the inflow discharge in specified canal length (m^3/s)

Table 2: Indicative values of the conveyance efficiency

Canal length	Earthen Canal			Lined Canal
	Soil type			
	Sand	Loam	Clay	
Long (> 2000m)	60	70	80	90
Medium(200-2000m)	70	75	85	95
Short (< 200m)	80	85	90	95

Source: (Brouwer et al., 1989)

3.6.2. Application efficiency

After determining the depth of water actually applied into the fields and the depth of the water retained in the root zone using methods described in the previous sections, the application efficiencies (E_a) of irrigation practice at the selected fields of three farmers were calculated as a measure of how much of the water that is applied is actually retained in the root zone after irrigation

The application efficiency was computed as the ratio of moisture added to the soil profile due to irrigation to the total water supplied to the farm or the ratio of moisture retained due to irrigation with total water added to the field (Michael, 2008).

$$Ea\% = \frac{Ds}{Da} * 100 \quad \text{.....(3.14)}$$

Where: Ea is application efficiency (%),

Ds is depth of water applied to the root zone as storage (mm), and

Da is depth of water applied to the field (mm)

The depth of water retained (stored) in the soil profile of the root zone, Ds, and the total depth applied to the field, Da, was determined by using the following equations (Michael, 2008)

$$Da = \frac{Q\Delta t}{A} \quad \text{.....(3.15)}$$

Where: - Q is stream size during the irrigation (m^3/s)

Δt is duration of the irrigation (s)

A is area irrigated (m^2)

Table 3: Indicative values of the field application efficiency

Irrigation methods Field	Application efficiency (%)
Surface irrigation (border, furrow, basin)	60
Sprinkler irrigation	75
Drip irrigation	90

Source: (Brouwer et al., 1989)

3.6.3. Evaluation of water storage efficiency

To evaluate how effectively the irrigation practices satisfied the water requirement of the soil to compensate the moisture depleted by evapotranspiration, the evaluation parameter called water storage (requirement) efficiency calculated using equation (Michael, 2008). After determining the average depths of water stored due to irrigation and the required water depths to fill to the field capacity moister content level prior to irrigation in the previous section, the storage efficiency was calculated using equation (3.14).

$$Es(\%)=\frac{Ds}{Dreq}*100 \quad \text{...(3.17)}$$

Where: - Ds is Amount of water added to (stored in) the root zone during the irrigation (mm)
Dreq is Amount of water potentially required to fill the root zone to field capacity (mm)

3.6.4. Evaluation of distribution uniformity

Distribution Uniformity of the irrigation practice of each considered plot was evaluated using the Christiansen's Uniformity Coefficient parameter. First the depth of water stored (as the difference between the after and before moisture contents) in the root zone (in this case 0-30 and 30-60 cm) was calculated at each particular sampling point as describe in the previous section. Then the determination was based on mean values of the total soil moisture contents stored (mm) at the nine sampling locations per plot and average of the absolute values of deviations from the mean as follow.(Appendix table 15)

$$Cu=\left(1-\frac{\sum d}{Dsa}\right)*100 \quad \text{...(3.18)}$$

Where, Cu = Christiansen's Uniformity Coefficient (%)

d=average water depth of the absolute values of deviations from the average depth (mm)

$$d=\frac{\sum_{i=1}^{n} | Ds_i- Ds_a|}{n} \quad \text{...(3.19)}$$

Dsa =Average depth of water stored during irrigation (mm). It was worked out by dividing the sum of all depth of measured soil moistures by the number of observations at proposed crop root depth as follow:

$$Dsa=\frac{\sum_{i=1}^{n} Dsi}{n} \quad \text{...(3.20)}$$

Dsi= soil moisture depth of observation i due to irrigation (mm)

n=Number of observations per irrigation at each plot

3.6.5. Evaluation of irrigation Efficiency

Scheme Irrigation efficiency (SIE) can be calculated, using the following formula (FAO, 1989; Brouwer et al., 1989)

$$IE=\frac{Ec*Ea}{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.21)$$

Where: - IE is scheme irrigation efficiency (%)

Ec is conveyance efficiency (%), and

Ea is field application efficiency (%)

A scheme irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme Irrigation efficiency of 20-30% is poor (Brouwer et al., 1989).

3.6.6. Deep Percolation Ratio

Deep percolation ratio can be calculated indirectly from values of application efficiency and runoff ratio as given by:

$$DPR = 100-Ea- RR \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.22)$$

Where: Ea is field application efficiency (%)

RR is runoff ratio (%)

3.7. Determination water depth stored in the root zone

To determine the depth of application, the soil's moisture content after irrigation was tested by gravimetric method. Application depth is one of important indicators in evaluation of water management in every irrigation systems. The depth of application per irrigation is the amount of water added to the root zone in irrigation event. Three furrows (one furrow from the center and two furrows from opposite sides) per plot were considered. Moisture contents of the soils from 36 soil samples taken from point locations at the top, center and bottom end of the furrows of each chosen research plot before and after irrigation. The moisture content of the soil samples collected from the chosen research plots was measured to determine how much water depleted below the field capacity moisture content level before irrigation and how much water stored to the root zone after irrigation. The standard method known as the gravimetric moisture determination method was used in this study to determine soil water content. The samples were made dry using universal hot air oven at 105^0C for 24 hours. After the soil samples had been dried, the dry mass of the soil samples was also weighed again. So, the amount of moisture content of the soil samples before and after irrigation was determined.

Then the average dry mass soil moisture contents (θ_{wam}%) of the sampled soils at each research plot before and after irrigation were worked out by dividing the sum of all dry mass soil moistures (θ_w%) by the number of respective observations at each research plot.

Pre and post irrigation soil moisture analysis method was employed to estimate water stored in the crop root zone. One days after irrigation, the depth of water stored in the root zone (D_s) was determined as the difference between the after and before irrigation. The irrigation depth stored within the crop root zone as farmers' practice for each trial irrigation event at each marked sample location along the furrows has been determined using equation (Michael, 2008). (Appendix Table, 6-14)

$$Ds=\sum_{i=1}^{n}\frac{(Wai\text{-}Wbi)}{100}*BDi*Di \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.23)$$

Where:-

Ds is average depth of water applied to the root zone as storage (mm),

Wai is moisture content of the i^{th} layer of the soil after irrigation on oven-dry weight basis, (%)

Wbi is moisture content of the i^{th} layer of soil before irrigation on oven-dry weight basis, (%)

BDi is bulk density of i^{th} layer of soil

Di is depth of i^{th} layer of the soil

n is number of layers in the root zone

3.8. Depth of irrigation water required

Depth of irrigation water that would be required to fill root zone to field capacity was determine using equation given by (Abebe et al, 2013).

$$Dreq=\sum_{i=1}^{n}\frac{(Wfci\text{-}Wbi)}{100}*BDi*Di \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.24)$$

Where:-

Dreq is Amount of water potentially required to fill the root zone to field capacity (mm)

Wfci is Moisture content of the i^{th} layer of the soil at field capacity (FC) on oven-dry weight basis (%)
Wbi is Moisture content of the i^{th} layer of soil before irrigation on oven-dry weight basis (%)
Di is root depth (m).
BDi is bulk density of i^{th} layer of soil
n is number of layers in the root zone

3.9. Determination of Irrigation Interval

For determination of irrigation interval of the irrigation schemes and to make comparison with the current irrigation practices of farmer's; moisture content at field capacity, permanent wilting point, depletion fraction at each growing stage, total available water and readily available water data were collected. Additionally Irrigation interval of farmer's was determined from field during irrigation event as farmer's practice and Irrigation Interval of farmer would be required was determined based on readily available water.

Total available water (TAW) for crop use in the root zone was calculated using Allen et al., 1998) equation.

The total available water in percent based:

$$TAW\% = FC\% - PWP\% \quad \text{……}(3.25)$$

Where: TAW (%): total available water in percent
FC%: soil moisture at field capacity in percent
PWP%: soil moisture at permanent wilting point in percent

Total available water content in volumetric based:

$$TAW = 1000 \sum (\theta FC - \theta PWP) * Zr \quad \text{……}(3.26)$$

Where: TAW: volumetric total available water in the root zone (mm)
FC: volumetric moisture content at field capacity (m^3/m^3) and
PWP: volumetric moisture content at permanent wilting point (m^3/m^3)
Zr: root zone depth (m)

Readily Available Water was calculated as

$$RAW = TAW * P \quad \text{……(3.27)}$$

Where: RAW: Readily available water (mm)

P: water depletion fraction/management allowable depletion (%).

The irrigation intervals of crops were determined through following equations (Michael, 2008).

$$I = \frac{RAW}{ETc} \quad \text{……(3.28)}$$

Where: I: irrigation interval (days)

RAW: Readily available water (mm)

ETc: crop evapotranspiration/crop water requirement (mm/day)

Crop water requirement of the major irrigated crops grown in the irrigation scheme was estimated using CROPWAT 8.0 model. The determination of the CWR by the model depends on the determination of the reference evapotranspiration value using the available climatic and soil data. Data for major crops grown in the study areas including growing stages and stage lengths (days), crop coefficients (Kc), rooting depths (Rdz), depletion levels (P), yield response factors (Ky) and planting date were obtained from FAO guidelines (Allen et al., 1998). Soil infiltration data was also taken from woreda agricultural office and used as input data to Cropwat.

Crop water requirement or ETc can be calculated as

$$ETc = Kc \times ETo \quad \text{……(3.29)}$$

Where: ETc: crop evapotranspiration/crop water requirement (mm/day),

Kc: crop coefficient, which is a function of crop type and stage of growth

ETo: reference evapotranspiration (mm/day)

4. RESULTS AND DISCUSSION

4.1. Soil characteristics analysis result

4.1.1. Particle size distribution and textural class

Based on laboratory analysis of particle size distribution, the textural classes of irrigation schemes were determined. As indicated in Table 4 Sandy loam is found in the field selected from head and field selected from tail of the scheme; whereas in the field selected from middle of the scheme loamy sand soil is found at the top layer and sand soil is found in the lower layer.

Table 4: Soil physical characteristics of irrigation scheme

Sample Field	soil depth(cm)	Particle size distribution			Textural class
		Sand (%)	Clay (%)	Silt (%)	
Head	0-30	70	6	24	Sandy loam
	30-60	80	8	12	Loamy sand
Middle	0-30	80	10	10	Sand
	30-60	60	15	25	Sandy loam
Tail	0-30	60	2	38	Sandy loam
	30-60	74	1	25	Loamy sand

4.1.2. Result of Bulk density

In the irrigation scheme as indicated in Table 5. The values of bulk density was 1.17, 1.2 and 1.24 gm/cm^3 at the top layer depth 0-30 cm of the soil for head, middle and tail end of irrigated area respectively and 1.27, 1.17 and 1.28 gm/cm^3 at the lower layer depth 30-60 cm of the soil for head, middle and tail end of irrigation area respectively. Average soil bulk density of the study area was obtained 1.2gm/cm^3 for 0-30cm and 1.24gm/cm^3 for 30-60 cm soil depth. the lower layer of the soil bulk density had larger than the top soil this indicated that the subsurface soil might have lower organic maters content and compacted due to the overlaying by the upper soil materials. Generally this revealed that the subsurface soils have lower soil porosity than surface soil. The overall results of the bulk density of the study area was in the interval for the ideal bulk density for plant growth which is less than or equal to 1.4 gm/cm^3 for the same soil texture reported by USDA-NRCS, (2014).

4.1.3. Result of total available water

The values of field capacity (FC), permanent wilting point (PWP) and total available water content (TAW) are indicated in Table 5. The result of total available water of the soil in the head, middle, and tail field were 136.6, 65.85 and 65.1mm respectively.

Table 5: Total available water in the scheme

Sample Field	soil depth(cm)	Bulk density(g/cm^3)	FC (%)	PWP (%)	TAW (%)	TAW (mm)	TAW in soil (mm)
Head	0-30	1.17	42.15	16.13	26.02	78.06	136.62
	30-60	1.27	41.79	22.27	19.52	58.56	
Middle	0-30	1.20	30.62	20.32	10.3	30.9	65.85
	30-60	1.17	32.65	21.00	11.65	34.95	
Tail	0-30	1.24	36.62	23.43	13.19	39.57	65.1
	30-60	1.28	31.12	22.61	8.51	25.53	

4.2. Evaluation of irrigation system performance

4.2.1. Conveyance efficiency and losses

The conveyance efficiency and losses were determined for main, secondary and tertiary canals using equation 3.13 and 3.14 described in section 3.5. The result showed that the average conveyance efficiency per unit length in the lined main canal, secondary canal 1 and secondary canal 2 of Melewe Irrigation Scheme is 86.9, 78.3, and 73.3 % as indicated in Table 3. The result was below FAO (1989) recommended values which less than 200 meters canal length earthen canals of conveyance efficiency should be (80-90%) and 95% for lined canals. As a result the conveyance efficiency of Melewe irrigation scheme was poor. Average conveyance efficiency in secondary canal is low this is due to illegal abstraction of water by farmers. On the other hand, the average conveyance efficiency per unit length in the unlined tertiary canal 1 and tertiary canal 2 was 77.1 and 81.1 %. This is due to loss through seepage in the side and bed of the earthen canals. Bayan (2017) reported a similar finding that unlined conveyance efficiency of Mada Batu small-scale irrigation scheme canals ranged from 47.1 to 88.6%. Nearly similar result was found in the main lined canal of Midhegdu small-scale irrigation scheme was 88.8 % as reported by Worku, (2013). This might be due to the difference in soil property and structural stability of the earth canals.

Grand average overall conveyance efficiency of the scheme was 79.3%. From that result it is concluded that conveyance efficiency of the schemes was good. The main reasons were illegal abstraction of water by farmers, seepages and over flow in unlined tertiary canal, and seepages due to high siltation by soil and weeds in canals.

Conveyance losses through the conveyance system, in canal, secondary canal1, secondary canal2, tertiary canal1 and 2 of scheme were 0.0126, 0.013, 0.12, 0.128 and 0.182 l/s/m, respectively. Over all conveyance loss from the conveyance system was obtained 0.347 l/s/m. As per the field observation during field data collection in canals, the conveyance loss in the unlined canal was due to illegal abstraction of water by farmers. However, loss of irrigation water in the unlined canals associated with seepage losses and breaching of canal. This was exacerbated by poor structural stability of earthen materials of the canals. The current finding is greater than the loss in the unlined canal of Mada Batu small-scale irrigation scheme, which is ranged from 0.02 l to 0.04 l/s/m as reported by Bayan, (2017).

Table 6: conveyance efficiency and losses

Canals	Length of each segment(m)			Unit length (m)	Avg. Conveyance efficiency (%)	Conveyance losses (l/s/m)
	Segmen1	Segment2	Segment3			
Main canal	100	150	120	370	86.9	0.0126
Secondary 1	150	100	120	370	78.3	0.013
Secondary 2	100	150	120	370	73.3	0.012
Tertiary 1	60	50		110	77.1	0.128
Tertiary 2	50	50		100	81.1	0.182
Grand average overall conveyance efficiency of scheme					79.3	
Over all conveyance loss of scheme						0.347

4.2.2. Water application Efficiency

The application efficiency was estimated using equation 3.14 and presented in Table 7. The results were found 42.3, 68.9 and 56.1% for the Head, Middle and Tail field of the irrigation scheme respectively. According to FAO (1989) water application efficiency for furrow irrigation method is ranged 60-70%. Whereas according Rogers et al. (1997) revealed that furrow irrigation methods have wider range of application efficiency i.e.50-90%. The result indicates that at the head field the farmers use long furrow and excess application time and due to this the head field was less efficient relatively to the middle and tail irrigation fields. The tail end field were efficient than the head and middle field this is due to short application time and less water application. On over all bases of the values of application efficiency for Melewe irrigation scheme was indicates less efficient.

Table 7: Application efficiency of scheme

Sampled field	Applied discharge (l/s)	Time elapsed (sec)	Area of field(m^2)	Total volume (l)	Applied depth (Da) in mm	Depth stored (Ds)in mm	Application efficiency (%)
Head	5.309	8250	350	43799.25	125.14	53.04	42.3
Middle	4.275	6530	300	27915.75	93.05	64.13	68.9
Tail	3.948	6420	290	25346.16	87.4	49.06	56.1
Scheme application efficiency							55.7

4.2.3. Water storage Efficiency

The storage efficiency was computed using equation 3.17 described in section 3.5 and result is displayed in Table 8. The storage efficiency varied from 83.8 to 90.8% with an average value of 87.1%. The result implies that about 87.1% of the Melewe irrigation schemes satisfies moisture deficit of crop root zone and irrigation water application is not successfully met its objective of refilling the root zone to field capacity. The storage efficiency of schemes is poor; this is due to soil at the sample field was mainly sandy loam and sand which has a low water holding capacity, excessive seepage loss form part of the problems and application of inappropriate flow rate with excess application time. The calculated value of storage efficiency at middle field was higher than head and tail fields.

Table 8: Storage efficiency of the irrigation scheme

Sample plot	Soil depth(cm)	Stored water at root zone(mm)	Required water(mm)	Storage efficiency (%)
Head	60	53.04	60.9	87.1
Middle	60	64.13	70.9	90.4
Tail	60	49.06	58.5	83.8
Scheme storage efficiency				87.1

4.2.4. Distribution Uniformity

The DU of the scheme was calculated using equation 3.18 described in section 3.5. And result is displayed in table 9. The results were found 84.1, 78.7 and 86.5% for the Head, Middle and Tail field of the irrigation scheme respectively. From the result observed, there was poor distribution uniformity at middle field of the irrigation scheme, at the head and tail field of the irrigation scheme was better distribution uniformity relatively. According to the typical recommended result by FAO (1989) ranged greater than 80% and Eisenhauer (1997) distribution uniformity greater than 60% is acceptable. According to this guide line water distribution uniformity is efficient and relatively uniform over the entire field.

Table 9 : Storage efficiency of the irrigation scheme

Sample plot	Average of all water stored in root zone (mm)	Average water depth of the absolute values of deviations from the average	Distribution Uniformity (%)
Head	53.04	8.45	84.1
Middle	64.13	13.8	78.5
Tail	49.06	6.67	86.5

4.2.5. Deep Percolation Ratio

The deep percolation of the scheme was calculated using equation 3.24 described in section 3.5. Farmers were practicing closed end furrow, only deep percolation loss was considered. The results were found 57.7, 31.1 and 43.9% with average values of 44.2% for the Head, Middle and Tail field of the irrigation scheme respectively. According to FAO (1998) water loss through deep percolation and surface runoff could be about less than 10%. Highest deep percolation loss recorded at the head and middle of the scheme. This is due to excess water application time and flow rate for the sand and sandy loam soil which contributes to the deep percolation loss. This result shows that deep percolation loss is considered as unacceptable and water is lost from the field in the form of deep percolation.

4.2.6. Scheme Irrigation Efficiency

The overall efficiency of the scheme is the product of conveyance efficiency and application efficiency and estimated using equation 3.28. The overall efficiencies of scheme were found to be 44%. According to FAO (1989) a scheme irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme irrigation efficiency of 20-30% is poor and according to this guide line the performance of schemes were reasonabe.

4.3. Evaluation of irrigation practices of the farmers

4.3.1. Depth of irrigation

The farmer's application depth of irrigation water and depth of irrigation water that would be required to fill root zone to field capacity estimated using equation 3.23 and 3.24 respectively. And results are indicated in table 10. In the Head, Middle and Tail field of the irrigation scheme farmer's application depth were 53, 49.1 and 49mm respectively. And depths of irrigation that would be applied were 60.9, 70.9 and 58.5mm respectively. This result shows that farmer is applying nearly required depth. In the middle field depth of irrigation water applied by the farmer is better compared with head and tail field

Table 10: Depth of irrigation applied by farmer and required depth

Sample plot	Soil depth(cm)	Depth would be applied(mm)	Farmer applied depth(mm)
Head	60	60.9	53.04
Middle	60	70.9	64.13
Tail	60	58.5	49.06

4.3.2. Irrigation Interval

Irrigation interval was calculated using equation 3.28 described in section 3.6. The result shows that calculated and farmers practiced irrigation intervals were varying in sampled crops. Farmers were applying the same irrigation interval in each growth stage of the irrigated crop but crops are required at different irrigation interval within each growth stage. Because requirement of water is depends on growth stage. Calculated irrigation interval at the head field shows greater difference than middle and tail field. As a result of applied the same irrigation interval throughout the growth stage, irrigated crop production would have declined. As result, farmer increase irrigation interval.

Table 11: Farmers practiced and calculated irrigation interval

Sample field	Crop type	TAW (mm)	depletion fraction(P)	RAW (mm)	ETc (mm/day)	Calculated Irrigation interval(in days)	Irrigation interval practiced (in days
Head	Cabbage	136.6	0.45	61.5	3.94	15	6
middle	Potato	65.8	0.35	23.04	4.09	6	4
Tail	Carrot	65.1	0.35	22.8	3.82	6	5

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study was conducted to evaluate the performance of Melewe Small-Scall Irrigation Scheme in Arbegona woreda, Sidama Regional State of Ethiopia. The performance evaluation was done using internal performance indicators and irrigation water management practices of farmer of the scheme. Primary data collections prepared and incorporated through field observations, measurements of flow rate in canal and at field level, determination of moisture content of the soils at selected irrigation fields before and day after irrigations. Discharge measurement in the canal and sampled field were determined using Float method and parshall flume.

Secondary data was collected from published and unpublished documents, books, working papers of different institutions such as Meteorological station, Arbegona Woreda Agriculture Office, and Keble development agent experts.

Soil sample analysis result shows that textural class of the soil was sandy loam in head and tail field while in middle field of the scheme sand at the top layer and sandy loam at the lower layer and the bulk density values ranged at 1.17, 1.2 and 1.24 gm/cm^3 at the top layer depth 0-30 cm of the soil for head, middle and tail end of irrigated area respectively and 1.27, 1.17 and 1.28 gm/cm^3 at the lower layer depth 30-60 cm of the soil for head, middle and tail end of irrigation area respectively. Average soil bulk density of the scheme was obtained 1.2gm/cm^3 for 0-30cm and 1.24gm/cm^3 for 30-60 cm soil depth.

The average results of conveyance efficiency per unit length on main, secondary1, secondary2, tertiary1 and tertiary2 canals were obtained 86.9, 78.3, 73.3, 77.1, and 81.1% respectively. Overall scheme conveyance efficiency was 79.3%. Conveyance losses through the conveyance system in the main canal, secondary canal1, secondary canal2, tertiary canal1 and 2 of the scheme, were 0.0126, 0.013, 0.012, 0.108 and 0.182 l/s/m, respectively. In the tertiary canals efficiencies were unlined throughout their lengths of tertiary canal so that increase seepage loss, sedimentation, eroded the side of canals, Lack of frequent canal cleaning and maintenance also the cause of low efficiencies of canals.

The study showed that the application efficiencies of head, middle and tail end of selected fields were 42.3, 68.9 and 56.1%, respectively. The result indicates that at the middle field the farmers were applying excess amount of water to their field due to this the head field was less efficient relatively to the head and tail irrigation fields. Low efficiencies were achieved due to the fact that poor water management by the farmers at field level. The values of application efficiency for the scheme were less efficient.

The result of Storage efficiency of the scheme shows that of the schemes satisfies 87.1% of moisture deficit of crop root zone and irrigation water application is not successfully met its objective of refilling the root zone to field capacity. The distribution uniformity at the head, middle and tail field was 84.1, 78.7, and 86.5% respectively. This indicates the applied irrigation depth was evenly distributed to the irrigated crops. The value of deep percolation loss about 44.2%. It indicate that farmer irrigate field with excess application time. Overall scheme efficiency was 44%. Based on the above observation overall efficiency of irrigation schemes were categorized under low efficiency.

The farmer's application depth of irrigation water and depth of irrigation water that would be required to fill root zone to field capacity estimated. Farmers practiced and calculated irrigation intervals were varying in sampled crops. Farmers were applying the same irrigation interval in each growth stage of the irrigated crop but crops are required different amount of water at different irrigation interval within each growth stage. According to the results obtained, water management practice of the scheme was generally poor.

Generally, based on evaluation findings the scheme requires improvement measures to maximize its performance and to achieve construction goals. Therefore, irrigation management and practice, frequent performance evaluation should be conducted to identify the critical level of the schemes.

5.2. Recommendations

Based on the result obtained the following recommendations were suggested:

- Water conveyance efficiencies are low. Therefore, it is better to improve efficiency of canal through regular cleaning, lining where more leakage loss occurred and by reducing illegal abstraction water by breaching canal.
- Conveyance losses of irrigation water in the unlined canals high. It should be lined or compact earthen materials of soil in order to get structural stability to reduce seepage losses.
- Institutional support and continuous monitoring and evaluation of the scheme are necessary to take immediate correction action to improve conveyance efficiencies.
- Application efficiency was low. It should be increased by applying appropriate discharge and application time to improve application efficiency.
- Farmer's application depth is not line with required depth. It should be increase depth of application by adjusting applied discharge and time.
- Irrigation intervals of farmer are inappropriate. It should be increase irrigation interval.
- Scheme irrigation efficiency is poor. Therefore, maintenance of unlined water conveyance system of the scheme and regular capacity building training on over all irrigation water management, scheme operation and maintenance should be given to beneficiary farmers.
- Assigning irrigation expert to the scheme and conducting on-job training of farmers to the improvement of the scheme performance.

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APPENDIX

Appendix 1: Tables

Appendix table 1: Climate data for study area from 1993 to 2018

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sunshine Hour (hr)	Rad (MJ/m²/day)	ETo	
							mm/day	mm/month
January	7.3	22.6	75	104	8.2	20.2	3.53	109.43
February	7.5	23	70	104	8	21	3.81	106.68
March	8.1	22.5	76	130	7.4	20.9	3.83	118.73
April	8.2	20.8	86	104	7.5	21	3.58	107.4
May	8.7	20.3	88	104	7.2	19.9	3.35	103.85
June	7.9	20.3	91	138	6.4	18.2	3.05	91.5
July	7.5	18.5	89	104	4.6	15.7	2.69	83.39
August	7.3	18.4	88	104	5.3	17.3	2.86	88.66
September	8.3	19.6	92	69	6.2	18.9	3.15	94.5
October	7.5	19.9	81	69	7.1	19.7	3.31	102.61
November	7.4	20.9	80	86	8.6	20.9	3.44	103.2
December	6.6	21.8	68	95	8.2	19.8	3.42	106.02
Average/Total	7.7	20.7	82	101	7.1	19.5	3.34	1215.8

Appendix table 2 : Mean monthly rainfall and effective rainfall

Months	Rain fall(mm)	Effective rainfall(mm)
January	41.2	38.5
February	38.1	35.8
March	75.0	66
April	182.6	129
May	200.6	136.2
June	125.5	100.3
July	104.1	86.8
August	158.8	118.5
September	144.0	110.8
October	175.5	126.2
November	68.8	60.6
December	27.5	26.3
Total	1340.3	1034.9

Appendix table 3: Reference evapotranspiration (ETo) and mean monthly rainfall

Months	ETo(mm/month)	Rainfall(mm)
January	109.43	41.2
February	106.68	38.1
March	118.83	75.0
April	107.4	182.6
May	103.85	200.6
June	91.5	125.5
July	83.39	104.1
August	88.66	158.8
September	94.5	144.0
October	102.61	175.5
November	103.2	68.8
December	106.02	27.5
Total	1215.97	1340.3

Appendix table 4: Main, secondary and tertiary canal conveyance efficiency

Canal	Length of each segment(m)	Observation point	Canal section	Distance (m)	Avg .time(sec)	Surface Velocity (m/s)	Velocity of flow (m/s)	Width (cm)	Avg.deth(cm)	Area (m2)	Discharge (m3/s)	Conveyance efficiency (%)
Main	100	1	MC initial	10	35.5	0.281	0.239	60	25.75	0.1545	0.0369	90.9
			MC final	10	37.5	0.266	0.226	60	24.75	0.1485	0.0335	
	150	2	MC initial	10	36.5	0.273	0.232	60	24.5	0.147	0.0341	92.4
			MC final	10	37.5	0.266	0.226	60	23.25	0.1395	0.0315	
	120	3	MC initial	10	32.5	0.307	0.261	60	23	0.138	0.036	77.5
			MC final	10	39.7	0.251	0.214	60	21.75	0.1305	0.027	
Secondary	150	1	SC1initial	9	33.5	0.268	0.228	50	20.75	0.1037	0.0236	86.4
			SC1final	9	37.5	0.24	0.204	50	20	0.100	0.0204	
	100	2	SC1initial	9	30.5	0.295	0.25	50	19.75	0.0987	0.0246	74.0
			SC1final	9	38.5	0.233	0.198	50	18.4	0.092	0.0182	
	120	3	SC1initial	9	31.5	0.285	0.242	50	17.75	0.0887	0.0214	74.6
			SC1final	9	40.5	0.222	0.188	50	17	0.085	0.0159	
	100	1	SC2initial	9	30.5	0.295	0.25	50	15.5	0.0775	0.0193	76.6
			SC2final	9	38	0.236	0.20	50	14.75	0.0737	0.0147	
	150	2	SC2initial	9	30.5	0.295	0.25	50	14	0.07	0.0175	75.6
			SC2final	9	39	0.23	0.196	50	13.5	0.0675	0.0132	
	120	3	SC2initial	9	28.5	0.315	0.267	50	13	0.065	0.0173	67.9
			SC2final	9	39.8	0.226	0.192	50	12.25	0.0612	0.0117	
Tertiary	60	1	TC1initial	8	27.3	0.293	0.249	50	11.5	0.0575	0.0143	71.5
			TC1final	8	37.3	0.214	0.182	50	11.25	0.0562	0.0102	
	50	2	TC1initial	8	31.8	0.251	0.213	50	10.75	0.0537	0.0114	82.7
			TC1final	8	36.8	0.217	0.184	50	10.25	0.0512	0.0094	
	50	1	TC2initial	8	30	0.266	0.226	50	9.75	0.0487	0.011	79.0
			TC2final	8	37	0.216	0.183	50	9.5	0.0475	0.0086	
	50	2	TC2initial	8	30.3	0.264	0.224	50	8.75	0.0437	0.0098	83.2
			TC2final	8	35.3	0.226	0.192	50	8.5	0.0425	0.0081	

MC, SC1, SC2, TC1 and TC2 are codes for Main canal, secondary canals1, secondary canals1, tertiary canal1and tertiary canal2 respectively. And Initial and Final1are points where discharge is measured starting from the head work.

Appendix table 5: Main, secondary and tertiary canal conveyance efficiency and losses

Canals	Length of each segment (m)	Conveyance efficiency (%)	Conveyances losses(m^3/s)	Conveyances losses(lit/s/m)	Remark
Main canal	100	90.9	0.0034	0.034	Lined canal
	150	92.4	0.0026	0.017	
	120	77.5	0.009	0.075	
Secondary canal1	150	86.4	0.0032	0.021	Lined canal
	100	74.0	0.0064	0.064	
	120	74.6	0.0055	0.045	
Secondary canal 2	100	76.6	0.0046	0.046	Lined canal
	150	75.6	0.0043	0.028	
	120	67.9	0.0056	0.046	
Tertiary canal1	60	71.5	0.0041	0.068	unlined canal
	50	82.7	0.002	0.04	
Tertiary canal2	50	79.0	0.0024	0.048	unlined canal
	50	83.2	0.0017	0.034	

Appendix table 6: Soil moisture content before irrigation for head field sample plot

Sample field	Soil depth(cm)	Before irrigation		Volume of core(cm^3)	Bulk density (g/cm^3)	Moisture before irrigation ($\boldsymbol{\theta}$g%)	Moisture before irrigation (vol %)
		Wet weight (gm)	Dry weight (gm)				
H1	0-30	152.40	113.40	98.125	1.15	34.4	39.5
	30-60	160.34	122.41	98.125	1.25	30.9	38.6
H2	0-30	159.42	118.44	98.125	1.21	34.6	41.8
	30-60	152.36	115.35	98.125	1.17	32.0	32.4
H3	0-30	153.41	110.53	98.125	1.12	38.8	43.4
	30-60	155.43	116.52	98.125	1.18	33.4	39.4
H4	0-30	161.42	116.75	98.125	1.19	38.3	45.6
	30-60	155.5	118.43	98.125	1.20	31.3	37.6
H5	0-30	153.5	110.32	98.125	1.12	39.1	43.8
	30-60	164.34	123.35	98.125	1.25	33.2	41.5
H6	0-30	157.32	113.48	98.125	1.15	38.6	44.4
	30-60	162.42	122.52	98.125	1.24	32.5	40.3
H7	0-30	164.23	113.60	98.125	1.15	44.5	51.2
	30-60	166.38	126.56	98.125	1.29	31.4	40.5
H8	0-30	162.58	120.62	98.125	1.23	34.7	42.7

	30-60	164.52	127.44	98.125	1.30	29.0	37.7
H9	0-30	159.52	118.61	98.125	1.20	34.5	41.4
	30-60	161.62	124.64	98.125	1.27	29.6	35.6

Appendix table 7: Soil moisture content after irrigation for head field sample plot

Sample field	Soil depth(cm)	After irrigation		Volume of core(cm^3)	Bulk Density (g/cm^3)	Moisture After Irrigation (θg %)	Moisture After irrigation (vol %)
		Wet weight (gm)	Dry weight (gm)				
H1	0-30	168.45	118.53	98.125	1.21	42.1	50.9
	30-60	166.43	122.64	98.125	1.25	35.7	44.6
H2	0-30	167.64	118.62	98.125	1.21	41.3	49.9
	30-60	164.65	120.48	98.125	1.23	36.6	45.0
H3	0-30	170.43	123.57	98.125	1.26	37.9	47.7
	30-60	172.52	118.66	98.125	1.20	45.4	54.5
H4	0-30	173.67	123.56	98.125	1.26	40.5	51.0
	30-60	172.53	125.57	98.125	1.28	37.4	47.8
H5	0-30	159.54	112.76	98.125	1.14	41.5	47.3
	30-60	170.86	119.67	98.125	1.22	42.7	52.1
H6	0-30	169.64	121.23	98.125	1.23	39.5	48.5
	30-60	170.72	125.67	98.125	1.28	35.8	45.8
H7	0-30	176.62	115.45	98.125	1.17	52.9	61.9
	30-60	177.71	127.23	98.125	1.30	39.6	51.4
H8	0-30	176.65	122.87	98.125	1.24	41.0	50.8
	30-60	179.32	128.83	98.125	1.31	39.2	51.3
H9	0-30	166.52	120.74	98.125	1.23	37.9	46.6
	30-60	168.72	123.63	98.125	1.26	34.5	43.5

Appendix table 8: Total Moisture stored in root zone of head field sample plot

Sample field	Soil depth (cm)	Moisture before irrigation (Vol %)	Moisture after irrigation (Vol %)	Moisture Stored (Vol %)	Moisture stored in depth(mm)	Total Moisture stored in root zone (mm)
H1	0-30	39.5	50.9	11.4	34.2	50.2
	30-60	38.6	44.6	6.0	16.0	
H2	0-30	41.8	49.9	8.1	24.3	62.1
	30-60	32.4	45.0	12.6	37.8	
H3	0-30	43.4	47.7	4.3	12.9	58.2
	30-60	39.4	54.5	15.1	45.3	
H4	0-30	45.6	51.0	5.4	16.2	46.8
	30-60	37.6	47.8	10.2	30.6	
H5	0-30	43.8	47.3	3.5	10.5	42.3
	30-60	41.5	52.1	10.6	31.8	
H6	0-30	44.4	48.5	4.1	12.3	48.6
	30-60	40.3	45.8	5.5	16.3	
H7	0-30	51.2	61.9	10.7	32.1	64.8
	30-60	40.5	51.4	10.9	32.7	
H8	0-30	42.7	50.8	8.1	24.3	65.1
	30-60	37.7	51.3	13.6	40.8	
	0-30	41.4	46.6	5.2	15.6	39.3
H9	30-60	35.6	43.5	7.9	23.7	

Appendix table 9: Soil moisture content before irrigation for middle field sample plot

Sample field	Soil depth (cm)	Before irrigation		Volume of core(cm^3)	Bulk Density (g/cm^3)	Moisture before irrigation (θg%)	Moisture before irrigation (vol %)
		Wet weight (gm)	Dry weight (gm)				
M1	0-30	155.45	112.53	98.125	1.15	38.14	43.7
	30-60	158.33	115.43	98.125	1.17	37.14	43.6
M2	0-30	158.52	118.55	98.125	1.21	33.7	40.7
	30-60	162.44	113.53	98.125	1.15	43.1	49.8
M3	0-30	154.51	115.64	98.125	1.17	33.6	39.6
	30-60	162.35	125.42	98.125	1.27	29.4	37.6
M4	0-30	159.57	122.83	98.125	1.25	29.9	37.4
	30-60	165.56	119.77	98.125	1.22	38.2	46.6
M5	0-30	160.38	117.78	98.125	1.20	36.1	43.4
	30-60	168.37	124.85	98.125	1.27	34.8	44.3
M6	0-30	157.36	118.93	98.125	1.21	32.3	39.2
	30-60	163.55	115.85	98.125	1.18	41.2	48.6
M7	0-30	158.56	113.56	98.125	1.15	39.6	45.8
	30-60	164.82	123.54	98.125	1.26	33.4	42.1
M8	0-30	162.63	126.53	98.125	1.28	28.5	36.7
	30-60	166.52	121.35	98.125	1.23	37.2	46.0

M9	0-30	162.44	116.77	98.125	1.19	39.1	46.5
	30-60	160.63	119.59	98.125	1.21	34.3	41.5

Appendix table 10: Soil moisture content after irrigation for middle field sample plot

Sample field	Soil depth(cm)	After irrigation		Volume of core(cm^3)	Bulk density(g/cm^3)	Moisture After Irrigation (θg %)	Moisture After irrigation (Vol %)
		Wet weight (gm)	Dry weight (gm)				
M1	0-30	165.53	113.53	98.125	1.15	45.8	52.9
	30-60	168.62	120.12	98.125	1.22	40.4	49.4
M2	0-30	169.54	111.45	98.125	1.13	52.1	59.2
	30-60	174.35	118.66	98.125	1.21	46.9	56.7
M3	0-30	165.56	119.77	98.125	1.22	46.9	57.2
	30-60	174.77	128.62	98.125	1.31	35.8	47.0
M4	0-30	168.48	118.93	98.125	1.21	41.6	50.5
	30-60	176.93	125.84	98.125	1.28	40.6	52.1
M5	0-30	170.33	120.65	98.125	1.23	41.2	50.6
	30-60	178.86	128.93	98.125	1.31	38.7	50.8
M6	0-30	168.53	113.85	98.125	1.16	48.1	55.7
	30-60	172.55	115.73	98.125	1.17	49.1	57.9
M7	0-30	174.66	120.52	98.125	1.22	44.9	55.2
	30-60	179.57	124.64	98.125	1.27	44.1	55.9
M8	0-30	174.54	120.56	98.125	1.22	44.7	55.0
	30-60	177.61	124.63	98.125	1.27	42.5	53.9
M9	0-30	173.42	120.61	98.125	1.22	43.7	53.8
	30-60	176.65	125.84	98.125	1.28	40.3	51.7

Appendix table 11: Total Moisture stored in root zone for middle field

Sample field	Soil depth (cm)	Moisture before irrigation (Vol %)	Moisture after irrigation (Vol %)	Moisture Stored (Vol%)	Moisture stored in depth(mm)	Total Moisture stored in root zone (mm)
M1	0-30	43.7	52.9	9.2	27.6	45.0
	30-60	43.6	49.4	5.8	17.4	
M2	0-30	40.7	59.2	18.5	55.5	76.2
	30-60	49.8	56.7	6.9	20.7	
M3	0-30	39.6	57.2	17.6	52.8	81
	30-60	37.6	47.0	9.4	28.2	
M4	0-30	37.4	50.5	13.1	39.3	55.8
	30-60	46.6	52.1	5.5	16.5	
M5	0-30	43.4	50.6	7.2	21.6	41.1
	30-60	44.3	50.8	6.5	19.5	
M6	0-30	39.2	55.7	16.5	49.5	77.4
	30-60	48.6	57.9	9.3	27.9	
M7	0-30	45.8	55.2	9.4	28.2	69.6
	30-60	42.1	55.9	13.8	41.4	
M8	0-30	36.7	55.0	18.3	54.9	78.6

	30-60	46.0	53.9	7.9	23.7	
M9	0-30	46.5	53.8	7.3	21.9	52.5
	30-60	41.5	51.7	10.2	30.6	

Appendix table 12: Soil moisture content before irrigation for tail field sample plot

Sample field	Soil depth(cm)	Before irrigation		Volume of core(cm^3)	Bulk Density (g/cm^3)	Moisture before irrigation (θg %)	Moisture before irrigation (Vol %)
		Wet weight (gm)	Dry weight (gm)				
T1	0-30	155.64	112.55	98.125	1.14	38.2	43.9
	30-60	160.53	115.73	98.125	1.17	38.7	45.6
T2	0-30	150.65	119.56	98.125	1.22	26.0	31.6
	30-60	154.23	113.67	98.125	1.15	35.6	41.3
T3	0-30	166.83	126.73	98.125	1.29	31.6	40.8
	30-60	161.85	121.35	98.125	1.23	33.3	41.0
T4	0-30	154.76	112.57	98.125	1.14	37.4	42.9
	30-60	158.58	110.57	98.125	1.12	43.4	48.9
T5	0-30	152.65	115.66	98.125	1.17	31.9	37.6
	30-60	154.88	116.65	98.125	1.18	32.7	38.9
T6	0-30	160.67	115.63	98.125	1.17	38.9	45.9
	30-60	165.82	123.51	98.125	1.25	34.2	43.1
T7	0-30	157.23	111.62	98.125	1.13	40.8	46.4
	30-60	164.81	122.53	98.125	1.24	34.5	43.1
T8	0-30	161.63	115.65	98.125	1.17	39.7	46.8
	30-60	156.65	119.67	98.125	1.21	30.9	37.6
T9	0-30	162.61	121.48	98.125	1.23	33.8	41.9
	30-60	157.63	122.76	98.125	1.25	28.4	35.5

Appendix table 13: Soil moisture content after irrigation for tail field sample plot

Sample field	Soil depth(cm)	After irrigation		Volume of core(cm^3)	Bulk Density (g/cm^3)	Moisture After irrigation (θg %)	Moisture After irrigation (vol %)
		Wet weight (gm)	Dry weight (gm)				
T1	0-30	165.53	116.82	98.125	1.19	41.6	49.6
	30-60	168.82	119.73	98.125	1.22	41.0	50.0
T2	0-30	153.84	112.72	98.125	1.14	36.4	41.5
	30-60	167.76	115.84	98.125	1.18	44.8	52.8
T3	0-30	165.87	117.85	98.125	1.20	40.7	48.8
	30-60	168.78	118.26	98.125	1.21	42.7	51.6
T4	0-30	166.96	113.84	98.125	1.16	46.6	54.1
	30-60	169.57	116.45	98.125	1.18	45.6	54.1
T5	0-30	160.95	115.53	98.125	1.17	39.3	45.9
	30-60	163.76	115.75	98.125	1.17	41.4	48.9
T6	0-30	168.62	120.26	98.125	1.22	40.2	49.3
	30-60	169.23	115.87	98.125	1.18	46.0	54.3
T7	0-30	164.82	110.51	98.125	1.12	49.2	55.0

	30-60	173.74	121.52	98.125	1.23	42.9	52.8
T8	0-30	172.73	115.84	98.125	1.18	49.1	57.9
	30-60	169.55	126.76	98.125	1.29	33.7	43.6
T9	0-30	158.76	113.77	98.125	1.15	39.5	45.4
	30-60	159.57	115.94	98.125	1.18	37.6	44.3

Appendix table 14: Total Moisture stored in root zone of tail field sample plot

Sample field	Soil depth (cm)	Moisture before irrigation (Vol %)	Moisture after irrigation (Vol %)	Moisture Stored (Vol %)	Moisture stored in depth(mm)	Total Moisture stored in root zone (mm)
T1	0-30	43.9	49.6	5.7	17.1	30.3
	30-60	45.6	50.0	4.4	13.2	
T2	0-30	31.6	41.5	9.9	29.7	64.2
	30-60	41.3	52.8	11.5	34.5	
T3	0-30	40.8	48.8	8.0	24.0	55.8
	30-60	41.0	51.6	10.6	31.8	
T4	0-30	42.9	54.1	11.2	33.6	49.2
	30-60	48.9	54.1	5.2	15.6	
T5	0-30	37.6	45.9	8.4	25.1	55.1
	30-60	38.9	48.9	10	30.0	
T6	0-30	45.9	49.3	3.4	10.2	43.9
	30-60	43.1	54.3	11.2	33.7	
T7	0-30	46.4	55.0	8.6	25.8	54.9
	30-60	43.1	52.8	9.7	29.1	
T8	0-30	46.8	57.9	11.1	33.3	51.3
	30-60	37.6	43.6	6.0	18.0	
T9	0-30	41.9	45.4	3.5	10.5	36.9
	30-60	35.5	44.3	8.8	26.4	

Appendix table 15: Total stored water and distribution uniformity of the scheme

furrow	Furrow length(m)	Sampling point	Head field sample plot		Middle field sample plot		Tail field sample plot	
			Depth of soil moisture stored due to irrigation (mm)	Absolute deviation from the mean(mm)	Depth of soil moisture stored due to irrigation (mm)	Absolute deviation from the mean(mm)	Depth of soil moisture stored due to irrigation (mm)	Absolute deviation from the mean(mm)
Right side furrow	25	1	50.2	2.84	45	19.13	30.3	18.76
		2	62.1	9.06	76.2	12.07	64.2	15.14
		3	58.2	5.16	81	16.87	55.8	6.74
Center furrow	25	4	46.8	6.24	55.8	8.33	49.2	0.14
		5	42.3	10.74	41.1	23.03	55.1	6.04
		6	48.6	4.44	77.4	13.27	43.9	5.16
Left side furrow	20	7	64.8	11.76	69.6	5.47	54.9	5.84
		8	65.1	12.06	78.6	14.47	51.3	2.24
		9	39.3	13.74	52.5	11.63	36.9	12.16
Average moisture stored in root zone(mm)		53.04			64.13		49.06	
Average water depth of the absolute values of deviations from the average				8.45		13.8		6.67
Du (%)		84.1			78.5		86.5	

Appendix table 16: Average soil moisture before irrigation for head, mid and tail field

Furrow	Sampling pont	Soil depth(cm)	Head field sample plot	Middle field sample plot	Tail field sample plot
			Moisture before irrigation (θg%)	Moisture before irrigation (θg%)	Moisture before irrigation (θg%)
Left side furrow	1	0-30	34.4	38.1	38.2
		30-60	30.9	37.1	38.7
	2	0-30	34.6	33.7	26.0
		30-60	32.0	43.1	35.6
	3	0-30	38.8	33.6	31.6
		30-60	33.4	29.4	33.3
Mid furrow	4	0-30	38.3	29.9	37.4
		30-60	31.3	38.2	43.4
	5	0-30	39.1	36.1	31.9
		30-60	33.2	34.8	32.7
	6	0-30	38.6	32.3	38.9
		30-60	32.5	41.2	34.2
Right side furrow	7	0-30	44.5	39.6	40.8
		30-60	31.4	33.4	34.5
	8	0-30	34.7	28.5	39.7
		30-60	29.0	37.2	30.9
	9	0-30	34.5	39.1	33.8
		30-60	29.6	34.3	28.4
Average moisture before irrigation (θg%)		0-30	32.5	35.1	35.4
Average moisture before irrigation (θg%)		30-60	31.4	36.5	34.6

Appendix table 17: Required water to fill root zone to field capacity

Sample plot	Soil depth (cm)	Soil moisture content at FC (%)	Average Soil moisture content before irrigation(Wbi)	Required depth(mm)	Total required water in depth(mm)
Head	0-30	42.15	32.5	28.9	60.9
	30-60	41.79	31.4	31.2	
Middle	0-30	30.62	23.1	34.5	70.9
	30-60	32.65	20.5	36.45	
Tail	0-30	36.62	29.4	23.6	58.5
	30-60	31.26	25.6	34.9	

Appendix table 18: Applied discharge to the sample field plot

Sample plot	H-Flume height (cm)	c-free flow coefficient	n-free flow exponent	Applied discharge (l/s)= $C*H^n$
Head	11.5	0.1205	1.55	5.309
Middle	10	0.1205	1.55	4.275
Tail	9.5	0.1205	1.55	3.948

Appendix table 19: Deep percolation ratio of the irrigation scheme

Sample plot	Application efficiency (%)	Runoff ratio (%)	Deep percolation ratio (%)
Head	42.3	0	57.7
Middle	68.9	0	31.1
Tail	56.1	0	43.9

Appendix table 20: Crop water requirement of potato

Crop: Potato			Season: dry season		Planting date: 05-Nov		
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.45	1.53	9.2	7.6	2.8
Nov	2	Init	0.45	1.55	15.5	5.8	9.7
Nov	3	Deve	0.45	1.55	15.5	5.1	10.5
Dec	1	Deve	0.59	2.02	20.2	4.7	15.5
Dec	2	Deve	0.81	2.76	27.6	3.2	24.4
Dec	3	Mid	1.03	3.55	39	3.3	35.8
Jan	1	Mid	1.1	3.83	38.3	3.6	34.7
Jan	2	Mid	1.1	3.87	38.7	3.6	35.1
Jan	3	Mid	1.1	3.98	43.8	3.3	40.5

Feb	1	Mid	1.1	4.09	40.9	2.2	38.7
Feb	2	Late	1.08	4.11	41.1	1.5	39.6
Feb	3	Late	1.02	3.89	31.1	4.4	26.7
Mar	1	Late	0.96	3.67	36.7	6.3	30.4
Mar	2	Late	0.91	3.5	14	3.2	10
				43.82	411.6	57.7	354.3

Appendix table 21: Crop water requirement of cabbage

Crop: Cabbage			Season: dry season		Planting date: 10-Nov		
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.45	1.53	1.5	1.3	1.5
Nov	2	Init	0.45	1.55	15.5	5.8	9.7
Nov	3	Deve	0.45	1.55	15.5	5.1	10.5
Dec	1	Deve	0.61	2.07	20.7	4.7	16
Dec	2	Deve	0.85	2.89	28.9	3.2	25.7
Dec	3	Mid	1.04	3.58	39.3	3.3	36
Jan	1	Mid	1.05	3.66	36.6	3.6	32.9
Jan	2	Mid	1.05	3.69	36.9	3.6	33.3
Jan	3	Mid	1.05	3.8	41.8	3.3	38.5
Feb	1	Mid	1.05	3.9	39	2.2	36.8
Feb	2	Late	1.03	3.94	39.4	1.5	37.9
Feb	3	Late	0.99	3.78	30.2	4.4	25.8
Mar	1	Late	0.96	3.67	14.7	2.5	11.6
				39.52	360.1	44.4	316.4

Appendix table 22: Crop water requirement of carrot

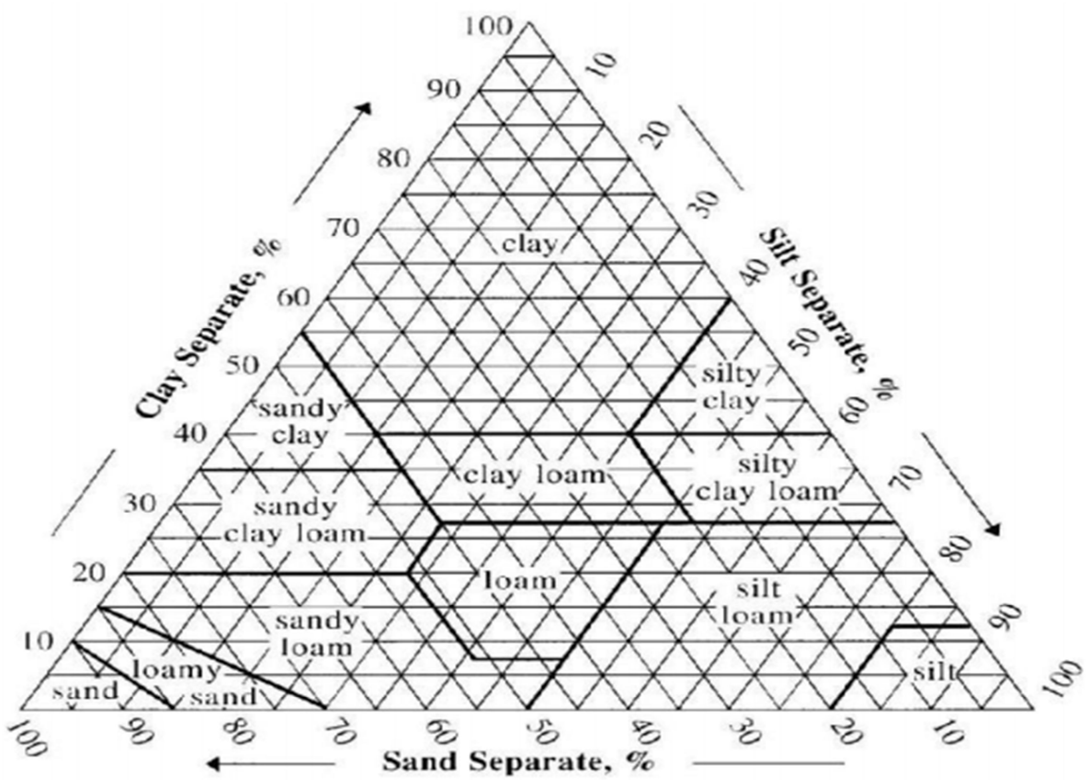
Crop: Carrot			Season: dry season		Planting date: 15-Nov		
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.5	1.72	10.3	3.5	7.5
Nov	3	Init	0.5	1.72	17.2	5.1	12.1
Dec	1	Init	0.5	1.71	17.1	4.7	12.4
Dec	2	Deve	0.53	1.81	18.1	3.2	15
Dec	3	Deve	0.67	2.32	25.5	3.3	22.2
Jan	1	Deve	0.82	2.86	28.6	3.6	25
Jan	2	Mid	0.96	3.38	33.8	3.6	30.2
Jan	3	Mid	1	3.62	39.8	3.3	36.5
Feb	1	Mid	1	3.72	37.2	2.2	35
Feb	2	Mid	1	3.82	38.2	1.5	36.7
Feb	3	Late	1	3.82	30.6	4.4	26.2
Mar	1	Late	0.96	3.67	36.7	6.3	30.4
Mar	2	Late	0.91	3.5	14	3.2	10
				37.57	347.1	47.8	299.1

Appendix table 23: Crop characteristic data for major irrigated crops in the scheme

crop	Crop parameters	Growth stages				Total	Root depth(m)	Maximum height(m)
		Int	mid	Dev't	late			
cabbage	LGP(day	25	30	45	20	120	0.5-0.8	0.4
	Crop coefficients(kc)	0.7		1.05	0.95			
	Depletion levels(p)	0.45		0.45	0.45			
	Yield response(ky)	0.8	1.1	1	0.6	0.95		
potato	LGP(day	25	35	45	15	120	0.4-0.6	0.6
	Crop coefficients(kc)	0.2		1.15	0.75			
	Depletion levels(p)	0.4		0.4	0.4			
	Yield response(ky)	0.4	0.8	1	0.7			
carrot	LGP(day	20	30	30	15	100	0.5-1.0	0.3
	Crop coefficients(kc)	0.7		1.05	0.95			
	Depletion levels(p)	0.43		0.35	0.36			
	Yield response(ky)	0.6	0.7	0.9	0.8	1		

Source: (FAO, Irrigation and drainage paper 24(1992) and 56(1998)

Appendix 2: Figures



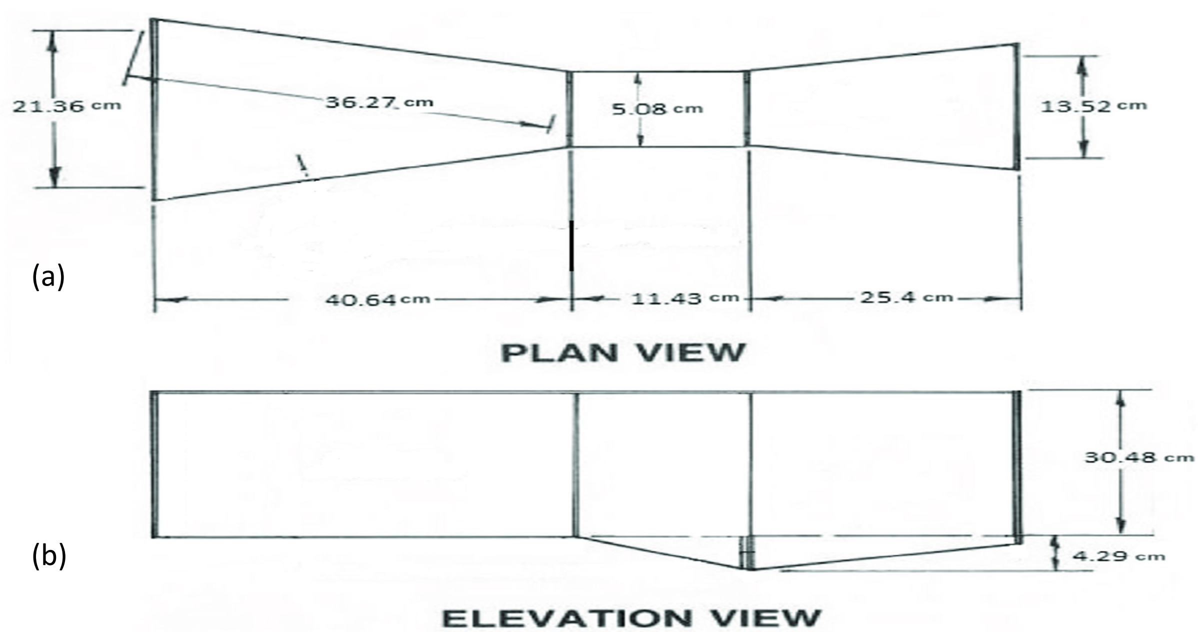
Appendix figure 1: Soil textural class triangle

Appendix figure 2: Materials used for soil sample collection

Appendix figure 3: Soil sample collection from sample field

Appendix figure 4: Materials used and soil analysis in laboratory

Appendix figure 5: Canal discharge and field discharge measurement



Appendix figure 6: Dimensions of two inch parshall flume

Appendix figure 7: Farmer irrigating his field.