

**PERFORMANCE EVALUATION OF UDO WETATE IRRIGATION  
SCHEME FOR WHEAT PRODUCTION USING FURROW  
IRRIGATION METHOD; IN SIDAMA REGION, ETHIOPIA**



**HAWASSA UNIVERSITY  
INSTITUTE OF TECHNOLOGY**

**MSc Thesis**

**By**

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**Hawassa, Ethiopia**

**May, 2024**

**PERFORMANCE EVALUATION OF UDO WETATE IRRIGATION  
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IRRIGATION METHOD; IN SIDAMA REGION, ETHIOPIA**

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**A THESIS SUBMITTED TO DEPARTMENT OF WATER RESOURCE  
AND IRRIGATION ENGINEERING**

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INSTITUTE OF TECHNOLOGY**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE  
DEGREE OF THE MASTER OF  
SCIENCE IN IRRIGATION AND DRAINAGE ENGINEERING**

**HAWASSA, ETHIOPIA**

**MAY, 2024**

## **DECLARATION**

I declare that this thesis is my work and that all sources of materials used in this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirement for the degree of Masters of Science, Water Resource and Irrigation department (Irrigation and Drainage Engineering) at Hawassa University. I confidently declare that I have not submitted this thesis to any institution anywhere for the award of academic degree, diploma or certificate.

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Place: Hawassa University, Ethiopia

## ADVISOR APPROVAL SHEET OF THE MSc THESIS

### HAWASSA UNIVERSITY

This is to certify that the thesis entitled with “Performance Evaluation of Udo Wetate Irrigation Scheme for Wheat Production Using Furrow Irrigation Method: in Sidama Region, Ethiopia” submitted in partial fulfillment of the requirement for the degree of Masters with specialization in Irrigation and Drainage Engineering, the graduate program of the department of Water Resource and Irrigation Engineering, and has carried out by Hana Wuletaw Id. No GpIrDrR/0003/14, under my supervision. Therefore, I recommend that the student has fulfilled the requirement and hence hereby can submit the thesis to the department for defense.

Moltot Zewdie (Ph.D)



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As members of the Examining Board of the Final MSc Open Defense, we certify that we have read and evaluated the thesis prepared by Hana Wuletaw entitled “PERFORMANCE EVALUATION OF UDO WETATE IRRIGATION SCHEME FOR WHEAT PRODUCTION USING FURROW IRRIGATION METHOD: IN SIDAMA REGION, ETHIOPIA and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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## LIST OF ABBREVIATIONS

GIS	Digital elevation model
FC	Field capacity
PWP	Permanent wilting point
ET <sub>c</sub>	Crop Evapotranspiration
ET <sub>o</sub>	Reference Evapotranspiration
E <sub>c</sub>	Conveyance efficiency
E <sub>a</sub>	Application efficiency
E <sub>s</sub>	Storage efficiency
DU	Distribution Uniformity
DPR	Deep percolation ratio
IWS	Irrigation water supply
IWR	Irrigation water requirement
CWR	Crop water requirement
MoWR	Ministry of water resource
SP1	Sample plot one
SP2	Sample plot two
SP3	Sample plot three
TC1	Tertiary canal one
TC2	Tertiary canal two
TC3	Tertiary canal three
FAO	Food and Agriculture Organization
°C	Degree celicious
cm	Centimeter
m	Meter
DA	Development agents
RAW	Readily available water
TAW	Total available water

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# PERFORMANCE EVALUATION OF UDO WETATE IRRIGATION SCHEME FOR WHEAT PRODUCTION USING FURROW IRRIGATION METHOD; IN SIDAMA REGION, ETHIOPIA

## **Abstract**

*Performance evaluation in irrigation systems plays a vital role in identifying the gaps and applying mitigation measures. The objective of the study was to undertake performance evaluation on winter wheat irrigation system of Udo Wetate irrigation scheme. For primary data collection field observations were conducted, discharge rates in the irrigation canals were measured, soil moisture content was determined, and the depth of water applied to the fields was also measured. For technical evaluation of the scheme using performance indicators, three sample plots were selected from the head, middle and tail-end of the main canal. The findings of this study revealed several performance issues with the Udo Wetate irrigation system. The irrigation water supply exceeded demand across all sample plots in February, ranging from 36.6% to 56.88% excess due to plot location and crop growth stage, but by March the supply only exceeded demand in two plots while falling short by 16.72% in the plot located at the canal tail, and by April crop water demands exceeded supply at all plots from 0.86% to 33% shortfall due to inadequate water application and conveyance losses. The conveyance efficiency was a major contributor to this inefficiency, with the main and tertiary canals having efficiencies of just 45.3% and 61.5% respectively. The mean field application efficiency was estimated to be 60.0%, which is considered good but had noticeable differences between plots due to different water application and relative location of plots from the source. The average storage efficiency was 50.8%, However, the distribution uniformity was 81.0%, indicating the irrigation water was fairly evenly distributed. Overall, the efficiency of the Udo Wetate irrigation scheme was found to be only 32.14% impacted by water management problems, insufficient water application, lack of awareness of crop water requirements, improper furrow design, and soil type, generally indicating moderate performance. Based on the results for this study non -proportionality of the irrigation water demand with supply, poor water delivery system, absence of frequent maintenance and management were problems strongly affecting the performance of the scheme. Therefore, it is suggested that frequent maintenance, giving training and applying a strong water delivery plan are required to mitigate this problem.*

**Keywords:** *Performance evaluation, irrigation water, performance indicators, overall efficiency, Udo Wetate irrigation scheme.*

# 1 INTRODUCTION

## 1.1 Background

Irrigation can be broadly defined as the practice of applying additional water (beyond what is available from rainfall) to soil to enable or enhance plant growth and yield, and, in some cases, the quality of foliage or harvested plant parts (Lal, 2017). Irrigation water can come from groundwater, through springs or wells, surface water, through rivers, lakes, or reservoirs, or even other sources, such as treated wastewater or desalinated water. Because of its simplicity and minimal energy use, one of the most common types of irrigation is surface irrigation (Gamal et al., 2023). Surface irrigation is the application of water by gravity flow to the surface of the field. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders) (Prins et al., 2001). The surface irrigation system is expected to supply the root zone reservoir uniformly and efficiently to avoid plant stress and ensure resources conservation such as water, nutrient, energy, and labor (Gamal et al., 2023). Surface irrigation can be used for all types of crops (Prins et al., 2001).

Furrow irrigation is suitable for a wide range of soil types, crops and land slopes. Furrows are small channels, which carry water down the land slope between the crop rows. Water infiltrates into the soil as it moves along the slope. The crop is usually grown on the ridges between the furrows. This method is suitable for all row crops and for crops that cannot stand in water for long periods (Prins et al., 2001).

It is evident that the usage of the major resources in irrigated agriculture, water, and land must be enhanced to obtain sustainable production from irrigated agriculture. As a result, on-farm and conveyance irrigation systems and activities must be assessed against the systems' potential efficiency (Wubetu et al., 2022).

In many countries around the world, there is an increasing concern about the performance of irrigation schemes because many schemes are not producing the expected returns, or they are suffering water supply restrictions and/or water quality problems. Although good on-farm irrigation is crucial for good performance of any scheme, the bottleneck is often in the irrigation delivery system (Mateos & Lo, 2002).

Performance is assessed for a variety of reasons: to improve system operations, to assess progress against strategic goals, as an integral part of performance – oriented management, to assess the general health of a system, to assess impacts of interventions, to diagnose constraints, to better understand determinants of performance, and to compare the performance of a system with others or with the same system over time (Molden et al., 1998).

There are several references of water distribution unfairness resulting in substantial discrepancies between head, middle, and tail areas; deficit water supplies and loss of output in some places; or excess water delivery and development of waterlogging and salinity in others. Water supplies at any particular area are frequently ill-suited to crop needs, are very variable in terms of timing and discharge, and are occasionally of deteriorating quality (Murray-Rust et al, 1993).

In total, the irrigation performance assessment includes different levels, starting from strategic goals, through operation process, and ending with customer satisfaction with outputs. This can be described as an indicator for resources management of the irrigation schemes. By measuring this indicator, irrigation systems efficiency and sustainability can be observed and monitored through different levels (Elshaikh et al., 2018).

Several studies have investigated the response of winter wheat to changing climatic conditions, particularly in the context of irrigation practices. Among these studies, the research conducted in the Ziway Lake Basin stands out. By employing advanced modeling techniques and considering climate projections, this study sheds light on the sustainability of winter wheat production under evolving environmental conditions. Notably, it examines the impact of climate change on yield, water availability, and crop water productivity (Hordofa et al., 2022).

## **1.2 Problem statement**

In many countries around the world, there is an increasing concern about the performance of irrigation schemes because many schemes are not producing the expected returns, or they are suffering water supply restrictions and/or water quality problems. Although good on-farm irrigation is crucial for good performance of any scheme, the bottleneck is often in

the irrigation delivery system. An inappropriate system design may be the root of some of the problems, but proper asset management is also essential for the effective operation and maintenance of irrigation water delivery systems (Mateos & Lo, 2002).

The Udo Wetate irrigation scheme in Hawassa Zuria Wereda is a government-led initiative aimed at improving agricultural practices. However, the success of the project depends on its performance and sustainability. Given that the farmers are unfamiliar with irrigation practices, it is crucial to conduct a comprehensive study to evaluate the project's effectiveness.

The successful implementation of the Udo Wetate irrigation scheme project is contingent upon understanding the project's performance and effectiveness. The farmers' lack of prior experience with irrigation practices raises concerns regarding their response to the new scheme. To address this, a detailed study is required to evaluate the project's performance. Specifically, the study examined and assessed the conveyance system, application system, water storage efficiency, irrigation water distribution uniformity, deep percolation ratio, the amount of water supply, and the project's long-term sustainability.

### **1.3 Objectives**

#### **1.3.1 General objective**

The general objective of this study was to undertake Performance Evaluation of Udo Wetate Irrigation Scheme for Wheat Production Using Furrow Irrigation Method in Sidama Region, Ethiopia.

#### **1.3.2 Specific objectives**

- To evaluate irrigation water supply versus demand on selected farmers sample plot.
- Evaluate the performance of the existing irrigation scheme using internal performance indicator.
- To identify the performance gaps and recommend remedial measure that will improve irrigation system performance.

#### **1.4 Research questions**

Having the above ideas, the research has attempted to seek answer for the following basic research question.

- What is the water supply demand gap in the system?
- How does the existing irrigation scheme perform in terms of internal performance indicators?
- What are the measures that can be taken in order to improve the performance of irrigation system?

#### **1.5 Significance of the study**

The government has been implementing winter wheat irrigation development programs across the nation to produce surplus wheat that replaces the imported ones. The comparison of the water supply and demand in the study area which helps the community to identify the amount of water needed to supply on their plot in accordance with the growth stage and climatic condition.

- Suggesting more efficient water allocation, distribution, application and management practices to improve performance of the scheme in a way that saves the natural resource and support the work of the government officials and the community.
- The measures that can be taken to avoid performance gap to achieve the national winter wheat project goal
- It also initiates other researchers to study the winter wheat irrigation projects all over the country since it is a national project.

#### **1.6 Scope of the study**

This study specifically was focused on evaluating the performance of the winter wheat irrigation by focusing on assessing irrigation water supply versus demand and using internal performance indicators such as conveyance efficiency, application efficiency, Storage efficiency, overall efficiency, distribution uniformity and deep percolation ratio.

## **2 LITERATURE REVIEW**

### **2.1 Irrigation**

Water required by crops is supplied by nature in the form of precipitation, but when it becomes scarce or its distribution does not coincide with demand peaks, it is then necessary to supply it artificially by irrigation. Irrigation systems are selected, designed and operated to supply the irrigation requirements of each crop on the farm while controlling deep percolation, runoff, evaporation, and operational losses, to establish a sustainable production process (Holzapfel et al., 2009).

Some of the advantages of irrigation are Increase in food production by increasing crop yields to attain self-sufficiency in food, Optimum utilization of water by obtaining maximum crop yield with required amount of water, Elimination of mixed cropping in the areas where irrigation is not assured, generally mixed cropping, we mean sowing together of two or more crops in the same field. If the weather conditions are not favorable to one of the crops, they may be better suitable for other and thus the farmer may get at least some yield. Mixed cropping, is thus, necessary and also economical when irrigation facilities are lacking, and especially during periods of crash programs in under developed countries. But if irrigation is assured mixed cropping can be eliminated(Garg, 2009).

### **2.2 Furrow irrigation**

Furrow irrigation is the oldest and more commonly used irrigation system. Lately, it has become important because of the high cost of energy in pressurized irrigation methods and the incorporation of automation in its operation (Holzapfel et al., 2009). Furrow irrigation is accomplished by running water in small channels (furrows) that are constructed with or across the slope a field. Water infiltrates from the bottom and sides of furrows moving laterally and downward to wet the soil and to move soluble salts, fertilizer and herbicides carried with the water. Land smoothing to provide uniform slopes can greatly improve the effectiveness of this method (James, n.d.).

Furrows are small channels, which carry water down the land slope between the crop rows. Water infiltrates into the soil as it moves along the slope. The crop is usually grown on the ridges between the furrows. This method is suitable for all row crops and for crops that

cannot stand in water for long periods (Brouwer et al.,2001). According to Rai et al. (2017) crops that can be Irrigated by furrow are row crops such as maize, sunflower, sugarcane, soybean, Crops that would be damaged by inundation, such as tomatoes, vegetables, potatoes, beans, Fruit trees such as citrus, grape, Broadcast crops (corrugation method) such as wheat.

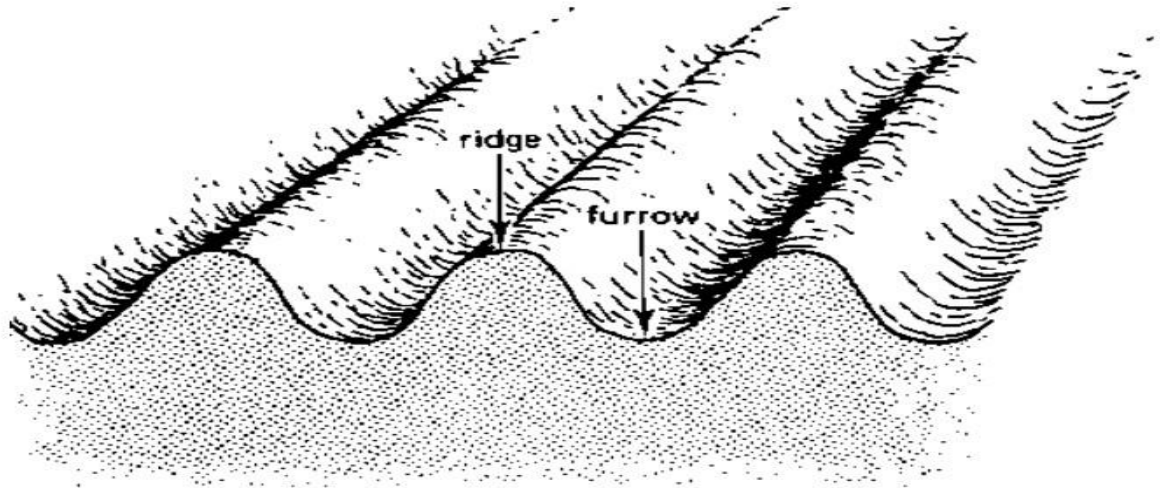


Figure 2. 1:Top view and cross-section of furrows and ridges(Garg, 2009)

### **2.2.1 Furrow size**

It may be more practical to make the furrow length equal to the length of the field, instead of the ideal length, when this would result in a small piece of land left over. Equally the length of field may be much less than the maximum furrow length. This is not usually a problem and furrow lengths are made to fit the field boundaries. The shape of furrows is influenced by the soil type and the stream size. In general, the larger the stream size the larger the furrow must be to contain the flow (Prins et al., 2001)

Table 2. 1: Practical values of maximum furrow lengths (m) depending on slope, soil type, stream size and net irrigation depth (Prins et al., 2001)

Furrow slope (%)	Maximum stream size (l/s) per furrow	Clay		Loam		Sand	
		Net irrigation depth (mm)					
		50	75	50	75	50	75
0.0	3.0	100	150	60	90	30	45
0.1	3.0	120	170	90	125	45	60
0.2	2.5	130	180	110	150	60	95
0.3	2.0	150	200	130	170	75	110
0.5	1.2	150	200	130	170	75	110

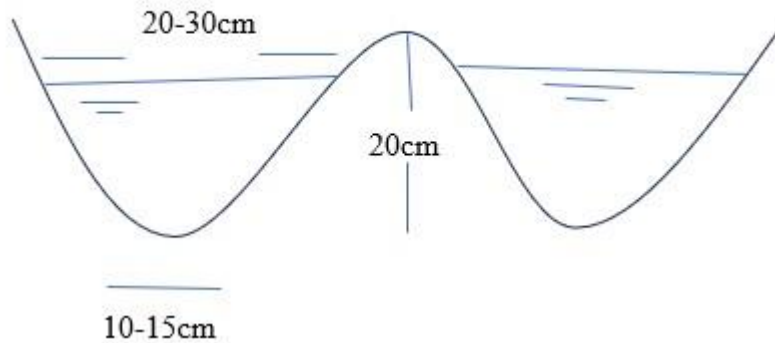


Figure 2. 2: A deep, narrow furrow on a sandy soil

In sandy soils, water moves faster vertically than sideways (= lateral). Narrow, deep V-shaped furrows are desirable to reduce the soil area through which water percolates. However, sandy soils are less stable, and tend to collapse, which may reduce the irrigation efficiency because of canal breach. In clay soils, there is much more lateral movement of water and the infiltration rate is much less than for sandy soils due to soil particles. Thus, a wide, shallow furrow is desirable to obtain a large wetted area to encourage infiltration (Prins et al., 2001).

## **2.3 Determining water supply**

Discharge measurement can be carried out using several methods depending on the size and nature of the stream. The procedure that are commonly used are area – velocity method, the related structure methods (flumes and weirs), and the volumetric method depending on the availability of material, the location of the structure, the size of the structure and availability of man power (MoECCS & RISC, 2018).

### **2.3.1 The area – velocity method**

The area- velocity method, commonly known as current meter method is based on determining the mean discharge using the velocity and cross – sectional area. If the mean streamflow velocity( $V$ ) is normal to the direction of flow, and the cross – sectional area ( $A$ ) of flow is known, then the product of these variables determines the stream discharge ( $Q$ ) (MoECCS & RISC, 2018). In case of open channels Hudson (1993) said it consists of measurements of stream velocity, depth of flow and distance across the channel between observation verticals. The velocity is measured at one or more points in each vertical by current meter and an average velocity determined in each vertical. The discharge is derived from the sum of the product of mean velocity, depth and width between verticals.

A simple way to estimate the velocity is to measure the time taken for a floating material to travel a measured distance downstream. The velocity is not the same at all places in the stream, being slower at the sides and bottom, and faster on the surface. Taking 0.8 of the surface velocity as measured by the float gives an approximate value for the average velocity. Alternatively, the velocity can be measured below the surface by attaching a submerged weight to a float. The float and weight move down the stream together at the velocity of the stream at the depth where the weight is suspended. At about half the stream depth, the velocity is approximately the same as the average velocity for the whole stream. Another method is to pour into the stream a quantity of strongly colored dye, and to measure the time for this to flow a measured distance downstream. The dye should be added quickly with a sharp cutoff, so that it travels downstream in a cloud. The time is measured for the first and last of the dye to reach the downstream measuring point and an average of the two times is used to calculate the average velocity. More accurate

determination of velocity can be obtained by using a current meter. A current meter measures the velocity at a single point, and several measurements are required to calculate the total flow (Hudson, 1993).

### **Advantages of using the area – velocity method**

According to Bengtsson & Enelund (2010) and Chow et al. (1988), The reason why area-velocity method is preferred over other methods:-

#### **1. Non-Intrusive measurement:**

- Unlike some other methods (e.g., weirs, flumes), the area-velocity method does not require physical structures within the flow channel.
- It's a non-intrusive technique that doesn't alter the natural flow conditions. This makes it suitable for environmental monitoring and research.

#### **2. Adaptability to various channel shapes:**

- The area-velocity method works well in irregularly shaped channels (e.g., natural rivers).
- It accommodates variations in channel geometry, including bends, widening, and narrowing.

#### **3. Continuous monitoring:**

- Stream gauging stations use the area-velocity method for continuous flow monitoring.
- It provides real-time data, essential for flood forecasting and water resource management.

#### **4. High flow rates and turbulent flows:**

- In high-flow situations, where direct measurements (using flowmeters) are challenging, the area-velocity method remains effective. It handles turbulent flows and rapid changes in velocity.

#### **5. Field practicability:**

- Hydrologists can collect data using handheld instruments.

- Field measurements are feasible even in remote or difficult-to-access locations.

#### 6. **Cost-effectiveness:**

- Compared to installing and maintaining physical structures (e.g., flumes), the area-velocity method is cost-effective. It relies on readily available tools and expertise.

In summary, the area-velocity method is versatile, adaptable, and widely used for flowrate estimation. Its practicality and ability to handle diverse conditions make it a preferred choice in many scenarios.

### **2.4 Determining water demand**

Crop water requirements (CWR) are defined as the depth of water [mm] needed to meet the water consumed through evapotranspiration (ET<sub>c</sub>) by a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment (Pereira & Alves, 2005).

#### **2.4.1 Evapotranspiration**

The combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to

as evapotranspiration (ET) (Allen et al., 1998). Evapotranspiration includes water evaporation into the atmosphere from the soil surface, evaporation from the capillary fringe of the groundwater table, and evaporation from water bodies on land. Evapotranspiration also includes transpiration, which is the water movement from the soil to the atmosphere via plants (Water science school, 2018).

Evaporation: is the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (vapour removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation (Allen et al., 1998). Evaporation occurs when energy (heat) forces the bonds that hold water molecules together to break. Most of the moisture in the atmosphere (about 90%) came from water evaporating from oceans, seas, lakes, and rivers. (And because over 70% of Earth's surface is covered by oceans, they contribute a lot to the overall volume of

water evaporating into the atmosphere.) The rest of the moisture in the atmosphere came from plant transpiration and (a very small amount) from sublimation (Water science school, 2018).

Transpiration: consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominately lose their water through stomata. These are small openings on the plant leaf through which gases and water vapour pass. Nearly

all water taken up is lost by transpiration and only a tiny fraction is used within the plant (Allen et al., 1998). Transpiration has three main steps Roots uptake water from the soil, Water moves through plant tissues, serving critical metabolic and physiologic functions in the plant, Leaves release water vapor into the air through their stomata (Water science school, 2018)

There are factors affecting evapotranspiration such as Weather which includes radiation, air temperature, humidity and wind speed, Crop Factors like crop type, variety and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions, Management Factors Such as soil salinity, poor land fertility, limited application of fertilizers, the presence of hard or impenetrable soil horizons, the absence of control of diseases and pests and poor soil management may limit the crop development and reduce the evapotranspiration. Other factors to be considered when assessing ET are ground cover, plant density and the soil water content (Allen et al., 1998).

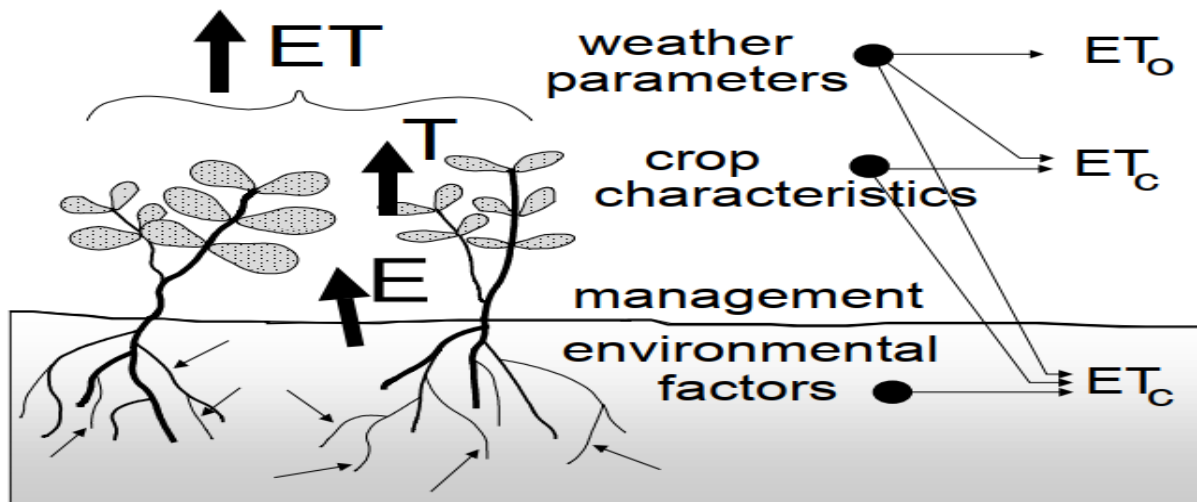


Figure 2. 3: Factors affecting evapotranspiration (Sabzevari & Eslamian, 2023)

#### 2.4.2 Crop evapotranspiration under standard conditions (ET<sub>c</sub>)

The crop evapotranspiration under standard conditions, denoted as ET<sub>c</sub>, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions (Allen et al., 1998). Crop evapotranspiration is highly dynamic through the season. In field crops, for instance, at the beginning of season, most of the Evapotranspiration originates from soil evaporation. Later crop transpiration is the dominant outflow of water. Crop evapotranspiration is highly dynamic through the season. In field crops, for instance, at the beginning of season, most of the Evapotranspiration originates from soil evaporation. Later crop transpiration is the dominant outflow of water (Shilo, 2022).

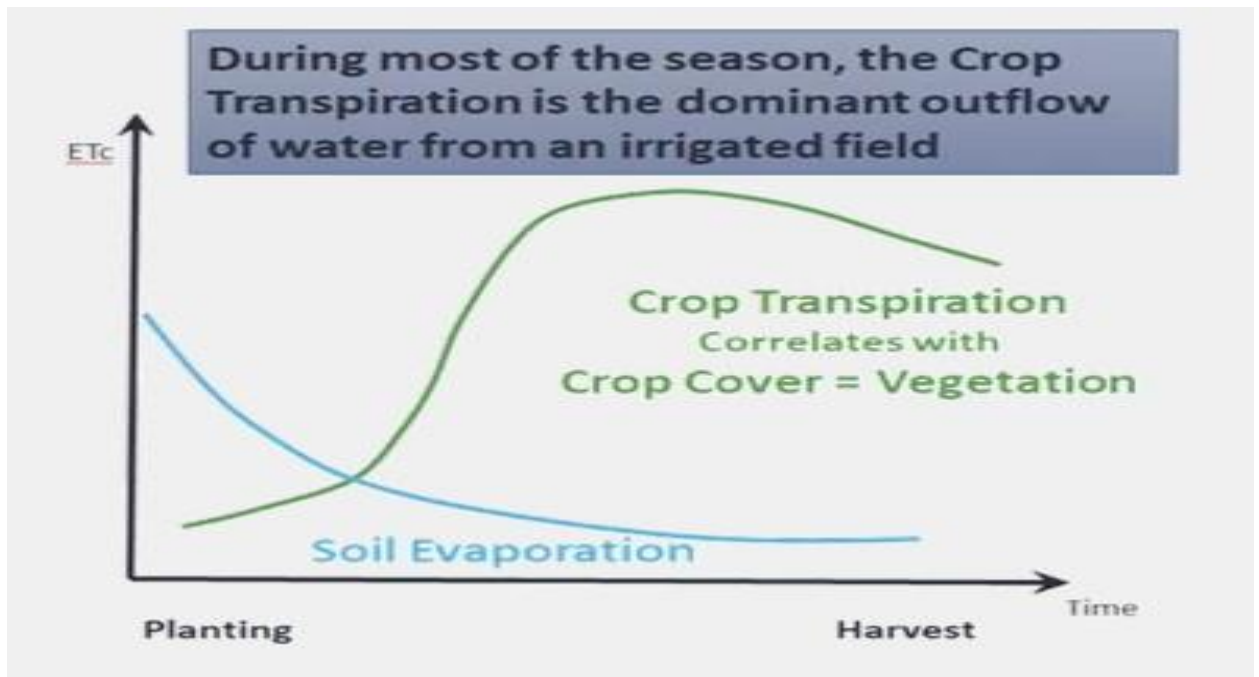


Figure 2. 4: Crop water requirement Vs growth stage ( Shiko,2022)

### 2.4.3 Reference crop evapotranspiration ( $E_{To}$ )

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as  $E_{To}$ . The reference surface is a hypothetical grass reference crop with specific characteristics. The only factors affecting  $E_{To}$  are climatic parameters. Consequently,  $E_{To}$  is a climatic parameter and can be computed from weather data.  $E_{To}$  expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors (Allen et al., 1998). The FAO Penman–Monteith (FAO PM) method has been considered as a universal standard to estimate  $E_{To}$  for more than a decade. This method considers many parameters related to the evapotranspiration process; net radiation ( $R_n$ ), air temperature ( $T$ ), vapor pressure deficit ( $\Delta e$ ), and wind speed ( $U$ ) (Sentelhas et al., 2010).

### 2.4.4 Irrigation water requirement (IWR)

Irrigation water requirement is the net depth of water (mm) that is required to be applied to a crop to fully satisfy its specific crop water requirement. Irrigation requirement is the total

quantity of water applied to the land surface in supplement to the water supplied through rainfall and soil profile to meet the water needs of crops for optimum growth(Garg, 2009).

## **2.5 Irrigation performance indicators**

### **Performance evaluation of irrigation system**

With the many variables that influence performance of irrigated agriculture including infrastructure design, management, climatic condition, price and availability of inputs, and socio-economic settings, the task of comparing performance across system is formidable. However, if we focus on commonalities of irrigated agriculture, water, land, finances and crop production it should be possible to see in a gross sense how irrigated agriculture is performing with in various setting (Molden et al., 1998).

Performance analysis is becoming a key issue in the engineering approach to the control of water supply and distribution systems, both as a natural process of evolution of the modelling and design methods available, and as a consequence of an ever increasing awareness to the quality of the service provided within the water industry today (Carvalho De Matos & Coelho, 1996). Performance is assessed for a variety of reasons: to improve system operations; to assess progress against strategic goals; as an integral part of performance-oriented management, to assess the general health of a system; to assess impacts of interventions; to diagnose constraints; to better understand determinants of performance; and to compare the performance of system with others or with the same system over time. The type of performance measures chosen depends on the purpose of the performance assessment activity (Molden et al., 1998).

Evaluating irrigation system performance requires more than simply monitoring the hydraulic operation of a given system. It requires understanding where irrigation fits in the farm management, water requirements of a crop, soil hydraulic characteristics, field conditions, and economics of the operation (Lord & Ayars, 1983). Evaluating irrigation schemes contributes to the identification of performance gaps and this may lead to implementation of necessary improvements for enhancing agricultural productivity (Hakuzimana & Masasi, 2020).

Monitoring irrigation performance indicators is key in checking general health, comparing the spatial and temporal performances of the scheme, and looking for causes and providing corrective action that aims at improving overall service provision and productivity (Molden et al., 1998).

It is important to ensure that indicators that are selected to quantify the performance for a system describe performance in respect to the objectives established for that system. A meaningful indicator can be used in two distinct ways. It tells a manager what the current performance is of the system and, in conjunction with other indicators, may help him to identify the correct course of action to improve performance within that system (Bos et al., 2005).

The ultimate purpose of performance assessment is to achieve efficient, productive and effective irrigation and drainage systems by providing relevant feedback to management at all levels. As such, it may assist management or policy makers in determining whether performance is satisfactory and, if not, which corrective actions need to be taken in order to remedy the situation (Bos et al., 2005).

### **Internal performance indicators**

These indicators examine the technical or field performance of a project by measuring how close an irrigation event is to an ideal one. The performance of irrigation practice is determined by the efficiency with which the water is conveyed through the canal how irrigation is applied to the field (Kibret et al., 2021b).

Many internal process indicators relate performance to management targets such as timing, duration, and flow rate of water; area irrigated; and cropping patterns. A major purpose of this type of assessment is to assist irrigation managers to improve water delivery service to users. Targets are set relative to objectives of system management, and performance measures tell how well the system is performing relative to these targets (Moges, 2022).

According to Bos et al. (1993), Attributes of performance indicators are of *scientific basis* (Indicator should be based on an empirically quantified, statistically tested causal model of that part of the irrigation process it describes), *quantifiable* (The data needed to quantify the indicator must be available or obtainable (measurable) with available technology),

*referred to a target value*, (relevance and appropriateness of the target values and tolerances can be established for the indicator), *provide information without bias* ( performance indicators should not be formulated from a narrow ethical perspective), *provide information on reversible and manageable processes* (particularly sensible from the irrigation manager's point of view. Some irreversible and unmanageable processes could provide useful indicators, although their predictive meaning may only be indirect), *ease of use and cost-effectiveness* (Performance indicators should be technically feasible, and easily used by agency staff given their level of skill and motivation. Further, the cost of using indicators in terms of finances, equipment, and commitment of human resources, should be well within the agency’s resources).

### 2.5.1 Conveyance efficiency (Ec)

It represents the efficiency of water transport in canals. It mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals (Brouwer et al., 1989). Conveyance efficiency focuses on minimizing losses during water transport from the source (such as reservoirs or canals) to the irrigation site. It considers losses due to seepage, leakage, evaporation, and system inefficiencies. Proper maintenance of conveyance structures, lining canals, and using efficient water conveyance methods (e.g., closed pipes instead of open channels) can significantly improve conveyance efficiency (Jamal, 2017).

Table 2. 2: Indicative values of the conveyance efficiency (Ec) for adequately maintained canals (Brouwer et al., 1989)

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

### 2.5.2 Field application efficiency (Ea)

Represents the efficiency of water application in the field by comparing the amount of water supplied to the field with the amount of water stored in the root zone. It mainly depends on the irrigation method and the level of farmer discipline (Brouwer et al., 1989). It considers losses from deep percolation, runoff, and non-beneficial evaporation. Techniques such as soil moisture monitoring, scheduling irrigation based on crop needs, and employing water-saving practices like mulching can enhance field application efficiency by minimizing water losses and ensuring efficient water uptake by plants (Jamal, 2017).

After the water reaches the field supply Channel, it is important to apply the water as efficiently as possible. A measure of how efficiently this is done is the water application efficiency. Water application efficiency below 100 percent are due to seepage losses from the field distribution channels, deep percolation below the crop root zone and runoff losses from the tail end of borders and furrows (in very long fields). Losses from the field occur as deep percolation beyond the root zone and as field tail water or runoff (Moges, 2022).

Table 2. 3: Indicative values of the field application efficiency (Ea) (Brouwer et al., 1989)

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

As Jamal (2017) said, overall efficiency is the product of field application efficiency and the conveyance efficiency of the distribution system expressed in percentage.

### 2.5.3 Water storage efficiency (Es)

It is the ratio of the quantity of water stored in the root zone during an irrigation event determined by gravimetric moisture content laboratory to water desired in the root zone before irrigation (Kibret et al., 2021b).

Small irrigation may lead to high water application efficiencies, yet the irrigation practice may be poor. The concept of water storage efficiency is useful in evaluating this problem. This concept relates how completely the water needed prior to irrigation has been stored in the root zone during irrigation. Water storage efficiency becomes important when water supplies are limited or when excessive time is required to secure adequate penetration of water in to the soil. Also, when salt problems exist, the water storage efficiency should be kept high to maintain favorable salt balance (Moges, 2022).

The storage efficiency ( $E_s$ ) is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of  $E_s$  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 most directly related to the crop yield since it reflects the degree of soil moisture stress (Moges, 2022).

#### **2.5.4 Irrigation water distribution uniformity (DU)**

When a field with a uniform slope, soil and crop density receives steady flow at its upper end, a water front will advance at a monotonically decreasing rate until it reaches the end of the field. If it is not dyked, runoff will occur for a time before recession starts following shutoff of inflow (FAO, 1989a). How evenly water is applied throughout a field - is important in managing water efficiently. Poor uniformity causes excessive deep percolation, where water percolates below the root zone and is lost to crop use (Hanson et al., n.d.).

As Moges (2022) Said, Distribution Uniformity shows how uniformly water is applied to the field along the irrigation run. In sandy soils there is generally over irrigation at upper reaches of the run when as in clayey soils, there is over- irrigation at the lower reaches of the run. Uniformity is related to crop yields through the agronomic effects of under and over-watering.

Distribution uniformities of less than 70% are poor. DUs of 80 - 85% are good, and Dus greater than 90% are excellent. The most effective way to increase the DU for field lengths of one-quarter mile or more is to reduce both field length and set time by one-half, but not

reduce the furrow flow rate. Keep in mind, reducing the run length and set time can greatly increase the surface runoff and/or ponding at the end of the field (Hanson et al., n.d.).

### **2.5.5 Deep percolation ratio (DPR)**

According to Irmak et al. (2017) Deep percolation (DP) is a crucial variable in the analysis of the hydrologic cycle and water balance. It also plays a significant role when quantifying crop water use (evapotranspiration), irrigation requirements (IR), recharge analyses, and the movement of nutrients and micronutrients within the soil profile and below the crop root zone. Depending on various factors, deep percolation can occur in both irrigated and rainfed agricultural fields. This makes DP an important consideration for researchers and practitioners working in areas such as agricultural water management, soil science, and environmental hydrology.

DPR represents the proportion of water that infiltrates beyond the root zone and percolates deeper into the soil profile. It is a critical factor in evaluating the efficiency of surface irrigation methods. High DPR indicates inefficient water use, as excess water is lost beyond the root zone (Kibret et al., 2021a).

**Factors Influencing DPR:** **Soil Properties:** Soil texture, structure, and hydraulic conductivity affect DPR. Coarse-textured soils (e.g., sandy soils) tend to have higher DPR. **Irrigation Method:** Different methods (furrow, basin, border) exhibit varying DPR levels. Furrow irrigation may result in higher DPR due to concentrated flow. **Slope:** Steeper slopes may lead to higher DPR due to runoff and faster percolation (Kibret et al., 2021a).

**To Management Strategies to Control DPR** **Optimize Irrigation Scheduling:** Apply water when the crop needs it to minimize excess. **Improve Soil Structure:** Enhance infiltration capacity through soil management practices. **Select Appropriate Irrigation Techniques:** Match the method to the crop and soil conditions. **Implement Water-Saving Practices:** Use mulching, cover crops, or soil amendments (Irmak et al., 2017).

### **2.6 Performance gaps in furrow irrigation system**

Irrigation ditches are open channels used to carry irrigation water to or part way to its point of use. Small, inadequate ditches without proper control structures and maintenance

probably cause more trouble in operating a furrow irrigation system than any other factor. In porous soils, unlined ditches lose considerable quantities of water by seepage. This loss frequently accounts for 25 percent or more of the water delivered to the conveyance system (Singh & Su, 2022).

Application efficiency extremely depends on soil type and moderately on furrow length, discharge rate and slope (Mojira, 2022). One common problem in furrow irrigation is the application of too much water, especially during the first irrigation. Furrow irrigation as practiced by farmers in Ethiopia results in large deep percolation losses and uneven water application. These not only result in large losses of limited water but also create problems of waterlogging and salinity (Asres et al., 2022).

As Priyono (2019)said, The inability to guarantee uniform water dispersion across a field, a rise in tail water losses, and an increase in the flow's erosive potential are the overall performance gaps in furrow irrigation systems. It is more challenging to automate, especially when it comes to controlling a uniform discharge in every furrow, Not ideal for sandy soil; difficult to keep water flowing. Determining the number of gates opened or tubes set requires experience and an assessment of the soil surface. If not, surface runoff or delayed water advance may happen, and salts will build up in the soil ridges that run between the furrows. Redistributing the accumulated salinity can be achieved by re-plowing the field for every new crop.

## **2.7 Irrigation water demand and supply**

Todorovic (2004) states that, Crop water requirements and crop evapotranspiration are closely interconnected as they both pertain to the same volume of water. However, there are distinctions between the two concepts. Crop evapotranspiration represents the actual hydrological water losses, whereas crop water requirements indicate the amount of water that needs to be supplied to compensate for these losses, specifically from an irrigation management perspective. This water quantity corresponds to the effective irrigation water supply necessary for achieving maximum yield. Consequently, estimating crop evapotranspiration precedes the estimation of crop water requirements, which typically aggregate crop evapotranspiration values over a specific time period. For management

purposes, crop evapotranspiration must be transformed into crop water requirements to estimate irrigation water needs and effectively manage water supply. Ultimately, crop water requirements are satisfied by the amount of irrigation water effectively supplied in the root zone and by effective precipitation.

In a study conducted by Inamullah et al. (2022), the researchers aimed to evaluate and compare the irrigation water supplies available at the Pabbi minor of the Warsak gravity canal with the actual crop water demand. The findings indicated that the crop water demand exceeded the available water supply at all outlets examined in the study.

The researchers identified two primary factors contributing to this imbalance. First, there was a lack of an adequate amount of water available for irrigation purposes. This scarcity of water resources could be attributed to various reasons such as limited water availability in the canal system or inefficient water management practices. Second, the study highlighted the presence of a large cultivable command area. This implies that there was a substantial area of land designated for cultivation within the study region. With limited water supplies, it became challenging to meet the water requirements of all crops cultivated in the area, resulting in a situation where the crops' demand surpassed the available water supply (Inamullah et al., 2022).

Consequently, due to this imbalance between crop water demand and available water supply, a significant proportion of the land had to be left idle. This means that farmers were unable to cultivate crops in certain areas due to the lack of sufficient water resources to meet the crop water requirements. These findings underscore the importance of addressing water scarcity issues and implementing effective water management strategies in the study region. It suggests the need for measures such as improved water allocation, efficient irrigation techniques, or potential water augmentation methods to ensure a more sustainable and equitable distribution of water resources for agricultural purposes (Inamullah et al., 2022).

Eshetie (2017) found that variations in water supply and irrigation water demand were observed during the investigation period. In March, there was an oversupply of water, which could potentially lead to waterlogging in the command area. Conversely, in April and

May, there was a higher irrigation water demand compared to the available water supply. This increased demand could be attributed to high temperatures and reduced rainfall during these months. As a consequence, a considerable portion of the cultivable area was left fallow. The specific outlets, Sample plot 1 and Sample plot 2, exhibited different characteristics. Sample plot 2 had a larger command area and lower water demand, while Sample plot 1 had a smaller command area and a water supply that exceeded the crop water demand. The limited water supply in relation to the high water-demanding crops and the substantial cultivable areas contributed to the insufficient fulfillment of crop water demands.

## **2.8 Performance evaluation using internal performance indicators**

Irrigation systems are members of a broad category of human systems whose existence and performance are greatly dependent on human behavior. Furthermore, most irrigation systems are characterized by the existence of some central coordinating agency responsible for making and implementing key decisions affecting the acquisition and distribution subsystems. Typically, this agency is a formally-structured organization, although in small irrigation systems the organization may be very informal. The performance of an irrigation system is strongly influenced by the behavior of this coordinating agency (Small & Svendsen, 1990).

The conclusion from Mulugeta. (2024) shows, the assessment of two irrigation schemes revealed significant deficiencies in on-field water management. The results indicated that the applied water was insufficient to meet the soil moisture deficit, highlighting the inadequacy of the irrigation practices. Additionally, the conveyance efficiencies and losses demonstrated unreasonable levels of water loss within the irrigation systems. Consequently, the overall irrigation efficiencies were found to be poor in both schemes.

Several factors contributed to the inefficient and inadequate performance of the irrigation schemes. Firstly, it is evident that the applied irrigation water fell short of the crop water demand, suggesting a lack of awareness among farmers regarding the varying water requirements of different crops. Furthermore, issues such as high sedimentation, illegal water turnout in main and secondary canals, water stagnation, grass cover in canal

waterways, and inadequate size of tertiary canals exacerbated the problems. Moreover, unreasonable losses of water in the conveyance systems were observed (Abo et al., 2024).

Despite these challenges, it is worth noting that the distribution of irrigation water within the fields was relatively uniform in both schemes. This can be attributed to the farmers' use of short-length and closed-end furrows. However, this alone does not compensate for the broader deficiencies in the irrigation practices. In light of these findings, it is crucial to implement measures to address the identified shortcomings. Improving farmers' knowledge and understanding of crop-specific water requirements is essential. Additionally, mitigating issues such as sedimentation, illegal water turnout, water stagnation, and grass cover in canal waterways should be prioritized. Furthermore, optimizing the size of tertiary canals and reducing water losses in conveyance systems can contribute to enhancing overall irrigation efficiencies (Abo et al., 2024).

The study of Kelil (2015), revealed important findings regarding the efficiencies of the irrigation schemes. Conveyance efficiencies were assessed for the main canals, indicating moderate levels of efficiency. Application efficiencies varied across different fields, with downstream irrigators demonstrating higher efficiency compared to middle and upstream irrigators. Water storage efficiencies were found to be inadequate in both schemes, failing to fulfill the soil moisture requirements for optimal crop productivity. The distribution uniformity varied among test plots, indicating non-uniform water application across the fields.

Overall, these findings highlight the need for improvements in irrigation practices. Enhancing conveyance efficiencies, increasing application efficiency through awareness and training programs, and addressing inadequate water storage are crucial steps towards optimizing irrigation schemes. Additionally, improving distribution uniformity can help ensure more consistent water application throughout the fields, avoiding over- or under-irrigation in different areas. By addressing these issues and implementing measures to enhance irrigation efficiencies, it is possible to achieve more sustainable and effective water management in the irrigation schemes (Kelil, 2015).

### 3 MATERIALS AND METHODS

#### 3.1 Description of the Study Area

##### 3.1.1 Location of the study area

The research is conducted on a farm located in Ethiopia, Sidama Region Hawassa Zuria Wereda which is bordered on the south by Shebedino and Boricha, on the west and north by the Oromia Region, and on the east by Wondo Genet. This woreda almost surrounds Lake Awasa on all sides. Another water feature is Lake Chelaka which has vanished into the neighboring wetlands due to deforestation. It is geographically located at an altitude ranging from 1698 to 1724 meters above sea level (m.asl) with latitude  $7^{\circ} 03'47''\text{N}$  to  $7^{\circ} 05'30''\text{N}$  and Longitude  $38^{\circ} 20'04''\text{E}$  to  $38^{\circ} 23'14''\text{E}$ .

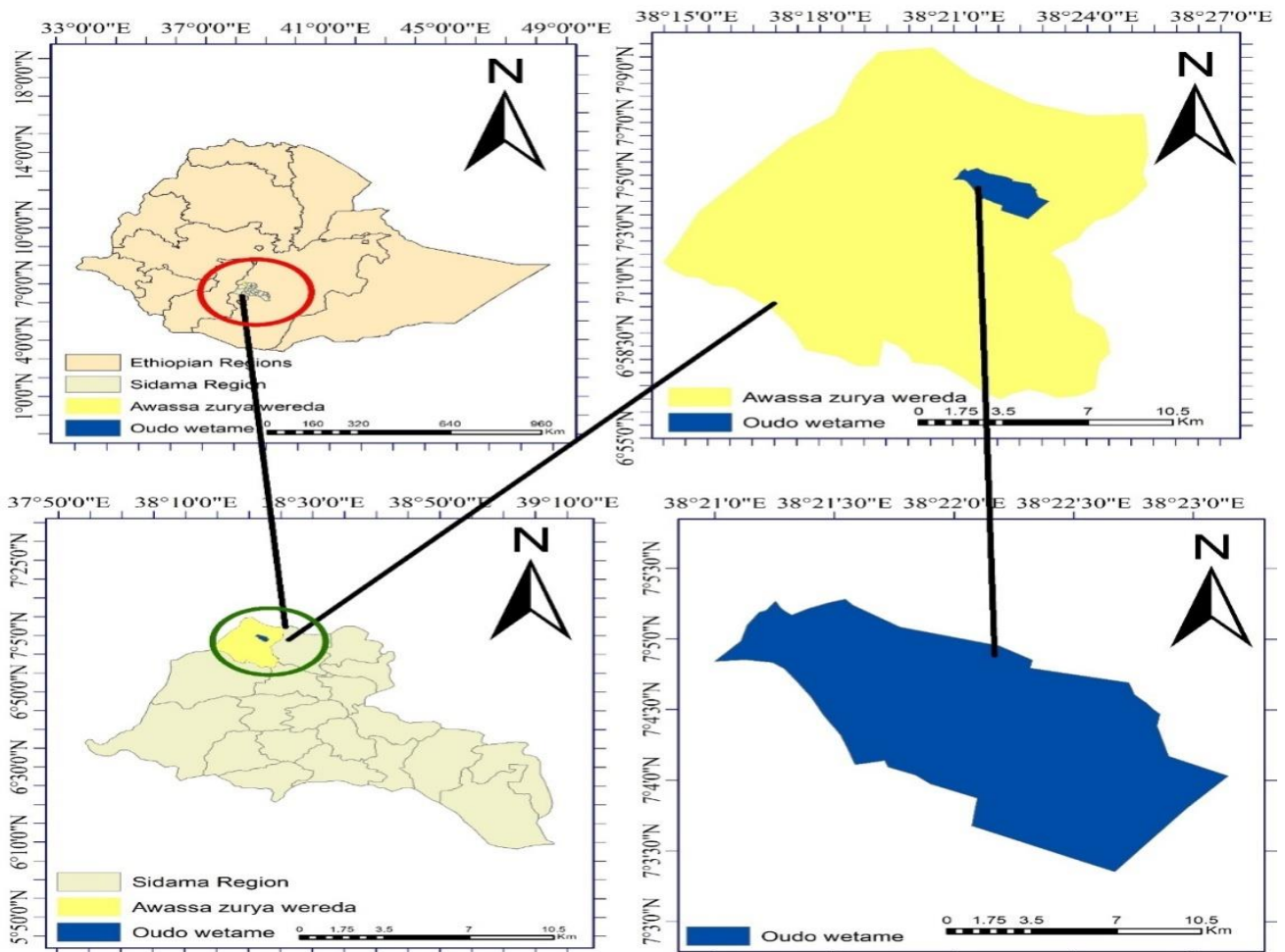


Figure 3. 1: Location map of Udo Wetate small scale irrigation project

### 3.1.2 Climate

**Rainfall:** Rain falls throughout the year in Hawassa Zuria wereda. The area receives a mean annual rainfall of 988.81 mm. The month with the most rain in the wereda is may, with an average rainfall of 129.02 mm and the month with the least rain is December with an average rainfall of 19.29mm.

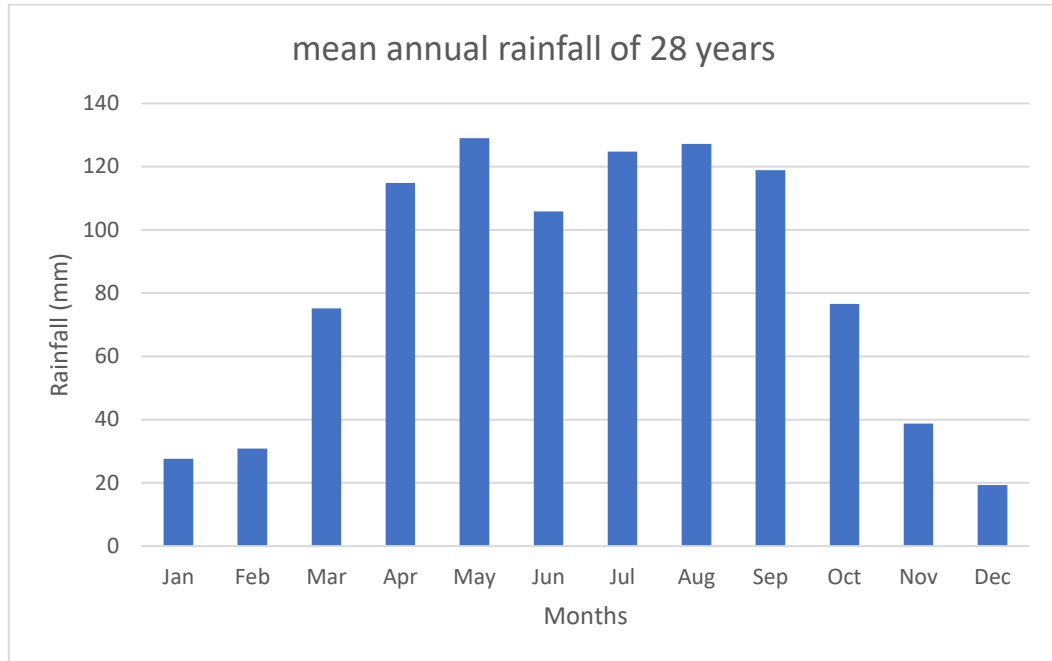


Figure 3. 2: Mean annual rainfall of 28 years (1993 - 2020)

**Humidity:** The average annual relative humidity in Hawassa is 62% while the peak value is 72% in July, August and September and the lowest value is 48% in February.

**Wind speed:** The average wind speed in Hawassa Zuria Wereda experiences mild seasonal variation over the course of the year. The windier month of the year is June with 0.91m/s wind speed and the calmer month of year is October with 0.53m/s wind speed.

**Temperature:** The climate of the area is mainly characterized as kola with the mean minimum temperature of 13.3°C and the mean maximum temperature of 27.6°C.

**Sunshine duration:** The study area enjoys a sunny climate with a mean annual daily value of bright sunshine hours of 7.3, while the mean monthly average sunshine duration varies between 4.7 hours (July) and 9.4 hours (December).

Table 3. 1: Mean monthly climate data of Hawassa Zuria Wereda

Month	Monthly rainfall (mm)	Monthly min. Temperature (°C)	Monthly max. Temperature (°C)	Mean monthly relative humidity %	Wind speed m/s	Sunshine hour Hr
Jan	27.64	11.86	29	51.11	0.72	9.1
Feb	30.89	12.41	30	48.29	0.74	9
Mar	75.16	13.53	30	53.48	0.71	8
Apr	114.88	14.45	28.72	63.02	0.65	7
May	129.02	14.59	27.47	68.48	0.73	7.2
Jun	105.81	14.64	25.91	69.19	0.91	6.4
Jul	124.72	14.66	24.77	71.98	0.81	4.7
Aug	127.19	14.62	25.07	71.98	0.76	5.3
Sep	118.84	14.15	25.84	71.73	0.62	5.7
Oct	76.64	13.15	27.13	64.06	0.53	7.1
Nov	38.71	11.22	28.17	54.85	0.6	8.7
Dec	19.29	10.74	28.23	51.68	0.68	9.4
Ave	<b>988.81</b>	<b>13.33</b>	<b>27.56</b>	<b>61.65</b>	<b>0.7</b>	<b>7.3</b>

### 3.1.3 The main soil type in the study area

According to the design document of the scheme the irrigated area is covered by the soil with the physical characteristics as follows: very porous, sandy-loam, shallow at top and along the slope length of the hills and deep at hill base.

### 3.1.4 Crop type and irrigation method

The crop grown is wheat, it was the first time for the farmers to grow wheat in their land and they use furrow irrigation system which can be used for different kind of crops including wheat.



Figure 3. 3: Furrow irrigation in selected sample plot

### **3.1.5 Water source and command area**

The source of water for the scheme is ground water, a bore hole is selected as a water resource to supply the irrigation demand of the area with estimated discharge of 80l/s. The irrigable area for Udo Wetate was estimated to be 64ha. The sample plots selected for this study was three which are located at the head, middle and tail of the main canal. Sample plot 1 (Sp1) was 2800m<sup>2</sup> with length 280m and width 10m, Sample plot 2 (Sp2) was 2300m<sup>2</sup> with length 280m and width 8.2m, Finally, Sample plot 3 (Sp3) was equal in size with sample plot 1.

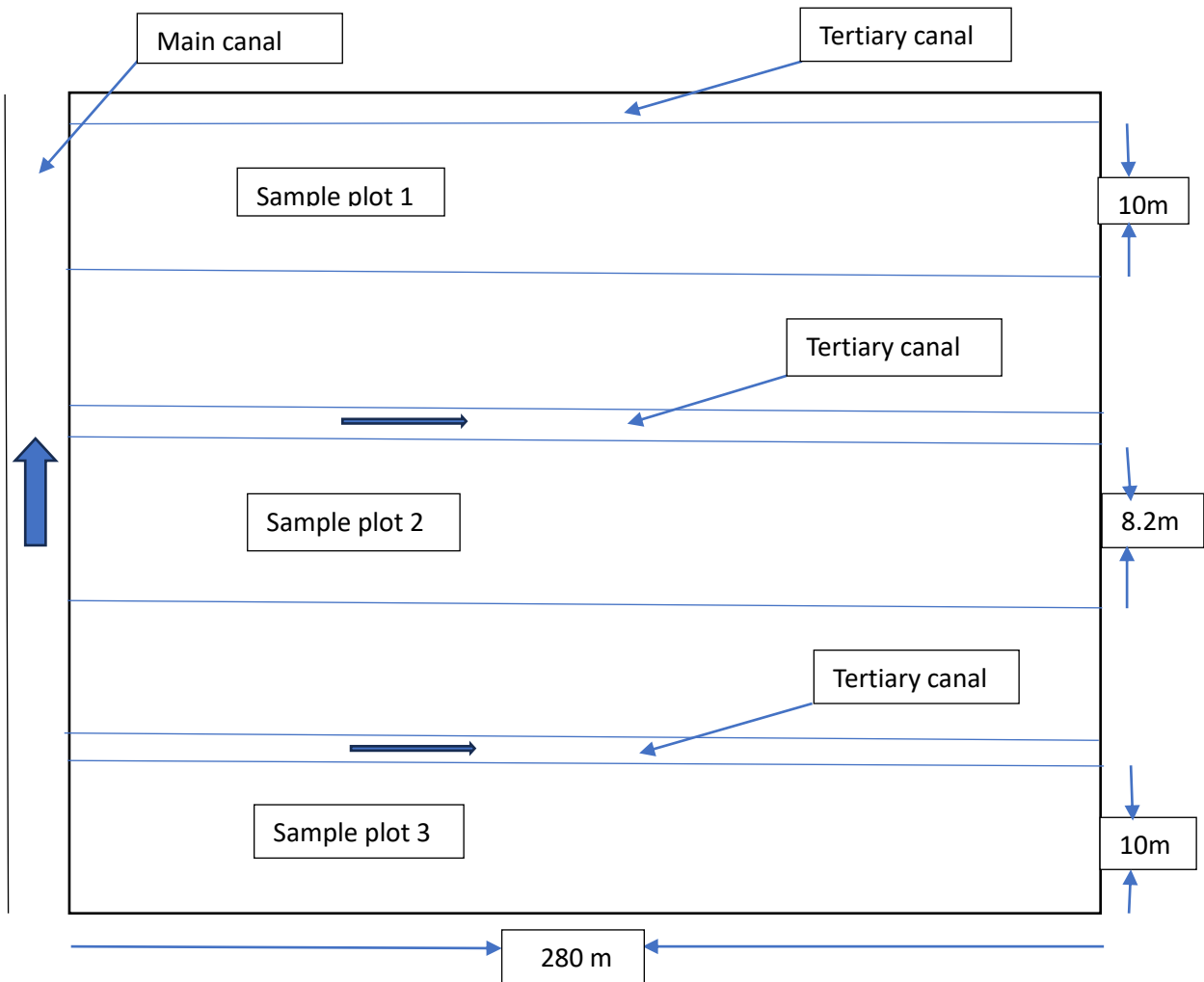


Figure 3. 4: Lay out of command area

### 3.2 Data collection

This research was a case study of the Udo Wetate irrigation scheme, which was designed to irrigate 64ha of land. Data collected included primary and secondary sources, three farmers' fields were selected each from the head, middle and tail water users. This research was carried out starting from February to April; 2023 of the irrigation seasons.

In this study, the required data were collected from primary and secondary sources. The primary data were collected by direct measurement from the field such as discharge, cross section of conveyance structures, and field observation like inspection of functional and nonfunctional structures. Secondary data was collected from different office and design documents.

### **3.2.1 Materials and models used**

- Discharge measurement instrument: Includes floating material, stop watch, stakes, tape measure.
- Measuring tape meter and staff gauge: For measuring the canal cross section and depth respectively.
- Arc GIS: Used for study area mapping, which is typically created when starting a project to ensure that the data is confined to a specified area.
- CROPWAT 8.0: - uses climate, rainfall, soil and crop data for the calculation of crop water requirements and irrigation requirements.

### **3.2.2 Primary data**

The primary data was collected directly from the field. Such activity includes; discharge measurement using velocity area method and field observations. Field investigations were conducted to evaluate the condition and effectiveness of irrigation structures, particularly canals, in terms of their structural stability and ability to manage water flow. Measurements were conducted in each irrigation event which means once in a week for each three sample plots for three consecutive months from February to April to determine the amount of water supplied at canal inlets and outlets, as well as to determine the quantity of water conveyed by the canals. Additionally, regular measurements were taken during each irrigation events to assess the irrigation water applied to the fields. This involved selecting sample plots and measuring the amount of water supplied, as well as the soil moisture content before and after irrigation events. These measurements helped determine the depth of water infiltrated into the soil during irrigation events by monitoring the amount of water stored in the crop root zone in selected furrows. Furthermore, observations were made regarding how farmers control and manage irrigation water during application and irrigation events.

### **3.2.3 Secondary data**

In addition to the primary data, secondary data were collected from different sources. The data collected from the secondary sources include necessary documents, studies, meteorological data and other useful written materials needed for the study. Organizations

contacted during the study period were office of Agriculture, office of Sidama Irrigation development authority and National meteorology agency.

To conduct a thorough study, 28 years climatic data were collected. This data included information on the average monthly temperatures (both minimum and maximum), rainfall levels, sunshine hours, relative humidity, and wind speed. This data was obtained from the National Meteorological Agency based in Hawassa. Additionally, Secondary data were collected from various sources. This data included details on the total command area, irrigable area, irrigated area, and the types of crops grown. This information's, reports, Design documents were obtained from office of Agriculture, office of Sidama Irrigation development authority, Sidama irrigation agency, local agricultural experts, reports, and input from relevant stakeholders.

### 3.3 Data analysis

#### 3.3.1 Estimation of irrigation water requirement

The crop water requirement was computed using CROPWAT and it requires climatic data (like minimum and maximum temperature, wind speed, sunshine hour, humidity and rainfall), soil data, planting and harvesting dates including area of the plot. The reference crops evapotranspiration ( $ET_o$ ) was estimated using the FAO Penman-Monteith method. The FAO Penman-Monteith method is selected as a method by which the evapotranspiration of this reference surface ( $ET_o$ ) can be unambiguously determined, and as a method which provides consistent  $Eto$  values in all regions and climates.(Allen et al., 1998).

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$$ET_o = \frac{0.4087(Rn-G) + \frac{\gamma^{900}}{T+273} U^2 (es-ea)}{\Delta + \gamma(1+0.34U^2)} \dots\dots\dots \text{Equation 3. 1}$$

Where  $ET_o$  reference evapotranspiration [mm day<sup>-1</sup>],

Rn net radiation at the crop surface [MJ m<sup>-2</sup> day<sup>-1</sup>],

G soil heat flux density [MJ m<sup>-2</sup> day<sup>-1</sup>],

T mean daily air temperature at 2 m height [°C],

u2 wind speed at 2 m height [m s<sup>-1</sup>],

es saturation vapour pressure [kPa],

ea actual vapour pressure [kPa],

es-ea saturation vapour pressure deficit [kPa],

Δ slope vapour pressure curve [kPa °C<sup>-1</sup>],

γ psychrometric constant [kPa °C<sup>-1</sup>].

The amount of water required to compensate the evapo-transpiration loss from the cropped field is defined as crop water requirement. Although the values for Crop evapotranspiration under standard conditions (ETc) and crop water requirement are identical,

crop water requirement refers to the amount of water that needs to be supplied, while crop evapo-transpiration refers to the amount of water that is lost through evapotranspiration.

The crop evapotranspiration (ETc) was estimated based on equation:

$$ETc = ETo * Kc \dots\dots\dots \text{Equation 3. 2}$$

Where: ETo is reference evapotranspiration

ETc is crop evapotranspiration

Kc is crop coefficient

The irrigation water demand for each irrigated crop in the command area was computed by subtracting effective rainfall from daily Etc.

$$IWR = ETc - RFeff \dots\dots\dots \text{Equation 3. 3}$$

Where: IWR - Irrigation water requirement

ETc – crop evapotranspiration

$RF_{\text{eff}}$ - Effective rainfall

### 3.3.2 Irrigation water supply measurement

Flow of water to the sample passages of the tertiary canals for the selected 3 farm plots was determined by using floating method. By comparing the actual irrigation water supply and demand, it is possible to identify the extent in which actual supply is in deficit and/or excess over demand. Hence, this technique was applied to compare irrigation water supply with demand on the system. Generally, evaluation of irrigation water supply versus demand is very important to identify whether the actual supply is greater than demand (surplus) or the actual supply is less than demand.

#### Flow measurement

To calculate the total amount of water diverted to the total irrigated areas within a season, the flow velocity measurement was taken at three locations in the main canal (head, middle and end) and at two locations in tertiary canal (head and tail).

Flow of water to the main and sample tertiary canals was determined by velocity area method. The floating method was used for estimating the average flow velocity. The average cross-sectional areas of the test canal were also measured. Both main and tertiary canals were unlined and covered with the same soil type as the farm plot (Sandy loam). The main canal average cross-sectional area was  $0.11 \text{ m}^2$  with top width 60cm and average depth 17cm. For secondary canals, in this study three sample secondary canals were considered and they had cross sectional area of  $0.097$ ,  $0.099$  and  $0.081 \text{ m}^2$  respectively.

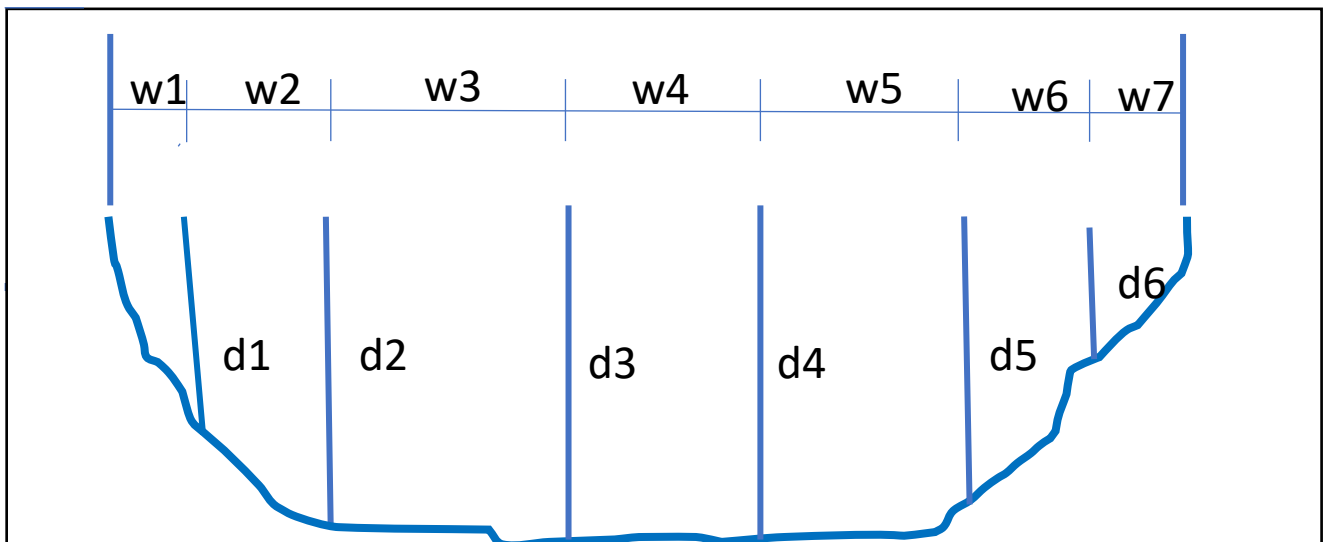


Figure 3. 5: Main canal cross sectional area

The cross-sectional area can be calculated from the profile by using the following formula

$$A_i = \frac{(d_2 - d_1)}{2} * ((w_2 - w_1)^2 + d_1), A = A_i * N \dots\dots\dots \text{Equation 3. 4}$$

Where: A – Cross sectional area (m<sup>2</sup>)

A<sub>i</sub> – Area of a section (m<sup>2</sup>)

d<sub>1</sub> and d<sub>2</sub> – depth of section (m)

w<sub>1</sub> and w<sub>2</sub> – width of section (m)

A simple way to estimate the velocity was to measure the time taken for a floating object to travel a measured distance downstream, here for this paper 5m distance was used. The velocity was not the same at all places in the stream, being slower at the sides and bottom, and faster on the surface. Taking 0.8 of the surface velocity as measured by the float gives an approximate value for the average velocity (Hudson, 1993). In this case a plastic bottle was used as floating material. Materials needed for floating method tape measure, stop watch (phone)

The process taken to measure velocity and discharge

- Choosing a suitable canal section.
- Marking the beginning and end of the distance the floating object will travel.
- Throwing the floating object into the canal upstream of marker place.
- Starting the timer when the object crosses the upstream marker and stop the timer when it crosses the downstream marker.
- Repeating the measurement 3 times then calculate the average time taken.
- Calculating the velocity by dividing the length with the average time taken.

$$V_s = \frac{L}{T} \dots\dots\dots \text{Equation 3. 5}$$

Where V<sub>s</sub> = Surface velocity m/s

L = Distance between two points m

T = Travel time between two points

- Determining the area of the canal cross section by measuring the width and depth of the canal.
- Finally determining the discharge by multiplying the velocity with area.

$$Q = Va * A \dots\dots\dots \text{Equation 3. 6}$$

Where Q = Discharge m<sup>3</sup>/s

Va = Average velocity m/s, Va = 0.8Vs

A = Area of canal m<sup>2</sup>

### 3.3.3 Performance evaluation

Three representative plots were selected located at the head, middle and tail-end parts of the main canal. An irrigation event was monitored to measure soil moisture deficit, stored moisture by the irrigation, inflow rate and depth of application. The areas of the selected fields vary between 2300m<sup>2</sup> and 2800m<sup>2</sup>. According to the design document the average texture of soils of the command area was found as sandy loam. Generally, soils are described as fine textured sandy loam having average bulk density of 1.46gm/cm<sup>3</sup>. The canal water delivery and On-farm irrigation water application were utilized to determine the performance indicators/parameters such as application efficiency, conveyance efficiency, Storage efficiency, Distribution uniformity and overall efficiency of plot during each irrigation event.

#### i. Conveyance efficiency

Water distribution is the central importance of any management of irrigation systems. Conveyance system diverts water from its source, transports and distributes water to the point of use. As water is transported from the diversion site to the irrigation field, some amount of water was lost in different ways such as seepage and evaporation. Efficient irrigation system transports water with minimum losses and hence has high conveyance efficiency.

In order to determine the amount of water lost through conveyance system in the main canal, the amount of flow rate that enters to the main canal and amount of flow rate that leaves the main canal was measured. Water transport efficiency from the source to the field was measured by conveyance efficiency. The conveyance efficiency is used to evaluate the efficiency of the systems to conveying water.

The conveyance efficiency ( $E_c$ ) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals (FAO, 1989b).

$$E_c = \frac{\text{Amount of water reach the field}}{\text{Amount of water diverted from the source}} * 100 \dots\dots\dots \text{Equation 3.}$$

7

**ii. Application efficiency**

The term most often used to define management effectiveness is application efficiency ( $E_a$ ). However, application efficiency is a function of water losses, a high value does not necessarily mean an effective and uniform irrigation. The application efficiency was computed by determining the moisture content before and after irrigation with the water delivered to the plots.

**Bulk density:** The soil bulk density is determined using core samplers of known volume, 27 undisturbed core samples with replicates from representative plots at different soil depths (0-30cm, 30-60cm and 60- 90cm) were collected and analyzed for bulk density in Hawassa university soil laboratory.

**Measurement of the depth of irrigation water stored at effective root zones:** The moisture contents of the soils collected from representative fields at different depths were determined. It helps to know soil moisture deficit before irrigation and the amount of moisture stored in the root zone for the computation of irrigation system performance measures. Soil moisture measurements were conducted for three sample plots. From each of these plots, three representative furrows were selected: one at the beginning of the plot, one in the middle, and one at the end. Within each furrow, three points were chosen: the head, middle, and tail. At each of these points, soil samples were taken at different depths, specifically at 30cm, 60cm, and 90cm. These measurements were taken both before and 24 hours after irrigation, ensuring consistency in location and timing.

About 160 soil samples were collected just 24 hours before and about 24 hours after an irrigation event at three sampling plots located at the head, middle and tail-ends of the scheme. The samples were taken from 9 sample furrows, with 3 furrows located in each of the 3 sample plots. Within each furrow, 3 sample points were chosen at the beginning, middle and tail, resulting in 27 total sample points across the 3 plots. At each of these 27 sample points, soil samples were collected at 3 depths 30 cm, 60 cm, and 90 cm, yielding a total of 81 soil samples per sampling event. This means 162 soil samples were collected in total, with one set taken 24 hours before the irrigation event, and another set taken 24 hours after. All the soil samples were then analyzed in the Hawassa University soil laboratory. This was done by weighing the soil samples before and after drying them in an oven at 105°C for 24 hours with the container lids removed. The difference in weights allowed the water content of the soil to be determined gravimetrically. The water content was determined on weight basis using the following equation: -

$$\theta_w = \frac{W_w - W_d}{W_d} * 100 \dots\dots\dots \text{Equation 3. 8}$$

Where:  $\theta_w$  = Gravimetric soil moisture content [% weight basis]

$W_w$  = Wet weight of the soil [gm]

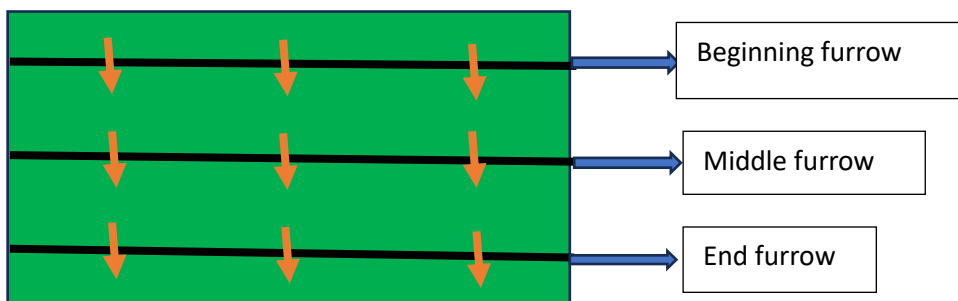
$W_d$  = Dry weight of the soil [gm]

$$\theta_v = \% \theta_w * BD \dots\dots\dots \text{Equation 3. 9}$$

Where:  $\theta_v$  = volumetric soil moisture content [%]

$\% \theta_w$  = Gravimetric soil moisture content [% weight basis]

BD = Bulk density



The diagram shows the layout of the tested points for moisture stored in each selected field. Where:

The field application efficiency (Ea) mainly depends on the irrigation method and the level of farmer discipline (FAO, 1989b).

$$Ea = \frac{\text{Average depth of water stored in the RZ}}{\text{Average depth of water applied to the field}} * 100 \dots \dots \text{Equation 3. 10}$$

**iii. Water storage efficiency (Es)**

To estimate water storage efficiency, the measured values of the depth of irrigation water stored at the effective root zone and the irrigation water needed before irrigation were used. The water storage efficiency was estimated for each selected field at the head, middle and tail-end of each sample plots. Then, water storage efficiency was estimated as the ratio of the depth of irrigation water stored during irrigation to the depth of water needed before irrigation at the effective root zone.

$$Es = \frac{\text{Water stored in the root zone during irrigation}}{\text{Water needed in the root zone prior to irrigation}} * 100 \dots \dots \text{Equation 3. 11}$$

The water needed in the root zone prior to irrigation is RAW in the root zone before irrigation.

➤ **The depth of irrigation water needed before irrigation (RAW)**

The readily available water at the effective root zone was computed from the total available water and depletion levels of each irrigated crop by equation (3.13). But, the total available water at the effective root zone was computed by equation (3.12).

$$TAW = 1000 (FC - PWP) * BD * Dz \dots \dots \dots \text{Equation 3. 12}$$

$$RAW = TAW * P \dots \dots \dots \text{Equation 3. 13}$$

Where; TAW is total available water (mm);

FC is the gravimetric soil moisture content at field capacity (fraction);

PWP is the gravimetric soil moisture content at permanent wilting point (fraction);

Dz is the effective root zone of a crop (m);

BD is bulk density (gm/cm<sup>3</sup>);

RAW is readily available water (mm);

p is water depletion fraction (%)

**iv. Overall efficiency (E)**

Once the conveyance and field application efficiency have been determined, the scheme irrigation efficiency (E) was calculated, using the following formula:

$$E = E_c * E_a \dots\dots\dots \text{Equation 3. 14}$$

Where:  $E_c$  is conveyance Efficiency

$E_a$  is Application Efficiency

**v. Distribution uniformity (DU)**

To estimate the distribution uniformity, the depth of irrigation water stored at the effective root zone at nine test points for each selected field was used. The distribution uniformity also was computed for each selected field at head, middle and tail-end of each sample plots. The distribution uniformity was estimated as the ratio of least quarter mean to total mean of the depth of moisture stored by equation (3.15).

$$DU = \frac{\text{Least quarter mean of stored depth of irrigation water}}{\text{The total mean of the stored depth of irrigation water in all test points}} * 100 \dots\dots\dots$$

Equation 3. 15

**vi. Deep percolation ratio**

Since the furrow had close end runoff ratio was considered zero so the runoff ratio was determined by minimizing the result of application efficiency from one hundred.

$$DPR(\%) = 100 - E_a - RR$$

Where: DPR is Deep percolation ratio

$E_a$  is Application efficiency

RR is Runoff ratio

In general, the following figure shows the conceptual frame work of the study.

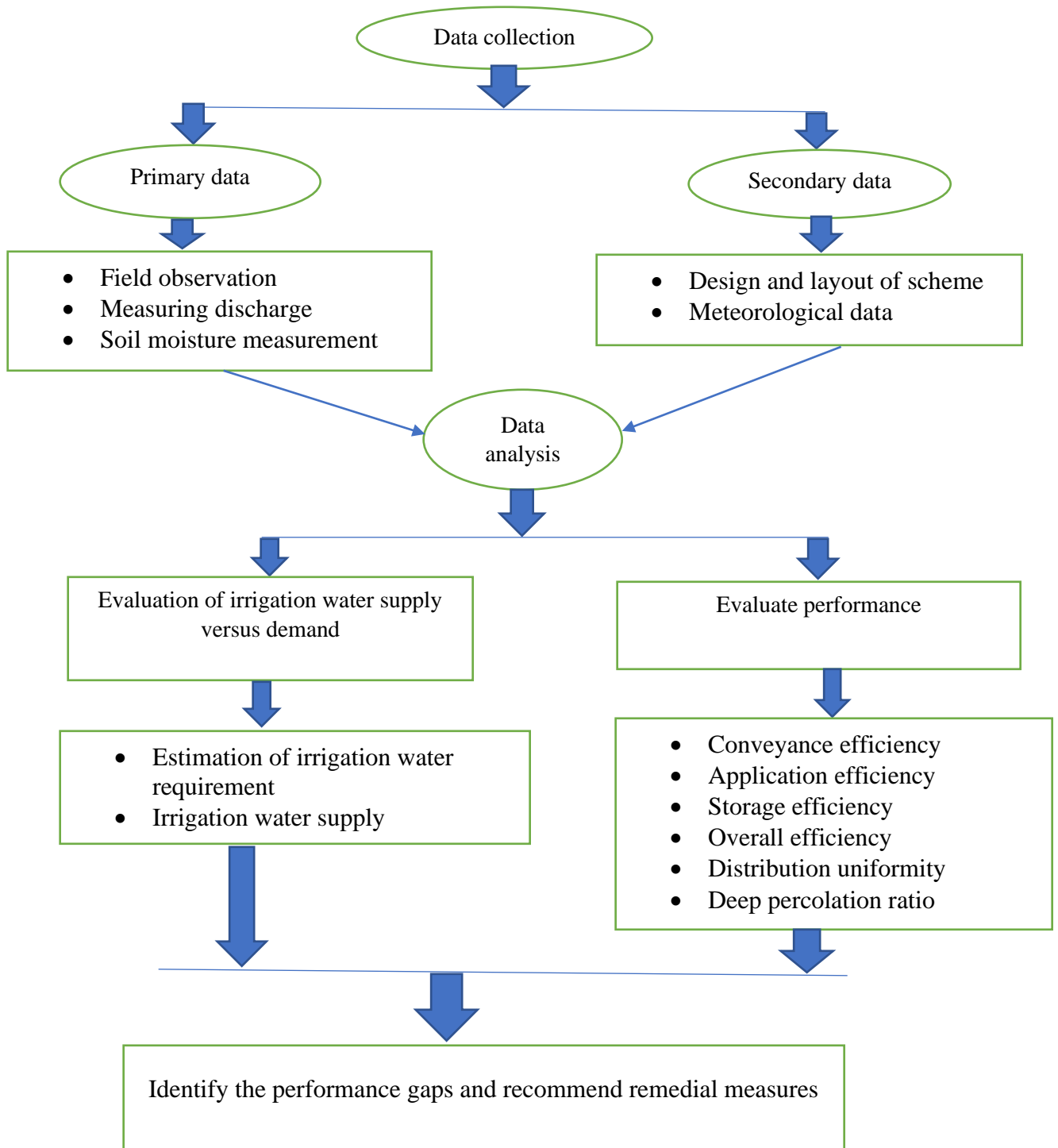


Figure 3. 6: The conceptual frame work of the study

## **4. RESULTS AND DISCUSSIONS**

### **4.1 Comparison of Irrigation water supply and Irrigation water demand**

#### **4.1.1 Irrigation water supply**

The irrigation water supplies in the main canal system were estimated for Over three-month period from February to April 2023. The monthly irrigation water supplies to the system were determined by calculating the average monthly supply for each successive month, as shown in Table 4.1. To gather the data, velocity readings were taken for tertiary canal at three different locations along the main canal head, middle, and tail reaches. These velocity measurements were obtained using the floating method. Based on the velocity data collected at these three tertiary canals, the average monthly irrigation water supply was calculated using equation 3.6. The result showed that the maximum average monthly supply was 0.033 m<sup>3</sup>/s, which occurred in April. In contrast, the minimum average monthly supply was 0.018 m<sup>3</sup>/s, which was observed in March. For month March week 1 and 2 the value of the water supply is zero because water were not supplied during these weeks.

Table 4. 1: Average irrigation water supply of the tertiary canals (m3/s)

Month	Period	Reach		
		TC1	TC2	TC3
February	Week 1	0.029	0.02	0.00
	Week 2	0.031	0.021	0.00
	Week 3	0.033	0.029	0.011
	Week 4	0.034	0.029	0.019
	Average	<b>0.032</b>	<b>0.025</b>	<b>0.007</b>
March	Week 1	0.036	0.030	0.018
	Week 2	0.036	0.034	0.022
	Week 3	0.0	0.0	0.0
	Week 4	0.0	0.0	0.0
	Average	<b>0.018</b>	<b>0.016</b>	<b>0.01</b>
April	Week 1	0.035	0.027	0.021
	Week 2	0.036	0.031	0.024
	Week 3	0.030	0.023	0.019
	Week 4	0.032	0.031	0.018
	Average	<b>0.033</b>	<b>0.028</b>	<b>0.02</b>

#### 4.1.2 Irrigation water demand

##### Rainfall

The minimum and maximum rainfall amount occurs in December (19.29 mm) and May (129.02 mm), respectively. The irrigation scheme has an average total annual rainfall of 988 mm while the total available rainfall of the season (February, March and April) are 30.89

mm, 75.16 mm and 114.9 mm respectively. In this irrigation season the rainfall amount is not sufficient for crop production

### Reference evapotranspiration (ET<sub>o</sub>)

By using CROPWAT software the ET<sub>o</sub> of all months in the study area was ranging from 3.22 to 4.39 mm/day by multiplying with the day in each month ET<sub>o</sub> ranges from 99.82 to 136.09mm/month. Minimum ET<sub>o</sub> value was observed in July and maximum in March as Shown in Appendixes-A (Appendixes Table 1). The effective rainfall value for all months also ranges between 0.05mm/day and 2.55mm/day; the maximum average monthly effective rain fall was observed in May while the minimum was observed in December. The value is shown in Figure 4.1.

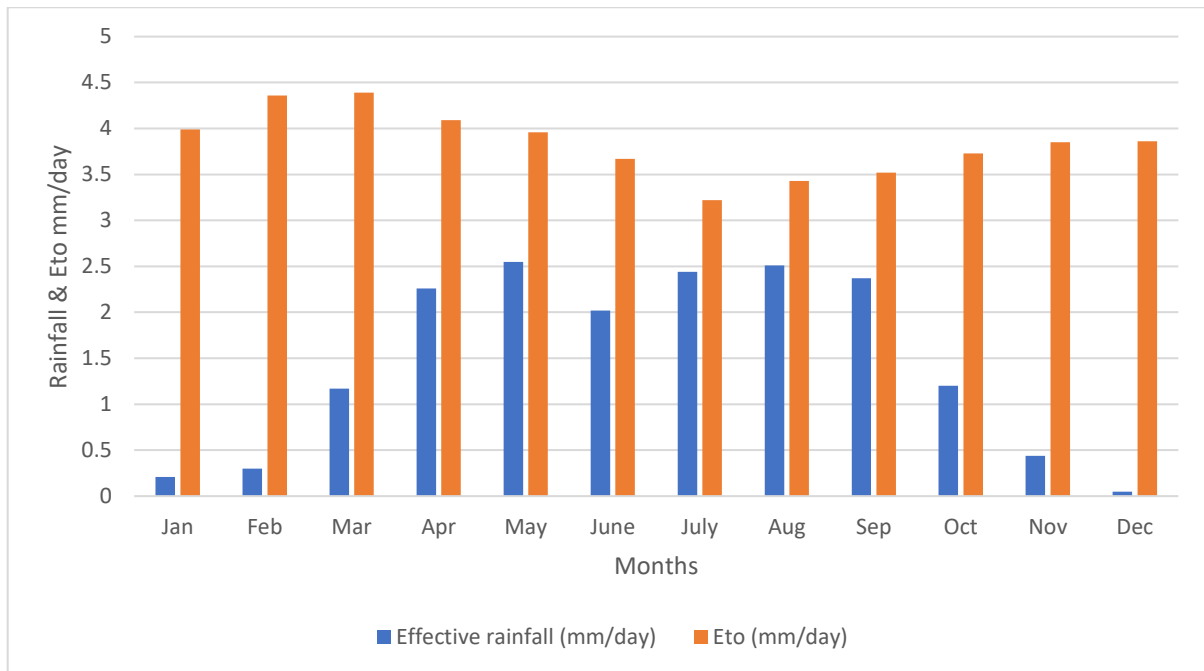


Figure 4. 1: Effective rainfall and referenced evapotranspiration

The values in Figure 4.1, shows that ET<sub>o</sub> was lowest during the rainy season (April, May, July, August and September) and highest during the dry season (December, January and February). The daily evaporating power of the atmosphere at this specific location exceeds the daily effective rainfall amount. As a result, extra water is required to fulfill the evapotranspiration demand.

### **Crop water requirement (CWR)**

The crop water requirement (CWR) of Wheat was estimated for the irrigation season (from February to June, 2023) using CROPWAT 8.0 software program. The planting dates were from February 01/2023 to June 10/2023. The results are summarized below in Table 4.3;

Table 4. 2: Total monthly crop water requirement of wheat that is cultivated in the scheme for the growth period.

Months	CWR (mm) for Wheat
February	36.3
March	91.8
April	137.9
May	114.3
June	15.9

The crops were planted and harvested over a 5-month period from February 1st to June 10th. During this full growing cycle, the average monthly crop water requirement (CWR) in millimeters, as shown in Table 4.2, fluctuated significantly. The CWR was much higher during the peak growing months of March through May, ranging from 91.8 mm to 137.9 mm. This reflects the increased water needs of the crops as they reached their maximum vegetative growth and development stages, requiring more irrigation to meet the higher evaporative demand during the drier season. In contrast, the CWR was relatively lower in the early part of the season in February (36.3 mm) and towards the end in June (15.9 mm), as the crops required less water during the wetter conditions. This variability in CWR across the complete 5-month planting and harvesting period highlights how the irrigation water needs of the crops change dynamically based on the stage of growth and prevailing environmental conditions.

#### **4.1.3 Irrigation water requirement (IWR)**

The effective rainfall is derived from observed rainfall. Therefore, irrigation water requirement was calculated from the difference between the total water requirement and

effective rainfall. Irrigation water requirement (IWR) on the system was estimated by using CROPWAT model and it was maximum in April and minimum in June (table4.3).

Table 4. 3: Monthly irrigation water requirement (mm)

Months	IWR (mm) for Wheat
February	27.7
March	55.6
April	70
May	35.2
June	0

Table 4. 4: Monthly irrigation water requirement at each sample plot (m<sup>3</sup>)

Month	IWR (m <sup>3</sup> )				
	Sample plot 1 (Head)	Sample plot 2 (Middle)	Sample plot 3 (Tail)	Total	Average
February	77.56	63.71	77.56	218.83	72.94
March	155.68	127.88	155.68	439.24	146.41
April	196.0	161.0	196.0	553	184.33
May	98.56	80.96	98.56	78.08	92.69
June	0	0	0	0	0
Total	527.24	433.55	527.24		

As shown in Table 4.4, the average irrigation water requirement (IWR) across the entire growing season ranged from 0 to 184.33 m<sup>3</sup>. The IWR was highest during the months of March and April, while it was lowest in February and May. In fact, there was no recorded

need for irrigation in June, which can be attributed to the lower evapotranspiration rates and more advanced crop growth stages during this wetter time of year.

From the sample plots, the highest irrigation water requirement was observed in sample plot 1 and 3, which was found to be 527.24m<sup>3</sup> and the lowest demand was observed sample plot 2, which was found to be 433.55m<sup>3</sup> (Table 4.4). It was because of sample plot 2 had a small command area compared to sample plot 1 and 3.

At sample plot 1, the lowest irrigation requirement was observed in the month of February (77.56 m<sup>3</sup>) and the highest was in the month of April (196m<sup>3</sup>). Similarly, at sample plot 2, the lowest irrigation requirement was observed in the month of February, which

was found to be 63.71m<sup>3</sup> and the highest was in the month of April, which was 161m<sup>3</sup> (Table 4.4). This variability in water requirements, even within a single plot, underscores the importance of scientific irrigation planning. The fluctuations are driven by changes in atmospheric evaporative demand as well as the differing water needs at each stage of crop development. Carefully matching water supply to these dynamic crop water demands is crucial for efficient irrigation management across the system.

#### **4.1.4 Evaluation of irrigation water supply versus requirement**

The comparison of irrigation water supply and irrigation water demand in the scheme has been considered only for three months from February to April; the situation is either deficit in demand or excess of supply. The comparisons of irrigation water supply and irrigation water demand have been shown below in graph (Fig. 4.2).

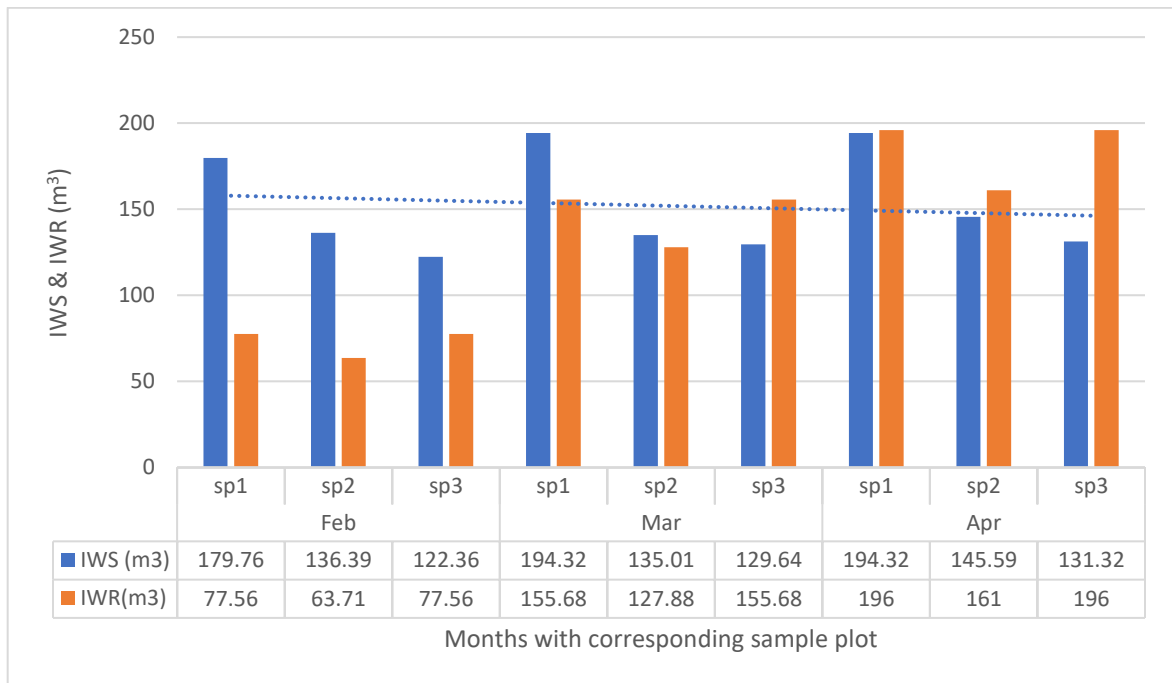


Figure 4. 2: Irrigation water supply and irrigation water demand

The percentage of excess and deficit of irrigation water supplied is shown below in graph (Fig 4.3).

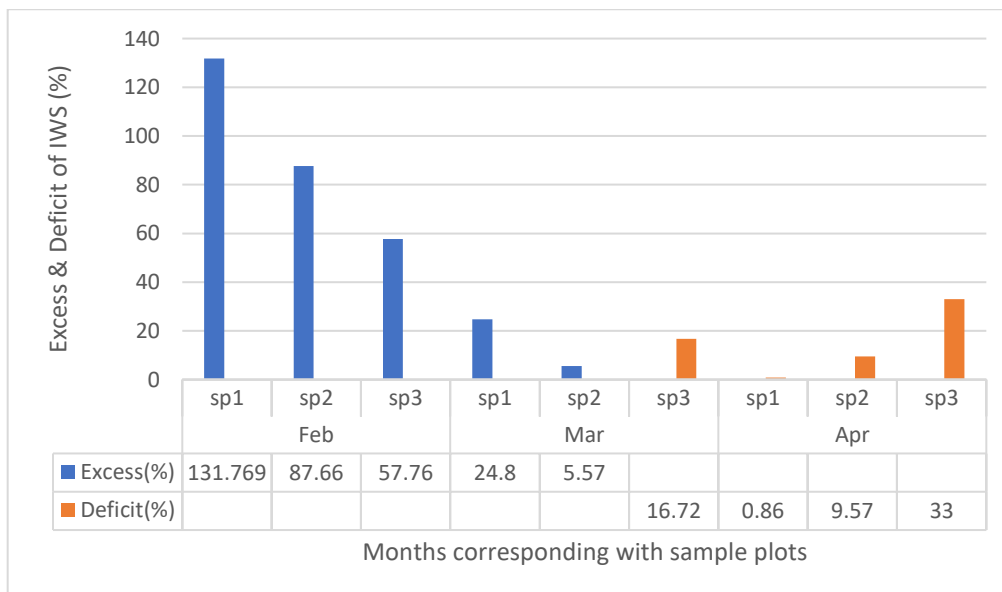


Figure 4. 3: The percentage of excess and deficit of IWS

From the results presented in Figure 4.2, in February the actual irrigation water supply to all sample plots was in excess of the requirements. In this month, supply in first sample plot (sp1) was  $179.76\text{m}^3$  and demand was  $77.56\text{m}^3$ . Thus, at sample plot 1 actual supply was exceeded the crop water demand by 56.88% (Figure 4.3). The supplied water was high because the command area was near the head of the main canal which minimizes the loss of water through the length and the required was low due to the crop growth stage is at initial. The supply in sample plot 2 (sp2) was  $136.39\text{m}^3$ , but demand was  $63.71\text{m}^3$ . Hence at sample plot 2, the actual supply was exceeded the crop water demand by 53.29%. Here the plot was at the middle of the main canal which means there was some loss through the length and for the requirement still the crop is at its initial stage since all the sample plots have same planting date. Similarly, the actual supply exceeded the crop water demand by 36.6% at sample plot 3 with amount of irrigation water supply  $122.36\text{m}^3$  and amount of irrigation water requirement  $77.56\text{m}^3$ . This sample plot is at the tail of the main canal with high water loss and mainly it was not receiving water for two weeks as shown Appendix C Appendix table 12 and for irrigation water requirement it is the same with sample plot one because they have the same size. This oversupply could result water loss to deep percolation and excess could also damage the crop through groundwater table rise and waterlogging.

March was a month in which in two of the sample plots the irrigation water supply exceeds the requirement and on the other hand in one of the sample plot the irrigation water requirement exceeds the supply. Irrigation water supply at the first sample plot was  $194.3\text{m}^3$ , but the requirement was  $155.7\text{m}^3$  (Figure 4.2). Thus, at this outlet (sp1) irrigation water supply was exceeding the requirement by 19.86% (Figure 4.3). This result is less compared to February due to the growth stage of the crop is at development and climatic conditions which increases the water demand as for the supply it is the same amount of water supplied from the source for all growth period the only difference is due to the plastic membrane lined on the main canal. Likewise, the irrigation water supply was exceeding the requirement by 5.57% at sp2, Finally, for sp3 the reverse is true which means the irrigation water requirement exceeds the actual supply by 16.72%, here the relative location of the plot from the source have great impact on the amount of water delivered.

In April all demands exceeded supply at all sample plots. Irrigation water requirement at the first sample plot (sp1) was  $196\text{m}^3$ , but the actual supply was  $194.32\text{m}^3$  (Figure 4.2). Thus, at this plot (sp1) crop water requirement was almost equal to the actual supply by exceeding only 0.86% (Figure 4.3). Likewise, the crop water demand was exceeding the actual supply by 9.57% and 33% at sp2 and sp3 respectively. The demand always increases in accordance with the crop growth stage and the climatic condition on the other hand the supply was insufficient because the time and amount of application was always the same throughout the study period. This shows that a shortage of water is advanced in this plot and such an undersupply could result the crop to suffer from water stress. Water shortages resulted from inadequate regulation and losses through deep percolation and low conveyance efficiency.

The scheme has maximum requirement in the month of April with 0.27 l/s/h and minimum in the month of June with value of 0 while its average value is 0.13 l/s/ha (figure 4.4). This is by considering the climate condition, the effective rain fall, the soil type, the crop type and its growth stage.

Results achieved from this research study differ from the results achieved during similar research study by (Inamullah et al., 2022). Both this research and the research by (Inamullah et al., 2022), investigated the relationship between irrigation water supply and demand. On this study the findings revealed variations in supply and demand across different months, (Inamullah et al., 2022) reported a consistent deficit in water supply compared to the demand throughout their research period. This variation can be attributed to factors such as high temperatures, low rainfall, high water-demanding crops, and large farm land. Additionally, they highlighted the issue of farmers leaving significant portions of the culturable area fallow due to the water deficit and emphasized the potential impact of government-sanctioned water supply on the actual supply.

The results achieved from this study are more or less similar to the findings of (Eshetie, 2017) study. Eshetie's study found an oversupply of water in March but deficits in April and May, potentially due to weather conditions. The findings highlight the challenges faced by farmers in meeting crop water demands, particularly for high water demanding crops and

larger cultivable areas. It underscores the importance of matching water supply with crop water requirements to optimize irrigation practices and avoid water related issues.

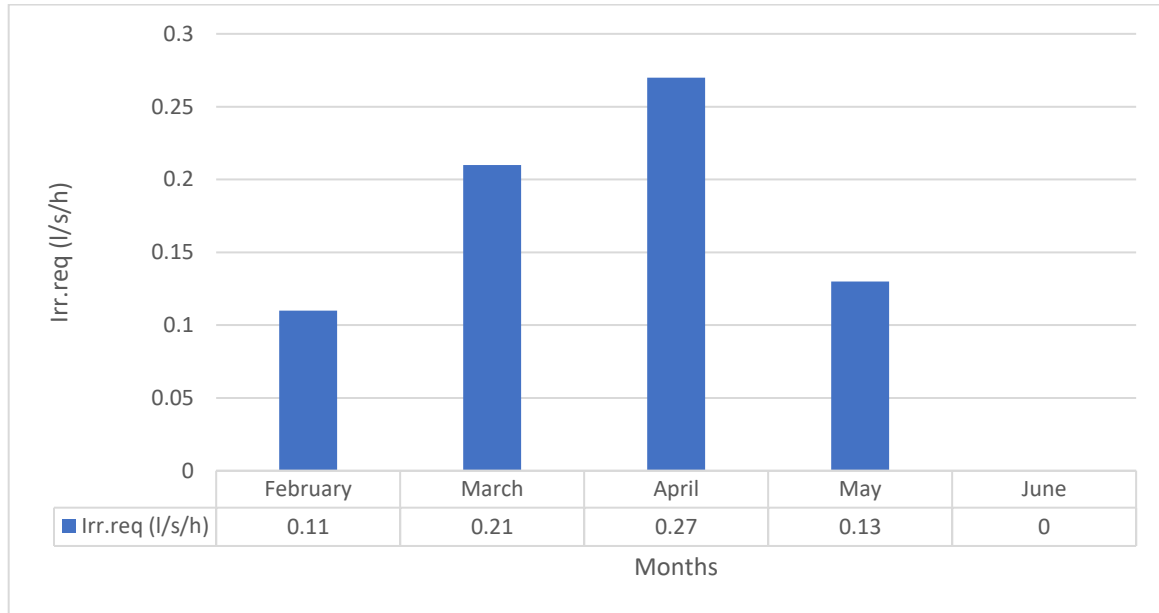


Figure 4. 4: Net irrigation requirement of the scheme (l/s/h)

## 4.2 Internal Performance

### 4.2.1 Main canal conveyance efficiency

The result obtained shows a wide range of variation. The conveyance efficiency values indicate that the amount of water lost during transportation of water starting from the source to the field canal. The conveyance efficiencies of the main canal were calculated using equation 3.7 and found to be 45.3%. The details of conveyance efficiency for the canal are shown below in table 4.5. This value is below the range of what is recommended in literature for specified soil types.(FAO, 1989c), stated that for sandy soil it is possible to have conveyance efficiency up to 70% for length between 200– 2000m.

Table 4. 5 Main canal conveyance efficiency

Month	Period	Discharge (m <sup>3</sup> )		Conveyance
		Head	Tail	Efficiency (%)
February	Week 1	0.029	0.00	0
	Week 2	0.031	0.00	0
	Week 3	0.033	0.011	33
	Week 4	0.034	0.019	55
	<b>Average</b>	<b>0.032</b>	<b>0.007</b>	<b>21</b>
March	Week 1	0.036	0.018	50
	Week 2	0.036	0.022	61
	Week 3	0.0	0.0	-
	Week 4	0.0	0.0	-
	<b>Average</b>	<b>0.018</b>	<b>0.01</b>	<b>55</b>
April	Week 1	0.035	0.021	60
	Week 2	0.036	0.024	66
	Week 3	0.030	0.019	63
	Week 4	0.032	0.018	56
	<b>Average</b>	<b>0.033</b>	<b>0.02</b>	<b>60</b>
<b>Mean</b>				<b>45.3</b>

The main canal's conveyance efficiency is significantly impacted by various factors. While the use of a plastic membrane lining from March onwards helps reduce seepage losses, the unlined period in the initial months remains susceptible. Additionally, the lining was not completely impermeable it allows some seepage. Generally, seepage, evaporation,

sedimentation, and breaches occurring during water flow are probable factors contributing to the observed low conveyance efficiency of the main canal.



Figure 4. 5: Main canal before it is covered with plastic membrane



Figure 4. 6: Main canal after it is covered with plastic membrane

The adverse effects of sediment accumulation on the canal performance were clear, leading to water overtopping and breaching of the canal. The sediment deposits reduced the canals capacity of providing smooth flow of water and causing interruption in its operation.



Figure4. 7: Sediment accumulation in main canal

#### **4.2.2 Tertiary canal conveyance efficiency**

Conveyance efficiency of tertiary canals was estimated in three selected canals for selected plots. The conveyance efficiency was found to be 61.5% (table 4.6). In Tertiary canal 1 since the canal is unlined the conveyance efficiency was low in February and relatively increases in March and more in April, these is due to the very low moisture content of the soil at the beginning of the irrigation season and then it starts to increase when the soil moisture that carries the water content starts to increase. The same reason goes for the rest of the tertiary canals. The result also shows efficiency difference between the canals because Tertiary canal 1 was more affected by canal breach at the beginning of the irrigation season.

Generally, the average conveyance efficiency is 53.4% was below the range of what is recommended in (FAO, 1989c) for specified soil types. The results achieved from this study is similar with the result of (Abo et al., 2024) and (Kelil, 2015). Authors reported that the cause for such inefficiency evaporation losses, malfunctioning of control gates, high sedimentation, illegal water turnouts in main and secondary canals, water stagnation, grass covers of the canals waterway, and canal size widening, Spillage and Seepage losses, Unauthorized diversion of water in the system and Overtopping.

Table 4. 6: Tertiary canal conveyance efficiency

Month	Secondary canal no	Mean flow velocity (m/s)	Cross section area (m <sup>2</sup> )	Release discharge (m <sup>3</sup> /s)	Available discharge at reach (m <sup>3</sup> /s)	Conveyance Efficiency (%)
February	1	0.26	0.097	0.025	0.012	48
	2	0.20	0.099	0.019	0.010	52
	3	0.21	0.081	0.017	0.009	52
March	1	0.28	0.097	0.027	0.015	55
	2	0.25	0.099	0.025	0.016	64
	3	0.22	0.081	0.018	0.011	55
April	1	0.28	0.097	0.027	0.021	78
	2	0.26	0.099	0.026	0.021	80
	3	0.25	0.081	0.02	0.014	70
<b>Mean</b>						<b>61.5</b>

#### 4.2.3 Field application efficiency

The field application efficiency of the three sample plots was estimated by the measured application depth and soil moisture content. The applied irrigation water amount stored in the crop root zone of selected sample furrows was measured by determining the moisture content of the soil before and after irrigation as shown in Appendix C Appendix table 13.

The overall mean application efficiency was computed using equation 3.10 and was estimated to be 60.2% for which it varies in between 31.1 % to 86.4 % (table 4.7). The result varies between irrigation event and replications. These variations were possibly caused by variations in inflow rate and cut-off times (generally called decision variables)

and field parameters mainly soil infiltration characteristics. The application efficiency also depends on the experience of the farmer since it is their first time irrigating their land.

Organization (FAO, 1989c) Reported that the attainable application efficiency for sandy soil is 60%, lower values would normally be considered unacceptable. The values obtained in this study is equal to the literature recommended value of surface irrigation.

Overall, the application efficiency of the irrigation scheme was considered good according to the FAO. However, there was noticeable differences between the plots. For example, in one plot in February, the efficiency was really low because no water was applied for two weeks. This highlights the importance of consistently applying water at the right times to make sure the system works well.

Table 4. 7: Field application efficiency of the scheme

Period	Sample plot	Depth of water stored in the root zone (mm)	Depth of water applied to the field (mm)	Application efficiency (%)
February	1	31.4	64.2	48.9
	2	32.0	59.3	53.9
	3	13.6	43.7	31.1
Mar	1	38.6	69.4	55.6
	2	38.0	58.7	64.7
	3	40.0	46.3	86.4
April	1	40.0	69.4	57.6
	2	45.7	63.3	72.2
	3	33.4	46.9	71.2
Mean				<b>60.2</b>

Generally the results found in this study is in agreement with the study of (Abo et al., 2024) which was 55.9% in Bilate irrigation scheme and 58% in Furfuro irrigation scheme.

He concluded the average field application efficiencies obtained in his study were within the recommended standard. Similarly, the results reported for field application efficiencies by(Dessalew et al., 2016), were also in agreement with these recommended standards. According to(Dessalew et al., 2016), the field application efficiency of the Bedene Alemtena irrigation project was reported to be 54.9%. These results indicate the importance of implementing measures to enhance on-field water management and day-to-day operations. It highlights the need for improvements in order to optimize water usage and improve the overall performance of the irrigation system.



Figure 4. 8: Irrigation water application at the beginning of the season



Figure 4. 9: Irrigation water application at development stage

#### 4.2.4 Water storage efficiency

The water storage efficiency was calculated using equation 3.11 from soil moisture stored and readily available water that was needed before irrigation at the effective root zone. The measured result for soil moisture stored in the root zone of a plant for each selected sample plots is indicated in Appendix -C, Appendix table 13. While readily available water for the crop is indicated in Appendix -C, Appendix table 15. The result obtained in this study for water storage efficiencies was indicated in table 4.8 below.

Table 4. 8: Water Storage Efficiency of the Scheme

Sample plot	Storage Efficiency Es (%)			
	February	March	April	Average
1	48.8	60.03	62.2	57.0
2	43.6	51.8	62.3	52.6
3	20.11	59.2	49.4	42.9
Average	37.5	57.01	58.0	<b>50.8</b>

The result obtained for water storage efficiencies of the selected fields sample plot 1, sample plot 2 and sample plot 3 were 57.0%, 52.6%, and 42.9% respectively with an average value of 50.8%. (Raghuwanshi & Wallender, 1998) recommended that the water storage efficiency for furrow irrigation systems is 63% which shows there is plenty room for improvement. This result is found due to water management problem, Insufficient water application, Lack of awareness of Crop water requirements, Improper furrow design and soil type.

The result of this study, as well as the study conducted by (Abo et al., 2024) in the Bilate irrigation scheme, was found to be the same. Based on the results presented by (Abo et al., 2024), the water storage efficiencies of the selected fields in the Bilate irrigation scheme were found to be 39.4% at the head, 41.1% at the middle, and 78.1% at the tail end, with an average value of 53.0%. In contrast. These results indicate that the water storage efficiencies obtained were very poor. This suggests that the applied irrigation water may not

have adequately satisfied the soil moisture deficit in this scheme, leading to soil moisture stress and insufficient application of irrigation water. The study suggests several potential reasons for these poor efficiencies, including the applied irrigation water being below the intended water demand prior to irrigation, farmers using fast application rates of irrigation water that exceed soil infiltration rates, and a lack of awareness among farmers regarding the varying water requirements of different crops.

In (Kelil, 2015) study also the irrigation system falls short in meeting the soil moisture requirements for optimal crop productivity. The storage efficiency of the left scheme ranges from 56.03% to 83.47%, with a mean value of 71.13%. On the other hand, the storage efficiency of the right scheme has a mean value of 76.73%, with minimum and maximum values of 57.26% and 96.81%, respectively. The recommended storage efficiency is 87.5%.

#### **4.2.5 Distribution uniformity (DU)**

To get how evenly an irrigation system distributes water over the field, determination of uniformity an irrigation water application provides a vital clue. Distribution uniformity (DU) is the most commonly used uniformity index in surface irrigation application. The distribution uniformity was calculated from soil moisture stored at the effective root zone at about nine test points in each sample plots. The results of the measured values of soil moisture stored at these points were found by computing the ratio of least quarter mean of stored depth of irrigation water to the total mean of the stored depth irrigation water in all test points as indicated in equation 3.15. The value of distribution uniformity is listed below in table 4.9.

The distribution uniformity values ( $\leq 60\%$ ) implied that the field irrigation water is unevenly distributed, while distribution uniformity values ( $\geq 60\%$ ) indicated that the field irrigation water is evenly distributed throughout the irrigated area (Burt et al., 1997). Therefore, the distribution uniformities of this scheme were good but also the result indicates that some areas of the test plot receive more water than other areas. This may result in over irrigating the crop in one portion of the field and under irrigation in the remaining portion.

(Abo et al., 2024), yielded similar results with this study. (Abo et al., 2024) reported average distribution uniformities of 86.9% for the Bilate scheme and 87.7% for the Furfuro scheme, indicating a high level of even water distribution throughout the irrigated areas. Both this study and his study attained similar levels of distribution uniformity in their measurements.

The distribution uniformity findings from this study were found to be relatively similar to those of the study conducted by (Kelil, 2015). In Kelil's research, distribution uniformity values of 72.71%, 77.35% and 75.53% of head, middle and tail test plot, respectively was found on the left scheme while that of right scheme was found to be 88.8%, 87.78% and 90.87% of head, middle and tail test plot respectively. These consistent outcomes indicate that both studies achieved uniform water distribution within their respective test plots. It is worth noting that non-uniform water depths were observed, implying the presence of variations in water distribution. These variations could potentially be attributed to factors such as field topography, irrigation techniques, or soil properties.

Table 4. 9: Distribution efficiency of the scheme

Location	Moisture stored in each point (mm)		
	Minimum depth (mm)	Average depth (mm)	DU (%)
Sample plot 1	31.46	36.7	85.7
Sample plot 2	32.0	38.6	82.9
Sample plot 3	21.6	29.0	74.5
Average			<b>81.0</b>

#### 4.2.6 Deep percolation ratio (DPR)

Deep percolation is an important factor to consider in irrigation systems, as it represents the amount of water that percolates past the root zone and is essentially lost from the perspective of plant uptake. The deep percolation ratio is a metric used to quantify this loss, expressing the proportion of applied irrigation water that ends up percolating deeply rather than being utilized by the crop. Determining the deep percolation ratio is crucial for

evaluating the overall efficiency and performance of an irrigation system. Deep percolation ratio was calculated by minimizing application efficiency from 100 percent.

Table 4. 10: Deep percolation ratio of the scheme

Period	Sample plot	Application efficiency (%)	DPR (%)
February	1	48.9	51.1
	2	53.9	46.1
	3	31.1	68.9
Mar	1	55.6	44.4
	2	64.7	35.3
	3	86.4	13.6
April	1	57.6	42.4
	2	72.2	27.8
	3	71.2	28.8
Mean		<b>60.2</b>	<b>39.8</b>

#### 4.2.7 Overall scheme efficiency

The overall scheme efficiency was determined from the result of main and secondary canals conveyance efficiency and field application efficiency. In other words, it is the product of conveyance efficiency and Application efficiency. In the present study the overall efficiencies Udo Wetate irrigation scheme is 32.14%.

A scheme irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme Irrigation efficiency of 20-30% is poor (FAO, 1989c), according to this literature the schemes efficiency is between reasonable and poor.

Generally, the inefficiency of the Udo Wetate irrigation scheme was due to several key problems. Conveyance losses were a primary issue, as seepage, evaporation, sedimentation, and breaches occurring during water transport through the main and secondary canals resulted in low conveyance efficiency. Uneven water distribution between individual plots also stalled effective field-level application. Additionally, storage efficiency was low, impacted by factors such as improper water management practices, insufficient water application, lack of knowledge about crop water requirements, as well as unsuitability of the furrow design and soil types in the scheme. While the distribution uniformity across the irrigation area was relatively good, the cumulative effect of these conveyance, application, and storage issues resulted in an overall poor performance of the Udo Wetate irrigation system.

#### **4.3 Major challenges that affect the performance of the scheme**

1. Insufficient irrigation water supply: the amount of water available for irrigation purposes is not adequate to meet the needs of the crop or plant being cultivated.
2. Mismatch between irrigation water supply and demand: During some months there were an oversupply of water available for irrigation purposes. However, in some months, there were deficit in the water supply compared to the actual crop water requirements. This seasonal imbalance between the availability of irrigation water and the demand from crops creates significant challenges for effective agricultural water management.
3. Uneven distribution of irrigation water: caused by inequitable allocation and delivery of available water supplies across areas requiring irrigation resulting in some regions receiving more water than needed while others face scarcity.
4. Failing to involve irrigation specialists in a project that lead to improper design and implementation of irrigation systems, resulting in inefficient water distribution and management.
5. Farmers low knowledge and experience about irrigation and its potential benefits reduce their initiative to participate in an irrigation project.

## 5 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

Evaluation of farm irrigation system plays a fundamental role in improving surface irrigation and to advice irrigators how to improve their system operation. This study was initiated with the purpose of evaluating the performance of Udo Wetate irrigation scheme by comparing irrigation water supply and demand as well as by using internal performance indicators such as application efficiency, conveyance efficiency, storage efficiency, distribution uniformity and overall scheme efficiency as a tool to recommend appropriate measures to improve the scheme.

According to the result of the study, irrigation water supplied to the sample plot was maximum in April, and minimum in February. However, irrigation water demand was maximum in March and minimum in February. During the evaluation period, the highest amount of irrigation water supply was observed at the head reach of the main canal, and the lowest supply was recorded at the tail reach. Irrigation water demand was very high in April and very low in June and the month February have been getting the discharges in excess of the requirement, whereas April was all in deficit of the requirement.

The main canal was covered with sedimentation load and it was breached by water at different places along its length. However, there is no maintenance system to overcome the problem. The scheme management was led by water government officials and daily workers only there was no involvement of farmers. As a result, the conveyance efficiency (main and secondary) was low and about 46.6% of the diverted amount of water was unproductive which means the conveyance efficiency is 53.4%.

The field water application of furrow system was evaluated. On-field mean application efficiency of the scheme was 60.5%. This result is acceptable but clearly shows it can be further improved.

Analysis of the continuous soil moisture records indicates that amount of water stored in the root zone varies with the location of the farm plots. Farm plots at the canal head, which have good access to water, were mostly irrigated up to the soil saturation level and their moisture level hardly drops below the permanent wilting point. For farm plots which

are located far from the canal head, the soil moisture content drops below the permanent wilting point for a number of consecutive days due to limited access to irrigation water. There was no appropriate water allocation system in the scheme that would ensure equity across the reaches.

The average water storage efficiency of the irrigation scheme across the three sample plots was found to be 50.8%, which is significantly lower than the recommended 63% efficiency for furrow irrigation systems. This indicates substantial room for improvement in the water management practices within this irrigation scheme, likely due to factors such as water management problems, insufficient water application, lack of awareness of crop water needs, improper furrow design, and soil type limitations.

The overall scheme efficiency of the Udo Wetate irrigation scheme was determined to be 32.14%, which is calculated as the product of the conveyance efficiency and application efficiency. According to the FAO guidelines, a scheme irrigation efficiency of 50-60% is considered good, 40% is reasonable, while 20-30% is poor. Since the Udo Wetate irrigation scheme efficiency of 32.14% falls within the "reasonable" category based on the FAO benchmarks, this indicates that there is significant room for improvement in the overall performance and efficiency of this irrigation system. The overall efficiency suggests issues with water conveyance and field application that need to be addressed.

The calculated distribution uniformity (DU) values for the irrigation system were found to be 81.0%, the distribution uniformities of this scheme were good but also the result indicates that some areas of the test plot receive more water than other areas. This may result in over irrigating the crop in one portion of the field and under irrigation in the remaining portion.

Generally, poor performance of the irrigation system was due to the following factors such as no support from skilled professional, not gaining the farmers trust and support, unreliable water deliveries, poorly control and distribution system, unplanned irrigation water application, lack of supportive training on irrigation water application and management, inadequate maintenance, malfunction of the pump, sediment accumulation,

improper operation of water delivery system, and non-availability of flow control structures.

## **5.2 Recommendations**

Based on the results of the study, the following recommendations are put forward to improve the performance of the scheme.

1. Installing proper flow control structures to enable equitable water distribution using Stell sheet or any local material that can be used as gate for flow control.
2. Implement a structured water allocation and scheduling system that ensures fair and reliable water deliveries to all reaches of the scheme, especially the tail-end areas currently experiencing water deficits.
3. Provide comprehensive training and engagement programs for the farmers to build their capacity in efficient irrigation water management practices.
4. The legal water user's association should be established
5. The Wereda experts, Development Agents, and Water Users Association should collaboratively plan and manage seasonal water demand, durations, and scheduling ensuring the irrigated area aligns with capacity.

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## 7 Appendix

### Appendix -A: Climatic, precipitation, soil and crop data results of the study area

Table 1: Monthly average reference evapotranspiration data of the scheme

Monthly ETo Penman-Monteith							
Country - Ethiopia				Station - Hawassa			
Altitude – 1694m		Latitude – 7.06 <sup>0</sup> N			Longitude – 38.48 <sup>0</sup> E		
Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (Km/day)	Sun (hours)	Rad MJ/m2/day	Eto Mm/day
January	11.8	29.0	51	62	9.1	21.4	3.99
February	12.4	30.2	48	64	9.0	22.4	4.36
March	13.5	30.1	53	61	8.0	21.8	4.39
April	14.4	28.7	63	56	7.0	20.2	4.09
May	14.5	27.4	68	63	7.2	19.9	3.96
June	14.6	25.9	69	79	6.4	18.3	3.67
July	14.6	24.7	71	70	4.7	16.0	3.22
August	14.6	25.1	71	66	5.3	17.3	3.43
September	14.1	25.8	71	54	5.7	18.1	3.52
October	13.1	27.1	64	46	7.1	19.7	3.73
November	11.2	28.1	54	52	8.7	20.9	3.85
December	10.7	28.3	51	59	9.4	21.3	3.86
<b>Average</b>	<b>13.3</b>	<b>27.5</b>	<b>61</b>	<b>61</b>	<b>7.3</b>	<b>19.8</b>	<b>3.84</b>

Table 2: Average monthly effective rainfall of the scheme

Monthly rain-fall		
Station - Hawassa		Eff.rain method-FAO/AGLW formula
Month	Rain (mm)	Eff rain (mm)
January	27.6	6.6
February	30.9	8.5
March	75.2	36.2
April	114.9	67.9
May	129.0	79.2
June	105.8	60.6
July	124.7	75.8
August	127.2	77.8
September	118.8	71.0
October	76.6	37.3
November	38.7	13.2
December	19.3	1.6
<b>Total</b>	<b>988.7</b>	<b>535.7</b>

Table 3: crop data

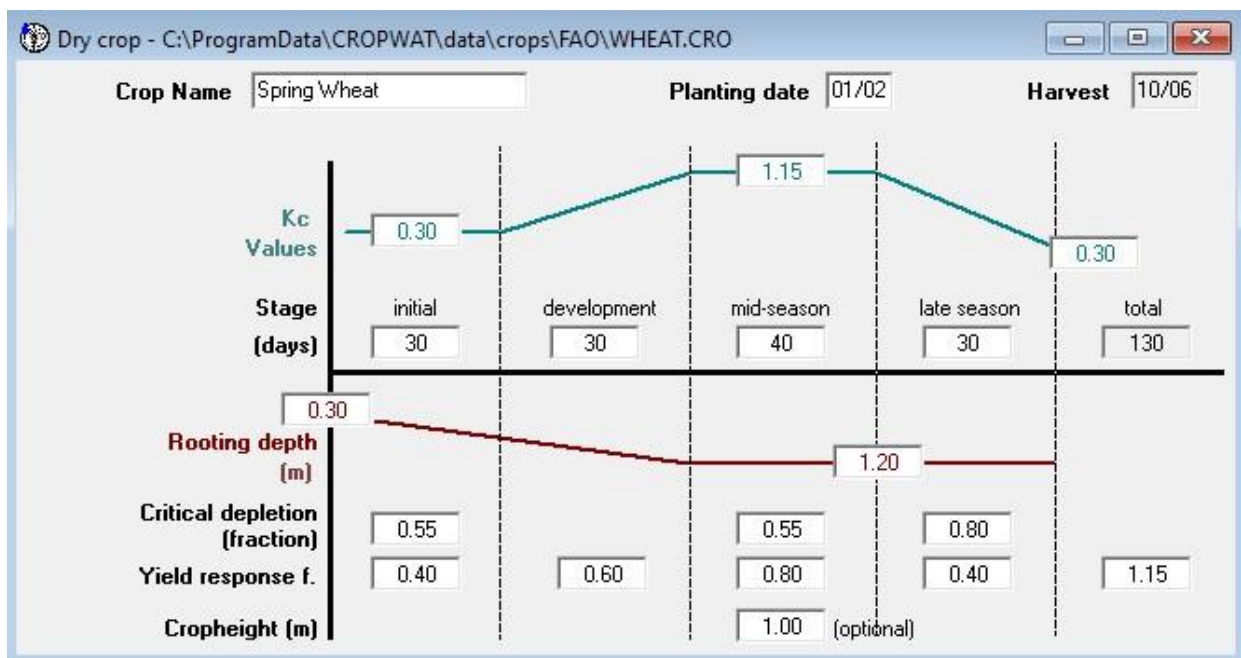


Table 4: soil data of the scheme

Soil	
Soil name (sandy loam)	
Total available soil moisture (FC - WP)	60.0 mm/meter
Maximum rain infiltration rate	40 mm/day
Maximum rooting depth	900 centimeters
Initial soil moisture depletion (as % TAM)	0 %
Initial available soil moisture	60.0 mm/meter

Table 5: Crop water requirement of Wheat

Crop Water Requirement							
ETo Station - Hawasssa				Crop - Wheat			
Rain station - Hawasssa				Planting date – 01/02			
Month	Decade	Stage	Kc	ETc (mm/day)	ETc (mm/dec)	Eff. Rain (mm/dec)	Irr. Req (mm/dec)
Feb	1	Init	0.30	1.27	12.7	1.8	10.9
Feb	2	Init	0.30	1.31	13.1	1.6	11.4
Feb	3	Init	0.30	1.31	10.5	5.1	5.4
Mar	1	Deve	0.40	1.74	17.4	8.9	8.6
Mar	2	Deve	0.67	2.93	29.3	11.9	17.4
Mar	3	Deve	0.95	4.10	45.1	15.5	29.6
Apr	1	Mid	1.12	4.69	46.9	19.7	27.1
Apr	2	Mid	1.12	4.57	45.7	23.6	22.2
Apr	3	Mid	1.12	4.53	45.3	24.5	20.7
May	1	Late	1.12	4.48	44.8	26.1	18.7
May	2	Late	1.00	3.94	39.4	27.8	11.6
May	3	Late	0.71	2.74	30.1	25.3	4.9
Jun	1	Late	0.42	1.59	15.9	21.2	0.0
					<b>396.3</b>	<b>213.1</b>	<b>188.5</b>

Table 6: Irrigation water requirement of the scheme

Scheme supply												
ETo station - Hawasssa						Rain station - Hawasssa						
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipit. deficit												
Net scheme irr. req												
In mm/day	0.0	1.0	1.8	2.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
In mm/ month	0.0	27.7	55.6	70.0	35.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
In l/s/h	0.0	0.11	0.21	0.27	0.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Irrigated area (% total area)	0.0	100	100	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Irr req. for actual area (l/s/h)	0.0	0.11	0.21	0.27	0.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0

**Appendix -B: Input climatic data's for CROPWAT8.0**

Table 7: Monthly average minimum temperature <sup>0</sup>c (data from 1993-2020)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1993	12.1	12.3	9.6	14.1	14.1	14.2	14.3	13.7	12.8	12.8	9.3	9.1
1994	9.7	11.6	13.0	13.8	14.3	14.5	14.2	14.7	14.0	10.1	10.0	8.9
1995	9.5	12.7	13.7	14.9	13.1	13.6	14.2	14.5	13.0	12.3	8.4	10.6
1996	12.2	10.5	13.0	14.0	14.1	14.3	14.5	14.4	13.6	10.9	8.8	9.6
1997	12.4	10.0	13.3	13.9	13.1	13.6	14.1	14.2	13.2	13.6	13.8	11.3
1998	13.3	14.3	14.0	14.4	15.7	14.7	15.7	15.9	14.5	14.4	8.9	8.1
1999	10.2	9.9	13.8	12.5	13.6	14.0	14.3	13.7	13.8	14.0	9.3	9.3
2000	9.6	10.6	11.1	14.1	14.0	13.7	14.3	14.0	13.4	14.0	10.5	9.7
2001	11.6	11.1	14.0	14.4	14.2	14.6	14.8	15.0	13.1	13.7	10.3	10.9
2002	12.4	11.8	14.0	13.5	14.8	14.5	14.3	14.2	13.4	12.8	9.8	13.2
2003	11.8	11.6	13.2	14.3	14.2	14.3	14.6	14.7	14.0	11.9	11.2	10.4
2004	12.9	11.6	12.2	14.7	13.2	13.9	14.0	14.3	13.6	11.5	11.6	11.4
2005	11.3	11.4	13.8	14.0	15.0	14.6	14.2	14.7	14.4	13.1	9.5	7.8
2006	11.8	12.4	13.8	14.6	13.9	14.3	15.0	14.7	14.5	14.2	11.4	12.4
2007	12.7	12.9	12.4	14.2	14.8	15.0	14.8	14.6	14.3	11.1	10.9	9.0
2008	10.5	11.7	11.4	14.1	14.6	14.4	14.9	14.5	14.2	13.0	11.1	10.3
2009	11.8	12.4	12.9	14.3	14.4	13.9	14.2	14.7	14.8	13.2	10.7	13.6
2010	13.0	15.3	14.7	15.6	16.3	15.1	15.2	15.3	14.4	13.5	11.1	10.9
2011	12.6	11.8	13.4	14.3	15.1	15.3	14.7	14.9	14.7	12.3	13.0	10.0
2012	10.2	11.7	13.5	15.1	14.4	15.1	15.3	15.0	14.4	12.2	12.3	11.3

2013	12.2	12.2	15.6	15.1	15.1	15.4	15.1	14.9	14.2	13.5	12.0	9.4
2014	12.2	13.5	13.4	13.1	14.1	14.0	15.3	14.9	14.7	14.2	12.3	10.7
2015	11.2	13.0	14.5	14.8	15.4	15.8	14.8	15.3	15.3	14.7	13.9	13.5
2016	15.3	14.7	15.4	16.7	16.1	14.7	15.8	15.4	15.3	14.9	12.1	11.2
2017	9.7	14.5	14.5	14.8	15.8	15.5	16.0	15.5	15.6	15.1	11.7	9.4
2018	11.3	13.3	13.9	15.6	15.6	15.4	15.0	11.3	13.3	13.9	15.6	15.6
2019	15.4	15.0	15.2	14.5	13.9	16.2	11.6	15.1	14.9	13.3	13.3	12.6
2020	13.1	13.7	15.6	15.3	15.5	15.3	15.2	15.4	15.0	13.9	11.4	10.4

Table 8: Monthly average maximum temperature °c (data from 1993-2020)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1993	27.7	26.9	30.6	27.8	26.9	24.9	24.4	24.9	25.8	26.9	29.0	29.9
1994	30.5	31.6	30.8	29.5	26.7	24.7	23.5	24.5	26.2	28.3	28.3	29.3
1995	30.4	30.7	29.9	27.3	28.0	27.0	24.3	24.5	25.9	27.6	29.3	29.2
1996	28.2	30.8	29.5	27.6	26.7	23.8	23.8	24.3	25.0	27.1	28.1	28.6
1997	28.9	30.3	30.8	26.9	27.5	25.7	23.8	25.5	26.8	26.5	26.5	27.3
1998	27.5	28.9	29.0	29.7	27.3	26.3	24.3	24.0	25.4	25.4	27.5	28.1
1999	29.1	31.4	28.1	29.4	27.2	26.1	23.6	25.0	25.6	24.8	27.2	28.0
2000	29.5	30.7	31.8	28.9	26.1	25.7	24.9	24.8	25.1	25.8	27.2	28.1
2001	28.6	30.2	28.3	28.4	26.8	24.8	24.4	24.5	25.9	26.7	28.2	28.9
2002	28.2	30.9	28.8	28.6	27.6	25.7	26.3	25.3	26.1	28.3	29.8	28.2
2003	28.4	31.3	30.6	28.1	28.3	25.6	24.2	24.9	26.0	28.2	29.3	27.2
2004	28.9	28.8	30.2	27.3	28.6	25.9	25.3	25.5	25.5	26.7	28.6	28.6
2005	28.9	31.5	30.0	29.4	25.9	25.6	24.6	25.7	26.0	27.3	28.0	28.5
2006	30.1	31.3	29.3	27.3	27.7	26.2	24.5	24.7	25.2	26.7	27.6	27.5
2007	28.5	29.2	30.0	28.2	27.7	25.3	24.6	24.2	25.1	26.7	27.8	27.9
2008	29.5	29.4	31.5	29.4	26.3	25.6	24.4	24.8	25.7	26.6	26.6	27.8
2009	28.4	30.0	31.3	29.2	29.0	27.7	26.0	26.0	26.3	27.5	29.5	28.1
2010	28.5	28.4	27.7	28.0	26.9	26.2	24.4	25.0	25.3	27.7	28.7	28.2
2011	28.7	30.6	30.2	30.7	27.6	26.2	25.6	24.6	25.3	28.2	27.8	27.6
2012	29.7	30.8	31.8	28.0	28.3	26.6	24.9	24.9	25.1	27.8	29.1	29.1
2013	29.9	31.4	30.3	28.8	26.7	26.1	24.3	24.7	26.2	26.8	28.0	28.0

2014	29.9	29.6	29.6	28.7	27.1	26.7	25.2	25.2	25.3	26.3	27.4	27.5
2015	28.7	31.0	31.5	30.8	28.5	26.1	26.1	26.8	27.1	28.5	29.0	28.4
2016	28.8	30.7	32.3	28.7	26.7	26.0	25.3	25.3	26.6	27.4	28.1	27.8
2017	29.0	29.9	31.6	31.6	28.4	27.7	26.1	26.6	26.3	27.9	28.5	28.3
2018	29.1	30.2	28.1	27.1	27.8	25.0	24.9	25.7	26.6	28.0	27.5	28.3
2019	29.8	31.2	31.7	29.7	29.1	26.4	25.6	25.2	26.0	26.6	27.9	27.8
2020	28.6	30.1	29.8	29.0	28.0	26.1	24.3	24.7	26.0	27.4	28.1	28.3

Table 9: Monthly average relative humidity % (data from 1993-2020)

	Ja	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
199	63	66	50	68	72	73	71	71	73	70	53	48
199	43	43	56	63	72	72	76	75	73	60	57	50
199	45	51	61	72	69	68	74	74	74	63	52	57
199	62	50	65	71	75	77	76	76	76	64	55	49
199	56	40	51	70	68	72	73	68	68	68	67	59
199	65	62	62	60	68	66	72	72	71	72	53	44
199	47	38	63	59	66	67	74	71	71	72	53	50
200	43	37	41	61	71	68	72	71	75	73	60	54
200	52	51	63	64	69	72	73	73	72	67	49	48
200	55	42	63	60	68	68	64	69	70	60	44	60
200	55	46	55	65	65	68	75	74	71	61	52	54
200	58	51	48	70	65	67	67	69	73	62	53	54
200	52	43	58	59	73	68	71	67	71	63	53	42
200	47	50	59	69	68	68	74	77	75	72	59	64
200	58	58	53	69	72	74	73	77	77	61	54	47
200	48	44	37	58	71	70	74	74	74	66	60	49
200	54	47	49	64	62	65	67	69	70	63	42	59
201	55	62	64	69	74	70	74	74	75	63	52	50
201	49	44	50	57	72	74	74	77	77	61	65	57
201	49	44	39	68	67	68	76	72	77	61	53	51
201	50	42	58	65	69	68	75	73	71	66	59	48
201	50	58	59	64	71	68	70	72	73	68	57	51
201	50	45	44	53	66	70	67	70	68	60	56	58
201	57	45	51	60	70	62	72	70	67	64	54	48
201	31	46	40	42	61	60	67	63	66	58	55	42
201	42	47	56	64	65	73	71	70	63	57	56	47
201	39	41	45	59	60	71	71	72	68	59	60	55
202	56	58	56	60	67	72	75	75	68	60	54	51

Table 10: Monthly average wind speed m/s (data from 1993-2020)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1993	0.63	0.58	0.63	0.72	0.76	1.18	1.18	1.01	0.79	0.56	0.73	0.92
1994	1.02	1.03	1.05	0.83	0.81	1.10	0.79	0.94	0.66	0.58	0.70	0.94
1995	0.93	0.90	0.94	0.75	0.88	1.20	0.96	0.88	0.68	0.64	0.55	0.72
1996	0.80	0.79	0.81	0.75	0.73	0.97	0.98	0.76	0.66	0.53	0.62	0.72
1997	0.80	1.02	0.91	0.68	0.84	0.92	0.98	0.83	0.66	0.53	0.62	0.74
1998	0.59	0.56	0.61	0.69	0.79	1.10	1.02	0.93	0.67	0.45	0.50	0.63
1999	0.75	0.75	0.64	0.75	0.97	1.08	0.99	0.88	0.72	0.56	0.65	0.59
2000	0.92	0.96	0.82	0.81	0.78	1.13	0.98	0.93	0.67	0.54	0.60	0.67
2001	0.82	0.70	0.68	0.67	0.81	0.91	0.86	0.80	0.54	0.54	0.59	0.64
2002	0.76	0.79	0.59	0.66	0.97	1.06	1.06	0.81	0.60	0.57	0.72	0.71
2003	0.76	0.82	0.82	0.66	0.74	0.91	0.86	0.85	0.69	0.54	0.79	0.77
2004	0.60	0.54	0.64	0.62	0.87	1.01	0.90	0.77	0.58	0.67	0.70	0.75
2005	0.71	0.74	0.69	0.71	0.60	1.06	0.95	1.01	0.75	0.67	0.68	0.81
2006	0.92	0.84	0.67	0.63	0.82	0.91	0.93	0.97	0.87	0.72	0.80	0.83
2007	0.95	0.82	0.79	0.79	0.90	1.07	0.98	0.93	0.82	0.64	0.87	0.92
2008	0.84	1.05	0.93	0.98	1.05	1.10	0.96	0.88	0.72	0.66	0.74	0.84
2009	0.83	0.91	0.83	0.78	0.99	1.01	0.98	0.98	0.75	0.75	0.80	0.73
2010	0.79	0.77	0.84	0.71	0.84	1.03	0.92	0.88	0.75	0.64	0.64	0.68
2011	0.67	0.72	0.74	0.64	0.68	0.78	0.68	0.65	0.57	0.55	0.50	0.60
2012	0.61	0.74	0.72	0.54	0.60	0.82	0.57	0.56	0.46	0.46	0.50	0.57
2013	0.65	0.64	0.60	0.56	0.60	0.74	0.49	0.53	0.48	0.37	0.42	0.49
2014	0.51	0.52	0.51	0.47	0.46	0.63	0.53	0.47	0.42	0.38	0.45	0.52
2015	0.63	0.61	0.71	0.57	0.60	0.63	0.65	0.63	0.51	0.46	0.56	0.69
2016	0.55	0.66	0.62	0.44	0.52	0.58	0.53	0.61	0.48	0.45	0.54	0.69
2017	0.75	0.65	0.65	0.63	0.49	0.70	0.50	0.56	0.51	0.44	0.52	0.61
2018	0.60	0.66	0.46	0.43	0.54	0.67	0.63	0.55	0.57	0.29	0.39	0.50
2019	0.56	0.60	0.54	0.50	0.43	0.68	0.41	0.38	0.45	0.38	0.39	0.32
2020	0.36	0.39	0.37	0.29	0.33	0.36	0.32	0.33	0.31	0.23	0.22	0.35

Table 11: Monthly average wind sunshine hour (data from 1993-2020)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	8	7	9	6	7	6	4	5	4	5	5	8
1994	10	9	8	7	7	6	4	5	5	8	9	10
1995	10	8	7	6	8	8	4	5	7	7	10	9
1996	9	9	8	7	7	5	4	5	6	8	9	10
1997	8	10	8	6	8	7	6	7	7	7	7	9
1998	7	8	8	8	7	7	5	4	5	5	10	10
1999	10	10	7	7	8	8	4	6	7	5	9	10
2000	10	10	9	7	8	7	6	7	6	6	9	9
2001	9	9	6	7	7	6	5	5	7	7	9	10
2002	9	10	7	8	7	6	7	6	7	7	10	8
2003	9	10	8	7	8	7	4	5	6	9	9	9
2004	8	9	8	6	9	6	5	5	5	8	9	9
2005	9	10	8	8	6	7	5	7	6	7	9	11
2006	9	9	7	7	8	6	5	5	5	6	9	9
2007	9	9	8	7	7	5	5	5	5	8	9	10
2008	10	9	10	7	7	6	5	5	5	7	9	10
2009	9	9	9	7	8	8	6	7	6	8	9	7
2010	9	6	8	6	7	7	4	5	5	8	9	9
2011	10	10	8	8	6	6	5	5	5	8	8	10
2012	10	10	8	6	8	7	4	5	5	8	9	10
2013	9	10	7	7	7	7	4	5	6	7	8	10
2014	9	8	8	8	7	7	5	5	6	7	9	10
2015	10	10	9	8	7	6	7	7	7	7	9	9
2016	9	9	8	7	7	6	5	6	6	7	9	10
2017	10	9	9	8	7	8	4	5	5	7	9	10
2018	9	8	6	5	5	3	3	6	6	7	8	10
2019	9	9	8	8	7	6	4	5	4	7	8	9
2020	9	9	8	6	7	6	3	3	5	8	9	10

**Appendix -C: Measured discharge, soil moisture data, irrigation water supply and RAW**

Table 12: Measured discharge at the head and tail of main canal

Month	Period	Discharge (m <sup>3</sup> )	
		Head	Tail
February	Week 1	0.029	0.00
	Week 2	0.031	0.00
	Week 3	0.033	0.011
	Week 4	0.034	0.019
	<b>Average</b>	<b>0.032</b>	<b>0.007</b>
March	Week 1	0.036	0.018
	Week 2	0.036	0.022
	Week 3	0.0	0.0
	Week 4	0.0	0.0
	<b>Average</b>	<b>0.018</b>	<b>0.01</b>
April	Week 1	0.035	0.021
	Week 2	0.036	0.024
	Week 3	0.030	0.019
	Week 4	0.032	0.018
	<b>Average</b>	<b>0.033</b>	<b>0.02</b>

Table 13: Soil moisture measurements before and after irrigation

Irrn event	Soil depth (cm)	Soil moisture measurement before and after irrigation								
		Sample plot 1			Sample plot 2			Sample plot 3		
		Bef (%Vol)	Aft (%Vol)	Difference (%Vol)	Bef (%Vol)	Aft (%Vol)	Difference (%Vol)	Bef (%Vol)	Aft (%Vol)	Difference (%Vol)
1	0 – 30	1.79	6.26	4.47	1.2	5.82	4.62	3.33	7.02	3.69
	30 – 60	2.51	7.31	4.8	2.69	6.16	3.47	2.64	9.2	6.56
	60 – 90	4.30	4.8	0.5	3.73	6.50	2.77	5.30	6.65	1.35
2	0 – 30	2.08	6.42	4.34	1.46	5.18	3.72	1.66	7.39	5.73
	30 – 60	2.66	6.08	3.42	2.48	6.22	3.74	1.92	8.69	6.77
	60 -90	5.36	8.8	3.44	6.30	9.33	3.03	6.14	8.11	1.97
3	0 – 30	2.08	6.16	4.08	2.05	6.82	4.77	3.09	6.98	3.89
	30 – 60	1.6	5.68	4.08	2.77	7.44	4.67	3.33	9.78	6.45
	60 – 90	4.21	7.39	3.18	4.74	8.42	3.68	4.38	7.94	3.56
4	0 – 30	2.16	5.44	3.28	1.74	4.4	2.66	2.02	4.74	2.72
	30 – 60	1.61	8.11	6.5	1.58	7.70	6.12	2.64	8.48	5.84
	60 – 90	5.17	9.79	4.62	1.58	5.18	3.6	4.59	8.8	4.21
5	0 – 30	3.09	6.29	3.2	2.37	5.06	2.69	2.62	5.86	3.23
	30 – 60	1.94	8.50	6.56	1.86	8.16	6.3	2.43	8.46	6.03
	60 – 90	2.72	5.63	2.91	1.92	8.48	6.56	4.43	7.41	2.98
6	0 – 30	3.50	6.75	3.25	3.2	7.94	4.74	3.39	8.02	4.63
	30 – 60	1.70	7.92	6.22	7.09	9.28	2.19	5.22	8.66	3.44
	60 – 90	2.38	6.88	4.5	3.81	11.18	7.99	4.46	6.42	1.96

Table 14: Irrigation water supply (m<sup>3</sup>)

Month	IWS (m <sup>3</sup> )				
	Sample plot 1	Sample plot 2	Sample plot 3	Total	Average
February	179.76	136.39	122.36	438.51	146.17
March	194.32	135.01	129.64	458.97	152.99
April	194.32	145.59	131.32	471.23	157.08
Total	568.4	416.99	383.32		

Table 15: Soil physical properties and RAW (physical properties from design document)

Sample plot	Soil depth (cm)	FC (mm/m)	PWP (mm/m)	TAW (mm/m)	Bulk density (gm/cm <sup>3</sup> )	TAW (mm)	RAW (mm)
1	0 – 30	179	81	98	1.46	29.4	21.5
	30 – 60	175	75	100	1.42	30.0	21.3
	60 - 90	181	83	98	1.46	29.4	21.5
Total	90					88.8	64.3
2	0 – 30	267	126	141	1.44	42.3	30.4
	30 – 60	179	81	98	1.46	29.4	21.5
	60 - 90	179	81	98	1.46	29.4	21.5
Total	90					101.1	73.4
3	0 – 30	205	105	100	1.44	30.0	21.6
	30 – 60	180	75	105	1.46	31.5	23.0
	60 - 90	185	80	105	1.46	31.5	23.0
Total	90					93.0	67.6

**Appendix -D: Appendix figures**



Figure 1: Intake structure



Figure 2: Command area at the beginning of the season



Figure 3: During canal cross section measurement



Figure 4: Sediment accumulation in canal



Figure 5: water logged in the land due to canal breach



Figure 6: command area at mid-season



Figure 7: Irrigation water supply at beginning stage



Figure 8: Irrigation water supply at beginning and development stage