PERFORMANCE EVALUATION OF HARGAYA SMALL-SCALE IRRIGATION SCHEME, EAST HARARGHE, ETHIOPIA

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BIOGRAPHICAL SKETCH

The author was born on September 9, 1983, in E.C. in Ifabas *Kebele* Meyu Muluke district East Hararghe Zone, Oromia Regional State, Ethiopia, from his father Jamal Ahmed, and his mother, Nuriya Matan. He attended elementary education at Chulul-07 Elementary School from 1991-1998, and secondary education at Meyu Senior Secondary School from 1999-2000. He attended his preparatory class at Haramaya Senior Secondary and preparatory school from 2001-2002. He took the Higher Education Entrance Certificate Examination (HEECE) and joined Haramaya University in 2003. He graduated with a B.Sc. degree in Hydraulic and Water Resource Engineering in July 2007 E.C.

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ACRONYMS AND ABBREVIATIONS

CWR	Crop water Requirement
DAs	Development Agents
DPR	Deep Percolation Ratio
Ea	Application Efficiency
Ec	Conveyance Efficiency
Es	Storage Efficiency
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
GPS	Global Positioning System
Ha	Hectares
HH	House Hold
IR	Irrigation ratio
IWMI	International Water Management Institute
IWR	Irrigation Water Requirement
Kc	Crop Coefficient
Ky	Crop yield response factor
LGP	Length of Growing Period
m	Meter
m.a.s.l	Mean Above Sea Level
MC	Main Canal
MoWR	Ministry of Water Resource
NCWR	Net crop water requirement
NGOs	Non-Governmental Organizations
NIWR	Net irrigation water requirement
NMI	National Meteorological Institute
P	Depletion fraction
PWP	Permanent wilting point

RAW	Readily available soil water
RIS	Relative Irrigation Supply
RWS	Relative water supply
SC	Secondary canal
SCS	Soil Conservation Service
SIA	Sustainability of irrigated area
SSIS	Small-scale irrigation scheme
TAW	Total Available Water
US$/ha	United State Dollar per hectare
US$/m^3	United state Dollar per cubic meter
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
WDPR	Water delivery performance ratio
WUAs	Water User Associations

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Performance Evaluation of Hargaya Small Scale Irrigation Scheme, East Hararghe, Ethiopia

ABSTRACT

*The study was carried out to evaluate the performance of Hargaya irrigation scheme in the Meyu Muluke district of the East Hararghe zone, Oromia regional state. Performance of the irrigation scheme was evaluated using internal and external performance indicators, farmer's perceptions of the scheme, institutional setup, and support services to suggest possible remedial measures for enhancing the scheme's efficiency. The primary data was collected through the interview, questionnaire, group discussion, field observation and field test while secondary data was collected from NMI, Zone, and district agricultural offices, design documents, and literature. Internal performance indicators selected for the study were conveyance efficiency, application efficiency, storage efficiency, deep percolation ratio, distribution uniformity, and overall scheme efficiency. External indicators, including agricultural output, water supply, water delivery capacity, and physical performance indicators, have been used in the study. The results indicated that conveyance efficiency, application efficiency, storage efficiency, deep percolation ratio, distribution uniformity, and overall scheme efficiency were 43.28%, 49.03%, 83.41%, 50.97%, 61.43%, and 21.22%, respectively. The results of output per unit irrigated area, production per unit command area, output per unit irrigation supply, and output per unit water consumed were 5312.95US$/ha, 2817.03 US$/ha, 0.4 US$/m*^{3} *and 1.37 US$/m*^{3} *respectively. Physical performance indicators; IR, SIA, and effectiveness of infrastructures were found to be 0.51, 0.52, and 0.615, respectively. The results of WDP, RWS, and RIS were 3.2, 4.0, and 5.3, respectively. According to HH survey, WUAs organizational and legal enforcement bylaws at the scheme were not effective. Based on the result of the study, to improve performance of Hargaya irrigation scheme; rehabilitation of left main canal, reduce water diverted to the scheme, lining of main canal, mobilizing community participation in operation and maintenance, and application of WUA proclamation can enhance performance of the scheme.*

Keywords: *Internal and External indicators, Farmer's perception, and Performance Evaluation*

1. INTRODUCTION

1.1. Background

Most world countries are challenged by problems related to insufficient water resources to fulfill their current agricultural, home, commercial, and water demands within the next two decades (MoWR, 2002). The world population is forecasted to grow by about 30% by 2025, reaching more than 8 billion people (Kidane, 2015). As a result of globalization, advanced communication, urbanization, and the living requirements of human beings are anticipated to grow. This means competition among agricultural, industrial, domestic, and different customers will boom at unexpected ranges (FAO, 2014).

Ethiopia is one of the countries that have ample water resources from the African continent (Asfaw and Gebremedin, 2015). The country consists of twelve river basins with an annual runoff of one hundred twenty-four billion cubic meters of water and groundwater capability was estimated to be 2.6 to 30 billion cubic meters (EPCC, 2015). The irrigation potential of Ethiopia is expected at 5.3 million ha from fifteen million ha of general cultivated area (Awlachew, 2011). The irrigation area of the country is predicted at 640000 ha. Of these, 120000 ha use rainwater harvesting, 383000 ha use small-scale irrigation, and 129000 ha use medium and large-scale irrigation structures (Bitew, 2017). One of the foremost troubles is generally terrible efficiency in which water diverted for irrigation is wasted on the farm through either deep percolation or surface runoff (FAO, 1989).

Irrigation is driving force in agricultural productivity considered as cornerstone of food security and alleviates poverty. Monitoring and evaluating irrigation scheme performance is very essential to ensure sustainable agricultural transformation in terms of crop production. Principal objective of monitoring and evaluating irrigation scheme is to investigate best alternatives that will enhance the system capacity. Irrigation performance is the degree to which the system achieves specified targets (Yebeltal, 2019).

Performance assessment have vital role; to assess how far goals and objectives set at time of project formulation is forwarded, to identify present status success or failure of the scheme, to identify best alternative management options, to point out areas where improvement is needed, to advise irrigators, to address existing problems and identify possible remedial measure, to recommend critical challenges, to bench mark for further irrigation development background problems and assists the engineers to design new systems (Kebede, 2021).

Irrigation is particularly predicted to play a primary position in the consciousness of Ethiopian food safety and poverty alleviation strategy (Minibel, 2019). In Ethiopia small scale irrigation schemes play a vital role in improving the livelihoods of the smallholder farmers. Irrigation complements agricultural manufacturing and improves the food supply. The income of the rural population opens employment opportunities for people with low incomes and helps the national economic system by producing industrial crops that are used as raw materials for value-adding industries and exportable crops (Yebeltal, 2019). One of the best alternatives to consider for reliable and sustainable food security development is expansion of small scale irrigation development in the country. Nowadays, the government gives more attention to small-scale irrigation development, and huge funds are allocated to this sector to construct new projects; however, the performance of most irrigation schemes cannot serve at the intended capacity (Yami, 2012).

For performance evaluation of irrigation scheme, different indicators are used by different researchers. The project performance indicators can be classified into five main group technical indicators, agricultural indicators and institutional indicators (Anteneh, 2019). Technical performance is investigated by the technical indicators. Agricultural aspects are evaluated by the agricultural indicators, socio viability and sustainability of the physical environment for irrigation. Institutional indicators measure the institutional capacity and organizations for managing and sustaining system (Minibel, 2019).

Irrigation scheme face various problems related to operation and maintenance, water management and sustainability, these problems have highly reduced their benefits and challenged their overall sustainability. Performance assessment is used to identify the present status of the scheme with respect to the selected indicators, which help to identify why the scheme is performing and means of improvement. Performance evaluation needs relevant and reliable data which are rarely available in Ethiopia (Kebede, 2021).

The irrigation system performance is to be evaluated with reference to set objectives and targeted benefits. The status of infrastructure, organizational and water distribution network, overall project efficiency, irrigation management practices The performance of many irrigation systems is significantly below their potential due to a number of challenges, including poor design, construction, operation, maintenance, and absence of knowledge on how to manage irrigation water (Anteneh, 2019). The irrigation system performance is to be evaluated regarding set targets and focused objectives (FAO, 1989). The status of infrastructure, organizational and water distribution network, overall project efficiency, and irrigation management practices will be evaluated to increase the scheme's performance (Zeleke, 2015). The studies made by many researchers earlier imply that worldwide irrigation efficiency was less than 40% (Mulatu, 2020). Moreover, scheme performance has been expected in Ethiopia at an average of 36% below design capacity (Awulachew, 2010).

Knowing the efficiencies and effectiveness of water use at farm level and to alleviate the current challenges caused by inefficient operation of irrigation system and poor management of irrigation water at Hargaya irrigation scheme is found to be important for possible recommendations of improvement of the scheme. Since its inception, on-farm irrigation system evaluation studies had never been conducted on the performance of this irrigation scheme. So, the performance evaluation of the scheme would help to improve the performance of the irrigation system in terms of water and land productivity to identify causes for poor irrigation management system.

1.2. Statement of the Problem

The problem of food security is worrier due to population growth rapidly (FAO, 2015). The costs of foodstuffs in the international market have increased unexpectedly (Tahir, 2020). In Ethiopia, irrigation development is a priority for agricultural transformation in terms of farm production and meal safety, enhancing the profits of rural people, and public investment in rural development. However, there is no good pleasure in most irrigation schemes' performance in the country (Mekonnen, 2018). More than ninety percent of small-scale irrigation schemes in Ethiopia operated below their designed capacity due to poor water management, leaky canals, and structural damage (Awulachew, 2010). The delivery and distribution of irrigation water are essential conditions limiting the ability to gain the highest productivity (Bitew, 2017).

Hargaya small-scale irrigation scheme is one of the community-managed small-scale irrigation schemes located in Meyu Muluke Woreda East Hararghe Zone in the Oromia region, where erratic rainfall and drought have been frequently observed. The scheme was designed to irrigate a command area of 200 ha and served the surrounding community to reduce crop disasters due to moisture stress (design document, 2012).

In the district, no attention is given to monitoring and evaluating the irrigation scheme's performance up to date. Performance assessment of the irrigation scheme had a fundamental role in enhancing its productivity by figuring out where the vital problem occurred (Kebede, 2021). So, it's essential to evaluate and gain facts that can improve the performance of such irrigation schemes to acquire the intended capacity of the scheme and achieve long-term productivity.

Up to date, no studies have been conducted regarding performance evaluation of the irrigation scheme in the district and the performance level of the Hargaya irrigation scheme was not studied. Therefore, the research is targeted to evaluate the performance of the Hargaya irrigation scheme through performance indicators, investigate the main causes that contributed to the reduction of implementation of the scheme, address possible solutions, recommend critical challenges, and the final output of evaluation forwarded to improve the scheme productivity.

1.3. The objective of the Study

1.3.1. General Objective

The general objective of the study was to evaluate the performance of the Hargaya small-scale irrigation scheme using selected performance indicators.

1.3.2. Specific Objectives

- To evaluate the performance of the Hargaya irrigation scheme using internal and external (comparative) performance indicators.
- To assess irrigation institutions and support services at Hargaya irrigation Scheme.
- To evaluate farmers' perceptions about the performance of the scheme.

1.4. Scope of the study

The study was conducted at Hargaya small scale irrigation scheme. The research was used internal indicators (conveyance, application, storage, distribution uniformity, deep percolation ratio and overall scheme efficiency) and external indicators (agricultural, water supply, water delivery and physical performance indicators) for evaluation of performance of the scheme. The study was carried out for eight months.

1.5. Significance of the Study

This study will provide information about the performance of the current irrigation scheme under investigation. The results of the study will have significant contribution to understand the drawbacks and best achievements. This research also used to identify the present status of the scheme with the help of selected indicators alternative strategies that will improve the performance of the scheme and also for other similar small-scale irrigation schemes.

Moreover, information collected from the study help government policy makers, development agents, and NGOs to formulate appropriate policies, design effective evaluation and development programs. It provides information for research and academic institutes as well for stakeholders. It also used as a benchmark for development works and future studies.

2. LITERATURE REVIEW

2.1. History of Irrigation Development in Ethiopia

The irrigation system is the application of water to crops within the agricultural area to fulfill crop water necessities artificially, outlined to permit cultivating in arid zones and to counterbalance the effect of the dry season in semi-arid regions. Indeed in areas where in general regular precipitation is adequately normal, it might be ineffectively disseminated within the year and change from one year to another year (FAO, 1997). Be that as it may, the current irrigation system commenced in the 1960s to supply industrial crops in Awash Valley. Individual organizations that operated farms for developing industrial crops including cotton, sugarcane, and vegetables started the formal irrigation system in the upper and lower Awash Valley (Adane, 2012).

According to (FAO, 1995), modern irrigation was started in the early 1960s by private investors in the middle awash valley where large quantities of sugar cane, fruit, and cotton were produced. The need for developing irrigation for crop production is acquiring more and more attention in Ethiopia in response to the growing demand for crops. Most of the eastern part of Ethiopia receives very little rain, while the western areas receive satisfactory rainfall. Production of a sustainable and reliable food supply is almost impossible due to the temporal and spatial imbalance in rainfall distribution and the consequential non-availability of water during the required period. Sometimes, even the country's western highlands suffer from food shortages due to discrepancies in the rainfall distribution (MoWR, 2002).

2.2. Current Status of Irrigation Schemes in Ethiopia

In Ethiopia, approximately 90% of the irrigation potential in terms of land and water assets has not been developed so far. In any case, there have been numerous ongoing medium and large-scale irrigation developments in recent years. In the country, almost 47% of the irrigated area is developed under large-scale irrigation systems, mainly for industrial crops such as cotton, and sugarcane whereas 65% of the irrigated area is under small-scale either modern or traditional (MoWR, 2002). Traditional irrigation systems are those built by farmers utilizing nearby materials without permanent water diversion, conveyance control, and dissemination facilities

(Berhanie, 2017). In Ethiopia, around 18% of the irrigated areas were served by modern SSIS those operated and overseen by the water user (Dejen, 2012).

Need for Performance Assessment For SSI Schemes in Ethiopia

Irrigation system practice is a vital factor that plays a major role in developing numerous world nations. Most of Ethiopia’s population depends on rain-fed agricultural production for their livelihood. In this case, crop production is not sufficient to fulfill the country's food necessities because it is practiced through rain-fed agriculture. Nowadays, various-scale irrigation developments have been getting consideration (Megarsa, 2017). Performance is the degree to which a system accomplishes its objectives and is represented by utilizing its quantifiable levels of accomplishments in terms of several parameters (Molden, 1998). Thus, it's vital to objectively measure and assess their success or failure and distinguish particular areas where advancement is needed. Performance assessment for any irrigation system is fundamental to evaluate how distant the objectives and targets set forward at the time of project formulation of the system have been accomplished (Zeleke, 2015).

The main purpose of performance assessment is to use resources efficiently and effectively by providing relevant responses to management at all levels. Therefore, it contributes to the system management in determining whether the performance is satisfactory, to take remedial actions needed. An indicator describes the level of actual achievements concerning the designed objectives of irrigation systems. It is useful to consider irrigation systems in the context of nested systems to describe different types and uses of performance indicators (Molden, 1998).

2.3. Irrigation Water Control and Management

Water management is defined as the planned development, distribution, and use of irrigation water determined by objectives and concerning both the quantity and quality of the water resources (Beneberu, 2020). Distributions of irrigation water and management activities were done by a collaboration of kebele administrative and head of WUAs who called “*Melaka*”, whereas farmers manage the on-farm water distribution and application system. The date of water application was decided based on the farmer's request and the go-ahead given by water distributors (*Malaka*), who decide by visual observation of the status of the crop.

2.4. Irrigation Performance Evaluations

The types of performance indicators to be chosen rely on the purpose of the performance assessment activity (FAO, 1989). Evaluation is information processing to examine goals and strategies and compare the results of monitoring and observations with the prevailing standards. Performance assessment is a major component of proper management, which is the basis for the optimal use of land and water resources (Awulachew, 2011). Performance can be 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 evaluate the general health of a system, to assess the impacts of interventions, to diagnose constraints, to better understand determinants of performance (Adane, 2012). Field irrigation efficiencies are influenced by soil type, field application methods, depth of application, and climate (Derbie, 2019).

2.5. Importance of Performance Evaluation of SSI Scheme

The objective of assessing surface irrigation system evaluation is to distinguish irrigation management techniques and system configuration setups that can be attainable and successful in improving irrigation system effectiveness (Yadeta, 2018). Irrigation performance is the degree to which it accomplishes the specified targets (Bitew, 2017). An irrigation system evaluation may show that better efficiency can be achieved by limiting the inflow time to the interval needed to apply the depth to fill the soil moisture deficit in the root zone (Anteneh, 2019). The evaluation may reveal opportunities to improve performance by increasing field size and making topographic changes. Performance assessment ensures that all activities are performed as if they are one step closer to achieving the scheme objectives (Yebeltal, 2019).

Evaluation of the system provides information used to advise irrigators on improving their system design and operation, and on improving the design and developing real-time irrigation management (Eticha, 2011). According to (Solomon, 2016), 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 the impacts of interventions, to diagnose constraints, and to better understand determinants of performance of the system with others. Effective irrigation management assures correct irrigation schedule, application depth, uniform irrigation, minimum runoff, and deep percolation except for that required for salt management, minimum erosion, and optimal return on irrigation investment (Tesfaw, 2017).

2.6. Irrigation Scheme Categories in Ethiopia

According to (Awulachew, 2010) irrigation schemes in Ethiopia are classified into three based on the size of the command area. An irrigation scheme consisting of a command area of less than 200 ha is classified as a small-scale irrigation scheme; an irrigation scheme that commands areas between 200 ha to 300 ha is classified as a medium irrigation scheme, and a system consisting of a command area greater than 3000 ha is categorized as a large-scale irrigation scheme. Large-scale irrigation scheme is constructed for commercial purposes and governed by the government.

2.7. Surface Irrigation Method Practice

Surface irrigation is the method of water application by gravity to the field's surface. These systems are based on moving water over the land's surface. They can be subdivided into furrow, border, and basin irrigation (Mogos, 2017). The spatial and temporal variability of soil characteristics, such as infiltration rate and soil texture, make water management practices difficult to define and implement (Jadhav, 2014).

2.8. Factors Affecting the Performance Irrigation Scheme

According to (Solomon, 2016), factors that account for the underperformance of irrigation the scheme includes poor system management and service provision, poor understanding of farmer priorities, inadequate market information, lack of clear and sustainable water rights accorded to users, lack of responsibilities of organizations, lack of transparent accountability, poor land preparation, and weak extension service in agriculture. Similarly, (FAO, 2014) suggests that agricultural water management is essential to increase agricultural productivity, eradicate poverty, improve the economy, and reduce the degradation of the surrounding environment. The principal objective of evaluating an irrigation system is to investigate alternatives that will enhance the system's performance. For instance, the evaluation may reveal that the application efficiency could be improved by adjusting the flow duration or changing field length and slope requiring modification for the existing system to operate more efficiently (Mekonnen, 2018).

Irrigation Efficiency

Irrigation efficiencies are evaluated at the scheme or on-farm level to identify the losses in the irrigation system starting at the water abstraction point, through the conveyance systems down to water application in the field, to determine the overall irrigation efficiency (Eticha, 2011). The design of the irrigation scheme, the degree of land preparation, skill, and care of the irrigator are the major factors influencing irrigation efficiency (Mukherjee, 2004). The most common way to express the efficiency of irrigation systems is to subdivide it into conveyance and application efficiencies (FAO, 2015).

The performance of field irrigation is determined by the efficiency with which water is diverted, conveyed, and applied; and by the adequacy and uniformity of application in each field on the farm (Negussie, 2013). According to (Tesfaw, 2017), the separate assessments of conveyance, distribution, and field application efficiencies indicate where remedial measures are required to improve the scheme's efficiency. As reported (Dinka, 2017), the success and failure of irrigation schemes depend on governance capacity and accountability.

2.9. Performance Indicators

Performance evaluation of irrigation systems plays a vital role in evaluating how far the current performance achievement differs from the formulated goals and objectives of the system during design. This is a useful means to identify success or limitation areas of the systems for improving system performance (Megarsa, 2017). Performance indicators can be categorized into internal and external indicators. Irrigation performance has to incorporate all aspects of the irrigated agricultural system including institutional setups, resources used, services delivered, and agricultural outputs. Internal indicators are used to assess the performance of the internal processes and irrigation services (Tesfaw, 2017). Internal indicators enable a comprehensive understanding of the processes that influence water delivery service and the overall performance of a system (Dejen, 2012). On the other hand, External indicators evaluate inputs and outputs to and from irrigation schemes. These indicators generally assess resource use efficiency (land and water) in irrigated agriculture (Mogos, 2017).

2.9.1. Internal Performance Indicators

The main purpose of this assessment is to assist irrigation managers in improving water delivery services to users. Performance measures tell how well the system performs in approaching the targets. If the performance is inadequate either the process must be changed to achieve the target or the target itself must be modified (Eticha, 2011). These performance indicators examine project technical or field performance by measuring different parameters as ideal irrigation can apply the right amount of water over the entire region of interest depth of the root zone uniformly and without losses (Tahir, 2020). Internal indicators such as conveyance efficiency, application efficiency, storage efficiency, distribution uniformity, runoff ratio, deep percolation ratio, and overall scheme efficiency were considered in this study.

The internal process describes the level of actual achievements related to the objectives of irrigation (Holzapfel, 2009). The number of indicators selected is based on the level of detail with the degree to which one needs to evaluate performance and the number of disciplines one needs to look at irrigation (Yebeltal, 2019).

2.9.1.1.Conveyance Efficiency (Ec)

Conveyance efficiency is the ratio of the outflow rate to the inflow rate of a system. It is one of the commonly used performance output measures that focus on the irrigation system's physical efficiency of water conveyance (FAO, 1989). As reported by (Bos, 1997), water distribution is the central importance of any management of irrigation systems. The conveyance system diverts water from its source and transports and distributes water to the point of use (Solomon, 2016). An efficient irrigation system transports water with minimum losses and has high conveyance efficiency (Holzapfel, 2009).

2.9.1.2.Application Efficiency (Ea)

Application efficiency can be described as the ratio of irrigation water stored in the root zone to irrigation water applied to the field. According to (Derbie, 2019), to compute Ea, it is necessary to identify at least one of these losses and the moisture stored in the root zone. This implies that the difference between the total amount of root zone storage capacity available during irrigation and the actual water stored due to irrigation can be separated (FAO, 1989).

2.9.1.3.Distribution efficiency (Du)

This type of indicator shows how irrigation water is uniformly applied to the field along the irrigation run. To know the distribution uniformity of irrigation water in the selected farmer's field augur samples were taken from the desired points along the furrow. Soil samples were collected at different depths with an interval of 30cm up to 90cm. Then, the soil moisture contents of the soils at the selected points were analyzed to determine the depth of water distribution. Distribution uniformity was defined as the minimum infiltrated depth divided by the average infiltrated depth (Jurreins, 2001).

2.9.1.4.Storage Efficiency (Es)

To compute the water stored in the soil root zone of each field, soil samples were collected before and after each irrigation event from a different location within the field at a depth of 0-30, 30-60, and 60-90cm. Using the gravimetric method, moisture content was determined.

2.9.1.5.Deep Percolation Ratio

The furrow that is practiced in the Hargaya scheme is closed-end. Therefore, the runoff ratio is neglected and the evaporation from the soil is also ignored because it is only a short period after irrigation. The loss of irrigation water beyond the root zone is only through deep percolation (Abdisa, 2017).

2.9.1.6.Overall scheme efficiency (E_o)

The overall efficiency of the irrigation scheme indicates the general condition of the level of the scheme (Amsalu, 2020). The overall efficiency of the scheme was calculated as the product of conveyance and application efficiency (FAO, 1993).

2.9.2. External Performance Indicators

2.9.2.1.Agricultural output indicators (Land and Water) productivity

Land productivity indicators

Four indicators related to the output of different units were used to evaluate agricultural performance. These indicators were output per irrigated area (\$/ha), output per unit command area (\$/ha), output per unit irrigation supply (\$/m^3), and output per unit water consumed (\$/m^3) was calculated as (Molden, 1998).

2.9.2.2.Water Supply Indicators (RWS and RIS)

Relative water supply indicates the adequacy of water applied to the crop's demand. It is the ratio of total water supplied by irrigation and rainfall to total water demanded by the crop. RIS is a relative irrigation supply described as the ratio of irrigation water supply to irrigation water demand. Irrigation water is an insufficient resource in many irrigation schemes and is a significant constraint for production. This indicator is useful to assess the degree of irrigation water stress/abundance/concerning irrigation demand (Alebachew, 2021).

2.9.2.3.Water Delivery System Performance

The success of an irrigation water-delivery system can be measured by how well it meets the objectives of delivering an adequate and dependable supply of water in an equitable, efficient manner to users served by the system (Berhanie, 2017). Crop yields may suffer if water does not arrive at farms adequately and timely. The water available for the irrigation systems at main canals, secondary canals, and farm inlets has been computed from the measured data at the specified locations (Kidane, 2015). Proper distributions of diverted water at the head to the whole irrigation system can be measured by the water delivery performances of the existing irrigation infrastructures (FAO, 2000).

Flow rate measurement at the canal

The velocity–area discharge measurement involves measuring the channel cross-sectional area and the average speed of flow. The cross-sectional area is measured using a tape, and the average flow velocity is determined with the floating method. According to (Solomon, 2016), the selection of the technique depends on several factors, including cost, the geometry of the canal, and required accuracy. The velocity-area method is complex but has several advantages over other methods. The technique can be used in the absence of hydraulic structures (weirs and flumes), it can be used with a variety of channel shapes, is more accurate than the hydraulic-radius method, and cross-sectional areas of the channels are calculated depending on various canal geometry.

3. MATERIALS AND METHODS

3.1. Description of Study Area

3.1.1. Location

The study was conducted in Meyu Muluke district, one of the districts in the East Hararghe administrative zone of the Oromia national regional state. The project area is 608 km from Addis Ababa to the east, 124 km from Harar, and 20 km from Huse town capital of the district. Geographically the command area laid upstream to downstream on 8°50’55” to 8°48’11” North latitude and 41°46’33” to 41°46’56” Eastern longitude, with an altitude ranging from 1292.56 m to 1278.90 m a.s.l. The headwork site is located at 8°50’55” North latitude and 41°46’33” Eastern longitude with an elevation of 1292.97 m a.s.l. The total targeted beneficiary population in the area is 1708. Of this, the number of males and females are 873 and 835 respectively. The weir is constructed across the Chulul River, which originated from the bottom of Gara Mulata Mountain, and the length of the river course from the weir site to the source was about 32 kilometers. The scheme is designed to irrigate 200 ha command area.

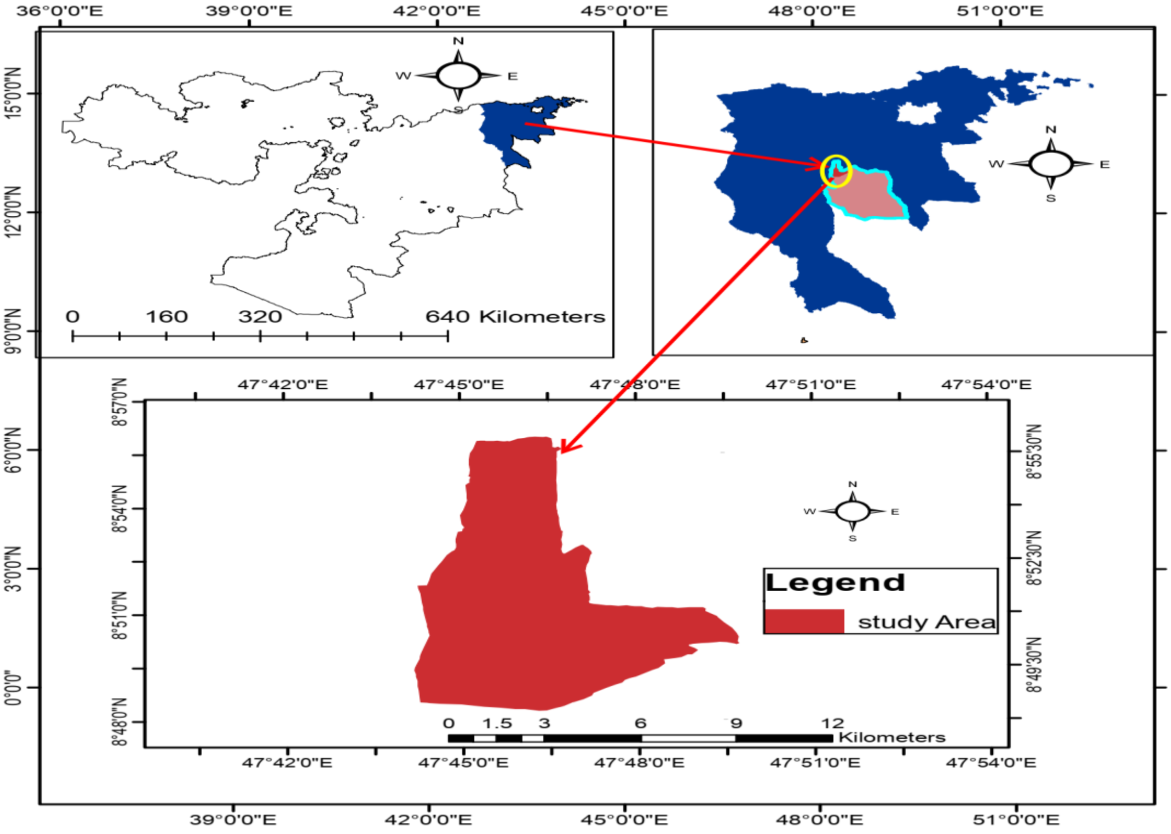

Figure 1 Map of the study area

Hargaya small-scale irrigation scheme is located in the Oromia regional state East Hararghe Zone Meyu Muluke district and Ifabas Kebele. The diversion weir is located 20 km from Huse town the capital of the district and 49 km from Girawa town to the irrigable area that is an all-weathered road. The designed command area of the scheme was 200 ha and served for 244 households. The scheme was constructed in 2007 E.C. and has had service for the last nine years. Two primary and four secondary canals are designed to irrigate the total command area of the scheme. The total length of each left and right main canal was about 3540 m and 100 m was a lined canal on both sides whereas 3440 m was an earthen canal. The left main canal was designed to irrigate a command area of 140 ha while the right canal was designed to irrigate 60 ha. However, the currently irrigated area served by the left canal decreased and became 38 ha because of the improper design of the left primary canal. The lack of drainage structures during the design period was the main factor that accounted for the reduction of the command area due to excessive water loss (Figure 2). This tells us water users at the lower reach of the left canal felt a shortage of water.

The right primary canal was designed to irrigate 60 ha of command area however; currently, the irrigated area served by the right canal has increased to 64 ha. On the other hand, the left primary canal was designed to irrigate 140 ha of command area, but the currently irrigated area was decreased to 38 ha. The result shows the intended command area of the left canal was almost only 27.14% irrigated. The main reason identified for the contraction of the irrigated area of the left canal was excessive water loss in the conveyance system due to design problem. Even if more than enough water was diverted through the irrigation season, there was a water shortage at downstream users.

Figure 2 Condition of left side main canal

3.1.1. Climate

The area's agro-climatic condition is considered a dry Kola type of climate condition and the mean annual temperature is between 10.85 C^o and 27.4 C^o. In contrast, the mean annual rainfall is 917.4 mm around the project area; the annual rainfall is not uniformly distributed over the period. The unpredictable nature of the rainfall has made the communities in the area often reliant on food aid. The project area received a bi-modal rainfall pattern. Rainfall data with records of 1990-2019 of the nearest meteorological station for the study area, was collected from the national meteorological institute. The seasonal rainfall pattern at Girawa meteorological station shows bimodal rainfall distributions. Climate data of the study area were analyzed using Girawa meteorological institute. Consistency of rain fall data was checked using double mass curve technique. Accumulated annual precipitation of Girawa meteorological station was compared with accumulated average of annual rainfall station in surrounding area Bedeno and Boko meteorological stations.

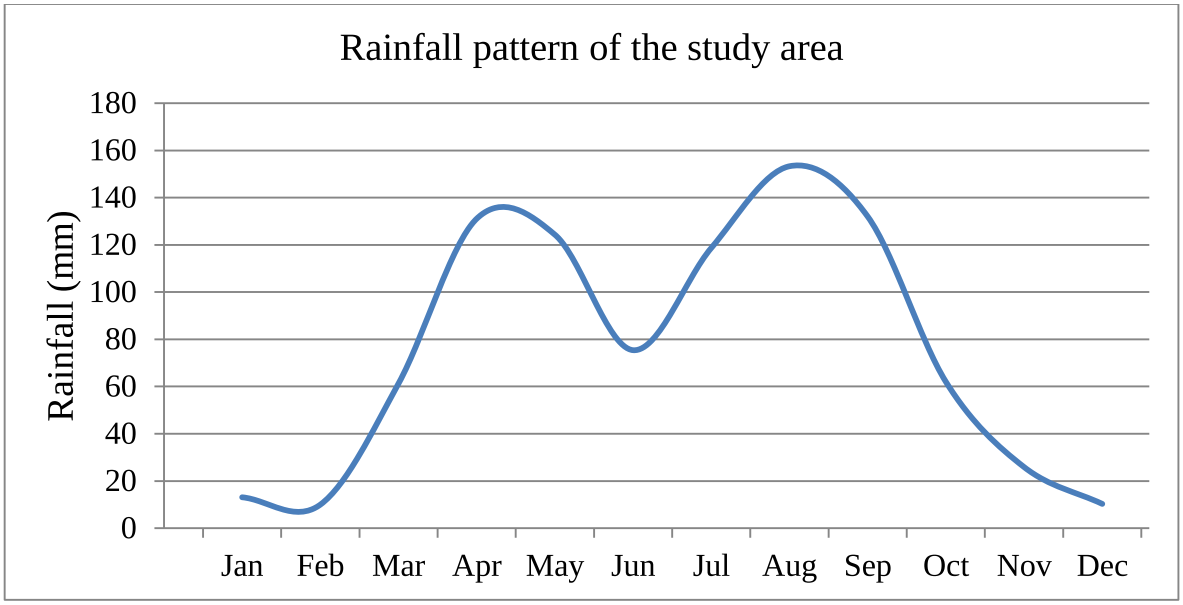

Figure 3 Rainfall pattern of the study area

3.1.2. Socio Economy

The main economic occupation of the project area is mixed agriculture in which cultivation of crops and livestock rearing are the sources of income for communities in the area. The irrigation project aims to maximize the income of the beneficiaries and enable the local farmers to improve their living standards. The average size of the farm held by individuals in the command area maximum is 2 hectares and the minimum is 0.25 hectares.

3.1.3. Land Use Pattern

According to the design document, the land use pattern of the study area can be classified as forest (58.3%), cultivable (29.2%), cultivated land (11.7%), grazing land (0.29%), and others (0.58%). The dominant soil type of the command area is clay loam (design document, 2012).

3.1.4. Topography

The topographic feature of the watershed of the Hargaya irrigation scheme consists of different landforms. The landform consists of a mountain area, and the Chulul River originated at the bottom of Gara Mulata Mountain. The watershed of the project area is bounded by the Wabishebele River basin sub-basin at the south, the Mojo River at the west, the Gobele River at the east, and Mojo Adano in the northwest direction. The watershed area is about 285.1 km^2 up to the upstream of the diversion weir (design document, 2012).

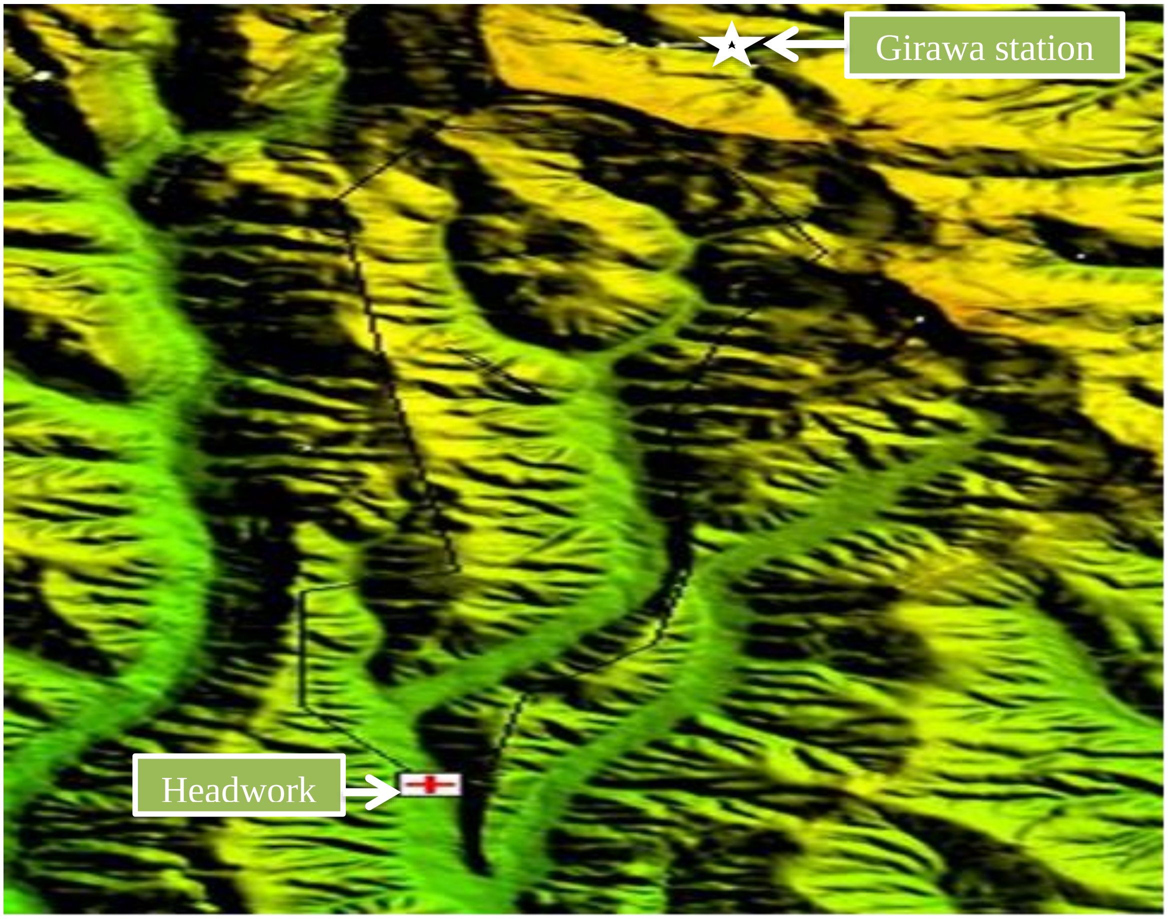

Figure 4 DEM of Chulul Catchment

The main water source for Chulul River is: surface water flow from runoff generated from the catchment and spring /sub surface water from the adjoining mountain side draining to the river. The lean flow of the river as measured during critical period of the study season found to be 300 l/s using floating method during feasibility study (design document, 2012).

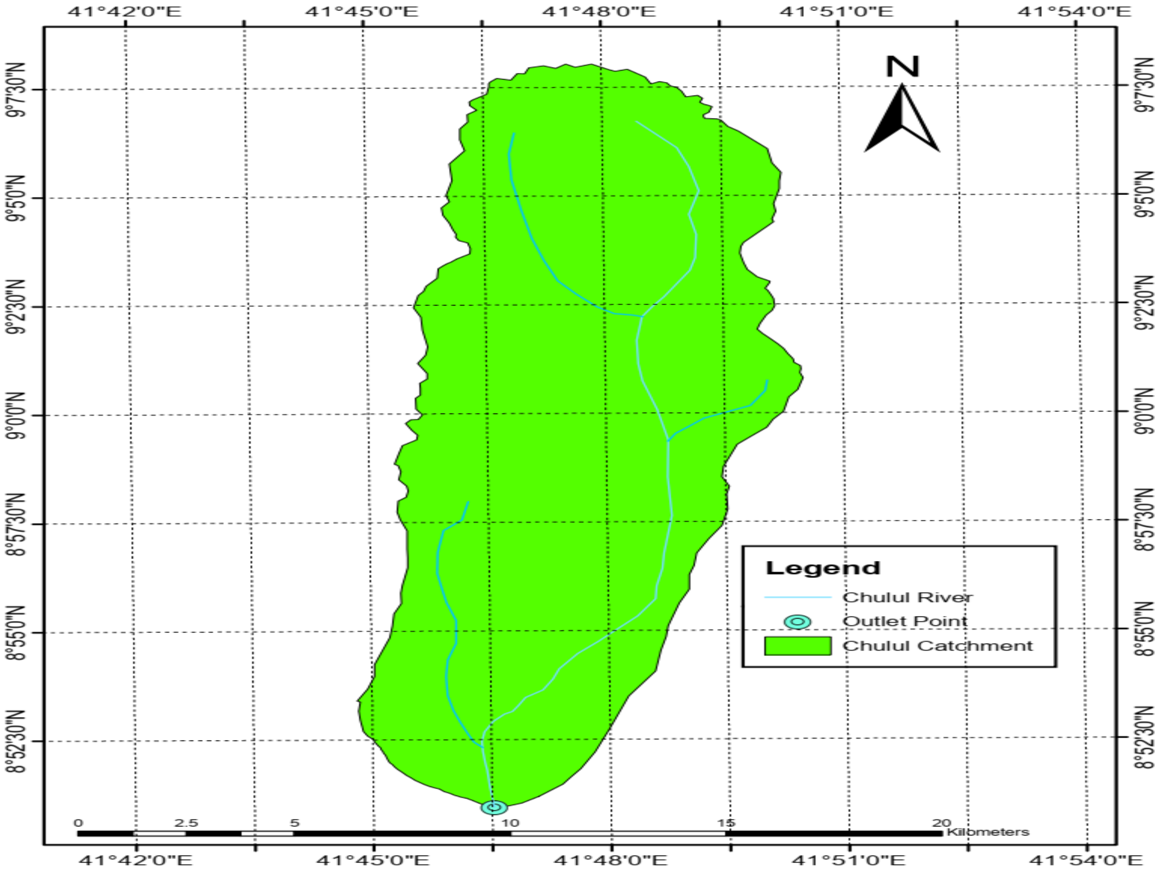

Figure 5 Chulul Catchment

The supply of irrigation water for the Hargaya irrigation scheme is diverted through the weir built across the Chulul River into the right and left canal, which consists of a 100 m lined and 3440 m earthen canal on both sides of the river bank. The lined canal part consists of a rectangular shape with a 1m width and 0.5 m canal depth to bring the discharge of 0.3 m^3/s for lined canal (design document, 2012), whereas the unlined canal consists of various shapes, widths, and depths. The average discharge measured at the left and right intakes during the study period was $0.135m^3/s$. The discharge measurement was taken four times at same point for precision and the measurement was held once per month through 8 months of study period.

Figure 6 Headwork of Hargaya irrigation scheme

The head work consists of two sluice gates designed to allow the free flow of water on both sides left and right, provided with fixed initial elevation and canal parameters to deliver an equal amount of the discharge.

Materials Used for data Collections

Materials used to conduct the research include double ring infiltro-meter, auger, core sampler, tape meter, weight balance, partial flume, floating material, GPS, digital camera, and peg interval have been used. Weight balance used to measure the weight of soil moisture, oven-dry used to dry the soil samples at 105˚C for 24 hours at Haramaya University soil laboratory, tape meter was used to measure the length of the canal and the area of the plots, stopwatch was used to know the time taken water passes through the partial flume, partial flume was used to measure the discharge at the field, GPS was used to measure the area of irrigated land and take coordinates, a hammer was used to hit the core sampler and to install double ring infiltrometer, stakes used to fix the measuring place, a floating object used to measure surface velocity and staff gauge used to measure water depth in the canal.

3.2. Data Collection and Analysis

3.2.1. Data Collection Methods

The research was carried out for two irrigation seasons, for eight months. The first irrigation season turned into began in early September to December 2022 while the second irrigation season included the period from January to April 2023. This study collected primary and secondary data to get the research findings. The velocity area method was used to measure the discharge at the main and secondary canals.

3.2.2. Primary Data Collection

Primary data have been collected through HH survey, interviews with respective stakeholders, and group discussions have been deeply practiced for cross-comparison and well-being of information gathering and analysis. Field measurements, including soil samples, were collected for the computation of various physical properties of soil, and infiltration rate tests were taken at head, middle, and tail fields along canal reach. A comprehensive field survey was carried out throughout the study period. The criteria for selection of field location is depend on main canal reach and command area of the scheme was divided in to three blocks head, middle and tail.

Field Observation

The functionality of irrigation structures, structural design system, carrying capacity, damage, condition of distribution structures, erosion, siltation of canal, weed and vegetation growth in the canal, total irrigated area, irrigation practices, and types of crops grown were observed at the field. Then, data collected through observation was analyzed using figures and tables.

A. Soil Sampling

The soil samples at 0-30 cm, 30-60 cm, and 60-90 cm depths considered as effective root zone have been taken at each stratum. Soil physical properties (soil texture, field capacity, permanent wilting point) were determined from a total of one hundred-eight disturbed soil samples taken from nine plots using an auger. Fifty-four soil samples were taken one day before irrigation, and fifty-four soil samples were taken post-irrigation to measure soil moisture content. The bulk density of the study area was determined using twenty-seven undisturbed soil samples collected with the help of a core sampler. Then the soil moisture content at field capacity and permanent wilting point values were computed through laboratory procedure (Appendix Table 2).

B. Discharge Measurement at Canal

To achieve sufficient and equitable water delivery to the fields it is necessary to know the discharge in the canal (Bos, 1994). The conveyance discharges have been measured using the velocity area method, which consists of estimating the average flow velocity and measuring the wetted cross-sectional area of the canal. Finally, the discharge can be calculated using equation (1).

$$Q = V * A \tag{1}$$

Where Q is the discharge in m^3/s, V is the average flow velocity in m/s and A is the area of the wetted cross-section in m^2.

Computation of average flow velocity

Flow velocities through main and secondary canals were obtained by the floating method. For computation discharge at main and secondary canal velocity area method was used. Canal discharge can be obtained by multiplying flow velocity at canal section with wetted cross sectional area of the canal at point of measurement. Floating material was put at the center of the canal on the upper end of the canal section, and the time it took to reach the marked section of the same canal was registered. This test was replicated four times to avoid mistakes, and the average time was taken to calculate the discharges. The average velocity and flow rate were calculated by dividing the distance by the average time and multiplying the cross-sectional area by the average flow velocity. Average flow velocity at the surface, Vs. is first determined by measuring the time it takes for a floating object to travel through a previously measured distance of 10 meters along the canal. To compute the surface velocity, Vs, the selected length, L, is divided by the travel time, t (Dinka, 2017).

$$\mathrm{Vs} = \frac{\mathrm{L}}{\mathrm{t}} \quad (2)$$

Where, Vs is the surface velocity in (m/s), L is the distance in meters between points A and B, and t is the travel time in seconds between points A and B.

The surface velocity must be reduced to obtain the average velocity because the surface water flows faster than subsurface water due to friction at the bottom of the water depth. For most irrigation canals this reduction factor is about 0.8 (FAO, 1993). The average flow velocity is computed using equation (3).

$$\mathrm{Va} = 0.8 * \mathrm{Vs} \quad (3)$$

Where Va is the average flow velocity (m/s), and Vs is the surface velocity (m/s).

The measurements were taken one time per month for successive eight months at selected twelve points on the main canal and at four points for the secondary canal to capture fluctuations of irrigation water flows in the canals. For lined canals, cross-sectional areas were calculated using measured canal width and depth while for unlined canal wetted cross-sectional areas were computed depending on canal geometry.

C. Discharge Measurement at the farm Level

To determine the discharge of water applied into the field a 3-inch partial flume was used to measure the flow rate applied to the field. Irrigation continued until the farmers thought enough water was applied to the field. When the irrigator completed irrigating the area, the average depth of irrigation water passing through the flume and the respective time were recorded for irrigated field sizes (Amede, 2014). The measurements were taken four times for accuracy and applied discharge at farmers plots were measured at developmental stage for the two irrigation seasons and average value was used. The discharge was directly read from the calibrated curve or computed using equation (4).

$$Q = C_f * H^n \quad (4)$$

Where Q is discharge through the flume (l/s), C_f is discharge coefficient from rated tables, H is water depth measured at one-third from in late of converging, and C and n are constants for flume with three-inch throat width from rated tables.

Flow rate at the farm level was measured by installing a three-inch partial flume at the inlets of farmers' fields for each of the selected nine plots from the head, middle, and tail reach. Farmer plots were selected from farmers selected for a questionnaire survey at each canal reach. This study used a three-inch calibrated partial flume to compute application efficiency and storage efficiency.

Figure 7 Discharge measurements at farm level using 3" inch Partial flume

3.2.3. Secondary Data Collection

Secondary data were collected from the district and zonal agricultural development experts, national meteorological institute, design documents, and related literature. This data includes total command area, irrigable area, irrigated area, annual production, climate data, and crop data such as Kc value at each growth stage, LGP, depletion fraction, and root depth. The long-term climatic data of 1990-2019 were collected from Girawa meteorological station, near the scheme site. Secondary data on the total command area, irrigable area, and irrigated area were collected from the woreda and zonal agricultural office.

3.3. Data Analysis Techniques

Data collected through interviews, group discussions, and observations were analyzed and discussed using figures and tables. Models used for this study were CROPWAT 8.0, ArcGIS 10.7, XLSTAT 2022, and Microsoft Excel sheets have been used. Finally, the selected performance indicators were determined.

Determination of soil parameters

For textural analysis of the soil, disturbed soil samples have been collected from selected plots in the scheme at three locations (head, middle, and tail) along the diagonal of the selected fields using an auger with soil depths of 0-30 cm, 30-60 cm and 60-90 cm (Appendix Figure 3b). The hydrometer method was used for analyzing particle size distribution at Haramaya University, and the textural class was assigned using the USDA textural triangle (Appendix Figure 2).

i. Soil bulk density

The soil bulk density was determined using twenty-seven undisturbed soil samples collected from three field locations using a 5 cm internal diameter and 5 cm height core sampler with a volume of 98.125 cm^3. The soil samples were collected from each three sample points at three depths 30 cm intervals up to 90 cm, considered an effective root zone, and oven-dried at 105 °C for 24 hours. Then, bulk density was determined (Hillel, 2004).

$$\mathrm{Bd} = \frac{\mathrm{Ms}}{\mathrm{Vtc}} \qquad (5)$$

Where Bd is soil bulk density (g/cm^3), Ms is the mass of dry soil (g) and Vtc is the total volume of soil in the core sampler (cm^3).

ii. Determination of Field capacity, Permanent wilting point, and Moisture content

In the laboratory, soil samples were analyzed to determine soil moisture content at field capacity and permanent wilting point, after soil samples were saturated for 24 hours and state where all pore spaces were filled with water using the pressure plate apparatus. The moisture content at FC and PWP was determined by applying pressure of 1/3 bars and 15 bars for field capacity and permanent wilting point respectively. Then, the values were determined experimentally in terms of gravimetric moisture content held in the soil at FC and PWP. Finally, gravimetric soil moisture was multiplied by bulk density to get the corresponding volumetric value.

The soil moisture content measurements before and one day after irrigation have been determined through a gravimetric approach, collecting soil samples with an auger, weighing the moist soil samples, removing the water by drying them in an oven at 105 C^o for 24 hours, and reweighing the sample to know the quantity of water eliminated. Finally, the soil moisture content has been computed using this formula (FAO, 2002).

$$\theta_m = \frac{Ww - Wd}{Wd} * 100 \tag{6}$$

Where θ_m is soil moisture status on a weight basis (%), Ww is the weight of the fresh sample (g), and Wd is the weight of the dry soil sample (g).

The moisture content of soil samples was converted to the volumetric moisture content (θ_v) has been computed (Minibel, 2019).

$$\theta v = \theta m * Bd \tag{7}$$

Where θ_v is volumetric moisture content (%) and Bd is bulk density

Total available water is the amount of water that crops can use from the soil for selected fields, which was computed from the moisture content in volume bases at field capacity and permanent wilting point. The volumetric total available water was calculated using the following equation (Allen, 1998).

$$TAW\ (mm) = 10 * (\theta FC - \theta PWP) * Rd \tag{8}$$

Where: TAW is total available water in the root zone (mm), θFC is moisture content at field capacity (%), θPWP is the moisture content at the permanent wilting point (%), and Rd is the depth of root zone (m).

iii. Soil infiltration rate

The infiltration rate of the soil in the study area was determined using a double ring infiltrometer of 30 cm and 60 cm inner and outer ring diameters, respectively at selected farmer's plots. The double ring infiltrometer was driven up to 15 cm depth, depending on the soil depth of the site, by a hammer. Depths of water levels were measured at successive time intervals from the datum established on the edge of each cylinder (Johnson, 1991). The infiltration rate tests were taken at three farmers' plots selected from head, middle and tail end users and average value was used as input for CROPWAT 8 software to compute crop water need. Infiltration rate test is used to identify water holding capacity of the soil in the study area.

3.3.1. Rainfall Data Analysis

The monthly rainfall data required for computation of crop water requirement were collected from Girawa meteorological station, which is a nearby station. Missing rainfall and temperature data were computed with the help of XLSTAT 2022 using multiple imputation methods with self-iteration up to several times. Multiple imputations is a strategy of filling each missing value by generating plausible values drawn from their predictive distribution and relationships among observed variables in the data set. This method is a simulation-based statistical technique to handle missing data. Multiple imputed data sets can be analyzed by complete data methods and the results from these analyses are combined and overall estimates are produced. This method avoids the problems observed in single imputation, can relieve the distortion of the sample variance, and produces unbiased estimates (Gebre, 2021).

To check the consistency of recorded data, the double mass curve was used. The accumulated total of the gauge in the study area is compared with the corresponding average accumulated total for a representative group of neighbor gauge stations. If the change in the regime of the curve is observed, it should be corrected. Fortunately, the selected station in the study area was consistent; there was no need for further correction.

Effective rainfall is a portion that crops can effectively use. This means that not all rain is available to the crops as some are lost through runoff and deep percolation. The effective rainfall was computed using the CROPWAT 8 model and the USDA Soil Conservation Service method (Negash, 2017).

3.3.2. Determination of Reference Evapotranspiration (ETo)

To estimate crop water and irrigation water requirements at the field CROPWAT 8.0 was used to calculate ETo using input data such as climatic, crop, soil, and, irrigation and rainfall data. Reference evapotranspiration can be computed using mean monthly maximum and minimum temperatures, relative humidity, sunshine hour, and wind speed data. Reference ETo was computed using the Penman-Monteith equation as stated in (Allen, 1998).

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn}-\mathrm{G})+\mathrm{y}\frac{900}{\mathrm{T}+273}\mathrm{U2}(\mathrm{es}-\mathrm{ea})}{\Delta+\mathrm{Y}(1+0.34\mathrm{U2})} \quad (9)$$

Where ETo is reference evapotranspiration in mm/day, Rn is net radiation at the top surface MJm2/day, G is soil heat flux density MJm^2/day, T is the mean daily air temperature at 2 m height (C^o), U_2 is the wind speed at 2 m height (m/s), es –ea is saturation vapor pressure deficit (Kpa), Δ is the slope vapor pressure curve (Kpa/oC), and Y is psychrometric constant (Kpa/0C).

3.3.3. Determination of Crop Water and Irrigation Water Requirement

Crop water is required to know how much of the crop's applied irrigation water is consumed. The crop water requirement of the major irrigated crops grown in the study area was estimated using the CROPWAT 8 model computer program. The determination of crop water requirement using the model was based on the computed reference evapotranspiration (ETo) value using the climatic data.

Data on crop type and planting date were collected using field visits, household surveys, and interviews with the beneficiary, and other data including lengths of growing period, growing stages, crop coefficients, rooting depths, depletion levels, and yield response factors were collected from FAO(1992) and 56 (1998) papers. According to Allen (1998), crop coefficient depends on relative humidity and wind speed at mid-stage. During high relative humidity (RH>80%) and low wind speed (u< 2 m/s), the kc-value is reduced by 0.05 while its values increased by 0.05 during low relative humidity (RH<50%) and high wind speed (5 m/s). The kc-value out of this range was adjusted and converted to the local area. Fortunately, the relative humidity and wind speed of all months during the study period were in the range; there was no need for further adjustment. Finally, after the values of ETo are calculated at each growth stage, ETc can be computed as (Kivumbi, 2006).

$$\mathrm{ETc} = \mathrm{ETo} * \mathrm{Kc} \tag{10}$$

Where ETc is crop evapotranspiration (mm/day), ETo is reference crop evapotranspiration (mm/day), and Kc is crop coefficient.

The irrigation water requirement was computed after the estimation of effective rainfall by the CROPWAT 8 model using the water budget equation (FAO, 1989).

$$\mathrm{IWR} = \mathrm{ETc} - \mathrm{Peff} \tag{11}$$

Where ETc is crop evapotranspiration (mm/season) and Peff is effective rainfall (mm/season).

Effective rainfall is the factor that influences irrigation planning and crop production, including soil slope, soil texture and structure, plant cover, storm intensity, and duration. The crop and irrigation water requirements of the Hargaya irrigation scheme were calculated with the CROPWAT 8.0 program using the climatic data, cropping pattern, planting dates, yield response, depletion fraction, and area of each crop.

$$\mathrm{CWRT} = \sum\left(\mathrm{CWRi} * \frac{\mathrm{Ai}}{\mathrm{At}}\right) \tag{12}$$

Where CWRT is the total crop water requirement in mm/season, CWRi is the individual crop water requirement in mm/season, Ai is the individual irrigated area of the respective crops in ha, and At is the total irrigated area in ha.

3.4. Internal Indicators

This study uses internal and external performance indicators to evaluate the irrigation system's performance. Internal performance indicators used in the study were conveyance efficiency, application efficiency, storage efficiency, distribution efficiency, deep percolation ratio, and overall scheme efficiency to investigate the existing performance level of the Hargaya irrigation scheme.

3.4.1. Conveyance Efficiency (Ec)

Discharge measurements were taken at various points on the main and secondary canal flow monitoring points set at a straight passage through the canal length to compute conveyance efficiency (Figure 9). For discharge measurement at the main and secondary canal, the floating method was used due to the absence of a current meter. Flow velocities were measured four times repeatedly at same point to gain precise data. The flow of the main canal was measured at six points for each left and right canal at the head, middle, and tail reach. For every secondary canal, the flow was measured at two points to determine the losses. The discharge measurement was conducted at the upper, middle, and downstream of the main canal to determine the actual discharge at each reach over the canal length. The wetted cross-sectional area of the canal was determined using measured canal depth and width at the flow monitoring point. The scheme consists of two main canals a 100 m lined and a 3440 m earthen canal for both the left and right canal. The lined canal is a rectangular shape with 0.5 m depth and 1 m width, while the earthen canal consists of various shapes, depths, and widths through canal reach respectively.

The second measurement was taken at a fixed distance following the first measurement, and the measurements were taken at selected points from both the right and left canal through canal length. The same procedure is followed from the upper parts of the canal to the tail end. Finally, conveyance efficiency was determined (Bos, 1994).

$$\mathrm{Ec} = \frac{water\ flowing\ at\ theoutlet}{waterflowing\ at\ the\ inlet\ of\ canal} \qquad (13)$$

Where Ec is conveyance efficiency (%), the water delivered and diverted discharge in specified canal length in m^3/sec and T_L is total loss. Loss in the conveyance system was computed by (Frenken, 2002).

$$T_L = \frac{\mathrm{Qi} - \mathrm{Qo}}{\mathrm{L}} \qquad (14)$$

The overall conveyance efficiency of the main canal is the product of Ec calculated at different sections over the length of the canal. The overall conveyance efficiency of the scheme was computed using the following equation (Bos, 2005).

$$Ec = Emc*Esc*100 \tag{15}$$

Where Emc is the conveyance efficiency of the main canal (%), and Esc is the conveyance efficiency of the secondary canal (%). Losses in the conveyance system were computed as (Alebachew, 2021):

$$Lc = Qin - Qout \tag{16}$$

Where Ec is conveyance efficiency (%) and Lc is conveyance loss (m^3/sec)

3.4.2. Application Efficiency (Ea)

The application efficiency is the ratio of moisture added to the soil profile through irrigation to the total water applied to the farm. The soil samples were collected from nine various plots from head users to tail-end users at 30 cm interval soil depths up to 90 cm, and the amount of water stored in the root zone was determined by the gravimetric method. The depth (Zr, mm) of moisture retained in the soil profile was determined by (Ahmed and Mishra, 1990).

$$Zr = \sum_{n=1}^{n} \left(\frac{Qf - Qi}{100}\right) * ASi * Di \tag{17}$$

Where Qf is the moisture content of the i^{th} layer of soil after irrigation on oven dry weight basis (%), Qi is the moisture content of the i^{th} layer of soil before irrigation on oven dry weight basis (%), ASi is the specific gravity of the i^{th} soil layer (dimensionless), Di is the depth of soil i^{th} layer (mm), and n is a number of layers in the root zone.

The assessment of the application efficiency was made at nine farmers' fields. Water applied to the area was measured by a three-inch partial flume installed at the entrance of selected plots when fields were being irrigated. Thus, the estimated water depth was changed to its respective discharge by directly reading from the calibration curve of water level versus discharge graph (Appendix Figure 1). Similarly, discharge can be calculated by measuring water depth through partial flume using equation (4). Finally, the moisture content stored in the root zone was determined by a gravimetric method using equation (6). Application efficiencies were computed (Amsalu, 2020).

$$\text{Ea} = \frac{\text{Zr}}{\text{Wd}} * 100 \tag{18}$$

Where Ea is application efficiency, Zr is the average depth of water stored in the plant's root zone, and Wd is the average water depth applied to the field.

3.4.3. Storage Efficiency (Es)

For the computation of the water saved in the root zone of each field, soil samples were collected from various locations of the field and soil depths at 30 cm intervals down from the surface up to 90 cm before and after each irrigation event. The soil moisture content was determined using the gravimetric method. The storage efficiency was determined (Alebachew, 2021).

$$Es = \frac{\text{Zr}}{\text{Wn}} * 100 \tag{19}$$

Where Es is storage efficiency (%), Zr is water stored in the root zone during irrigation (mm) and Wn is water required (needed) in the root zone before irrigation (mm).

The water needed in the root zone before irrigation was computed by (Michael, 2008).

$$\text{Wn} = \sum_{n=1}^{n} \left(\frac{Mfci - Mbi}{100}\right) * Bdi * Di \tag{20}$$

Where Wn is the net amount of water to be applied during irrigation (mm), Mfci field capacity moisture content in the i^{th} layer of the soil (%), Mbi is moisture content before irrigation in the i^{th} layer of soil (%), Bdi is bulk density of the soil in the i^{th} layer, Di is the depth of the soil layer within the root zone cm, and, n is several soil layers in the root zone.

3.4.4. Distribution Uniformity (Du)

This indicator shows how water is applied uniformly to the field along the irrigation run. Distribution uniformity of irrigation water at the farmer’s field soil samples was taken using an-augur at 30 cm depth intervals up to 90 cm. Then, the soil moisture contents of the soil samples at the selected fields were analyzed to determine the depth of water distribution along the field. To evaluate the water distribution uniformity, moisture contents were collected along the furrow then average depths of water stored during irrigation and numerical deviation in the depth of water stored were calculated. As reported by (Jurreins, 2001), distribution uniformity is defined as the minimum infiltrated depth divided by the average infiltrated depth. Similarly, (Jahromi, 2001) reported that distribution uniformity is the average infiltrated depth in the low quarter of the field divided by the average infiltrated field depth over the entire area. The moisture content collected from different locations was arranged in descending order, and then the least quarter and the mean were computed. Finally, the distribution uniformity was determined by (Walker, 2003).

$$\mathrm{Du} = \left(\frac{Zmin}{Zav}\right) * 100 \qquad (21)$$

Where Du is the distribution uniformity (%), Zmin is the minimum depth infiltrated at the i^{th} point (mm), and Zav is the mean depth penetrated (mm).

The depth of stored water at a particular soil layer was calculated using the equation (Mukherjee, 2004).

$$\mathrm{Z} = \left(\frac{\mathrm{Mai-Mbi}}{100}\right) * \mathrm{Bdi} * \mathrm{Di} \qquad (21a)$$

Where Mai is the moisture content of the i^{th} layer of the soil after irrigation weight basis (%), Mbi is the moisture content of the i^{th} layer of soil before irrigation weight basis (%), Bdi is the bulk density of the soil in the i^{th} layer, Di is the depth of the soil layer within the root zone (cm), and n is a number of soil layers in the root zone.

The total depth of water stored at the place of soil sampling from Z1 to Z9 was calculated as:

$$Z1 = Z_{1\,(0\text{-}30)} + Z_{1\,(30\text{-}60)} + Z_{1\,(60\text{-}90)} \qquad (21b)$$

$$Z2 = Z_{2\,(0\text{-}30)} + Z_{2\,(30\text{-}60)} + Z_{2\,(60\text{-}90)} \qquad (21c)$$

3.4.5. Deep Percolation Ratio (DPR)

The irrigation method practiced in the Hargaya scheme was the blocked-end furrow type. Therefore, the runoff ratio is neglected and the loss of irrigation water below the root zone is only through deep percolation. Consequently, the deep percolation ratio was calculated (Pratap, 2020).

$$DPR = 100 - Ea - RR \tag{22}$$

Where DPR is deep percolation ratio (%), Ea is application efficiency (%) and RR is runoff ratio

3.4.6. Overall scheme efficiency (E_o)

The overall scheme efficiency is calculated from conveyance and application efficiency. The overall scheme efficiency indicates the general condition of the scheme level and is computed using equation (23). The overall scheme efficiency was calculated as the product of conveyance and application efficiency (Amsalu, 2020).

$$Eo = Ec * Ea \tag{23}$$

Where Eo is overall scheme efficiency (%), Ec is conveyance efficiency (%) and Ea is application efficiency (%).

3.5. External performance indicators

External performance indicators used in this research were water use efficiency, agricultural output indicators, and water delivery capacity. In addition, maintenance and physical sustainability indicators have been used to assess the performance of the Hargaya small-scale irrigation scheme. External performance indicators evaluate irrigation systems based on a relative comparison of absolute values rather than being referenced to targets (Amsalu, 2020).

3.5.1. Agricultural output indicators (land and water) productivity

1) Land productivity indicators

Land productivity quantifies the change in crop yield (Bos, 2005). The data regarding production value in local price was collected from the Meyu Muluke district agricultural office and household survey, while the irrigated crop area and command area were measured using GPS during the field survey. Four indicators related to the output of different units used for evaluation of agricultural performance were output per irrigated area ($/ha), output per unit command area

(\$/ha), output per unit irrigation supply (\$/m^3) and output per unit water consumed (\$/m^3) were computed as (Molden, 1998).

$$\text{Output per unit Irrigated Area (\$/ha)} = \frac{\text{Production}}{\text{Irrigated Cropped Area}} \tag{24}$$

$$\text{Output per unit Command (\$/ha)} = \frac{\text{Production}}{\text{Command Area}} \tag{25}$$

2) Water productivity indicators

Water productivity quantifies the change in crop yield or value per m^3 of water supplied (Douglas, 1999). The following two water productivity indicators were calculated as:

$$\text{Output per unit irrigation supplied} = \frac{\text{production}}{\text{Diverted irrigation Supply}} \tag{26}$$

$$\text{Output per unit water consumed (\$/m}^3\text{)} = \frac{\text{Production}}{\text{Volume of water consumed}} \tag{27}$$

Agricultural output production values were determined by local price and finally converted to US\$, to standardize and compare the results with the other research findings in the world.

3.5.2. Water Supply Indicators

Water use performance was evaluated using two types of indicators, relative water supply, and relative irrigation supply. These indicators describe the state of water availability or shortage and how tightly supply and demand are related. The value of RIS more than one indicates excess irrigation water is being supplied. If the RIS value is greater than the RWS value, it shows that the major amount of water provided in the area is from irrigation (Bos, 1997).

3.5.2.1.Relative water supply (RWS)

Relative water supply indicates the adequacy applied to the crop's water demand. It is the ratio of total water supplied by irrigation and rainfall to total water it was demanded by crop ETc (Ayana, 2021).

$$\text{Relative Water Supply} = \frac{\text{Total Water Supply}}{\text{Crop water demand}} \quad (28)$$

Where Total water supply is the sum of diverted water for irrigation plus rainfall (m^3), Crop water demand is potential evapotranspiration or the real evapotranspiration (ETc) when full crop water requirement is satisfied (m^3).

3.5.2.2.Relative irrigation supply (RIS)

The water supply indicator described as the ratio of irrigation supply to irrigation demand is relative irrigation supply. Irrigation water is a limited resource in many irrigation schemes and is a major constraint for production. This indicator is useful to assess the degree of irrigation water stress or abundance concerning irrigation demand (Alebachew, 2021).

$$\text{Relative irrigation supply} = \frac{\text{Irrigation Supply}}{\text{Irrigation demand}} \quad (29)$$

Where Irrigation supply is only the surface diversion of irrigation (m^3), Irrigation demand is the ETc minus effective rainfall (m^3).

3.5.3. Water Delivery Performance Ratio (WDPR)

The water delivery performance ratio is the amount of water diverted to the scheme versus the amount needed at the peak period to be supplied. This means the actual water provided to the system is divided by peak irrigation water requirement (Raghuwanshi, 1998). It was computed to evaluate the actual carrying capacity of the canals relative to peak consumptive demand. Water delivery capacity indicates the degree to which irrigation infrastructure is constraining cropping intensities by comparing the canal conveyance capacity to peak consumptive needs.

$$\text{WDPR} = \frac{\text{The carrying capacity of the canal}}{\text{Peak consumptive demand}} \quad (30)$$

Where WDPR is the water delivery performance ratio, Peak consumptive demand is the peak crop irrigation requirement for a monthly period expressed as a flow rate required at the head of the irrigation system.

Irrigation scheduling

Irrigation scheduling decides when to irrigate and how much water is applied per irrigation. To determine the irrigation schedule and to compare with the current irrigation practices, data of moisture content at field capacity and the permanent wilting point was determined, and depletion fractions were adopted from FAO(1998). Also, farmer's irrigation practices, such as irrigation methods, irrigation frequency and irrigation interval, and application depths, were considered. The crops' irrigation intervals were determined procedurally through equations 31 and 32. Finally, the irrigation schedule of the main crops at the Hagaya irrigation scheme was calculated using CROPWAT 8.0.

$$I = \frac{RAW}{ETc} \qquad (31)$$

$$RAW = TAW * P \qquad (32)$$

Where RAW is readily available water (mm), P is water depletion fraction (%), I is irrigation interval (day), TAW is total available soil moisture (mm), ETc is evapotranspiration of the crop (mm/day). The value of P was taken from the table (FAO, 1998) and can be adjusted for different ETc using the equation (Allen, 1998).

$$P = Ptable + 0.04(5-ETc) \qquad (33)$$

Where P is the adjusted depletion fraction and ETc is the crop evapotranspiration (mm/day)

3.6. Physical Performance Indicators

Physical indicators are related to the changing or losing irrigated land in the command area for different reasons. Two indicators are categorized under physical sustainability indicators as enumerated by (Mogos, 2017).

A. Irrigation ratio (IR)

The irrigation ratio is the ratio of currently irrigated areas to irrigable areas. It tells the degree of utilization of the available command area for irrigated agriculture at a particular time. Improper design of irrigation infrastructure leads to a low irrigation ratio (Getamesay, 2019). On the other hand, cropping intensity, a ratio of annual cropped area to command area, indicates annual land utilization. Irrigation ratio is expressed as:

$$\mathrm{IR} = \frac{\mathrm{CIA}}{\mathrm{CA}} \tag{34}$$

Where IR is irrigation ratio, CA is command area (ha) and CIA is current irrigated area (ha)

B. Sustainability of Irrigated Area (SIA)

According to (Bos, 1997), the sustainability of irrigated area is the ratio of currently irrigated area to initially irrigated area when designed. It is a useful indicator for assessing the sustainability of irrigated agriculture. Lower values of this indicator show the abandonment of lands that were initially irrigated and, hence, indicate contraction of the irrigated area over time. On the other hand, values higher than unity indicate expansion of irrigated area and would imply more sustainable irrigation.

$$\mathrm{SIA} = \frac{\mathrm{CIA}}{\mathrm{IA}} \tag{35}$$

Where SIA is a sustainability irrigated area (ha), CIA is currently an irrigable area (ha), and IA is an initially irrigated area (ha).

C. Effectiveness of Infrastructure

This performance indicator focuses on the physical structures in irrigation system components. Maintenance indicators of the irrigation scheme would provide insight into the features of the conservation of the system (Alemie, 2021). As reported by (Bos, 1994), maintenance indicators show the condition of infrastructures at the scheme. The maintenance indicator used for this study was the effectiveness of infrastructure. The effectiveness of infrastructure is the ratio of functional structure to total number of structures initially installed (Kloezen, 1998).

$$\text{Effectiveness of infrastructure} = \frac{\text{Number of functioning structures}}{\text{Total number of structures initially installed}} \tag{36}$$

3.7. Data Source and Sampling Method

A random sampling method was used to select farmers for the household survey. To evaluate the farmers' perception of the scheme's performance and institutional aspects, the sample size of farmers was chosen out of 244 household farmers who own irrigable land from the head, middle, and tail end. Sample sizes were calculated as (Alebachew, 2021).

$$n = \frac{N}{1+N(e)^2} \qquad (37)$$

Where n is the sample size, N is the population size, e is designed to the level of precision, and e =10% precision level.

$$n = \frac{N}{1+N(e)^2} = \frac{244}{1+244(10\%)^2} = 71$$

This sampling method is suitable for comparative analysis of farmers' perceptions considering different interest groups. The Command area of the irrigation scheme was divided into three reaches and interviewed farmers selected from each section head, middle, and tail-end were 23, 25, and 23 farmers, respectively. Farmers' perceptions of the scheme's performance and institutional aspects were evaluated using a sample of 71 households that were interviewed. Out of the total respondents, the number of males and females was 52 and 19, respectively.

3.8. Organizational Setup and Irrigation Water Management

Sample questionnaires were prepared to answer the question related to organizational setup; performance of irrigation water management and scheme maintenance data were collected from DAs, woreda agriculture office experts, and beneficiaries' households selected from each reach were analyzed with the help of Microsoft excels sheet and interpreted using tables and chart.

3.9. Assessment of Irrigation Institution and Support Services

Assessment of irrigation institutions and support services has been conducted to incorporate local knowledge and farmers' perspectives on the irrigation system. Institutional and support services situations were assessed using household surveys and interviews with stakeholders, including sample beneficiary farmers, WUA leaders, and Woreda agricultural office heads through questionnaires. To evaluate farmers' perception of the scheme and institutional aspects a randomly selected sample of 71 households were interviewed from the head, middle, and tail reach.

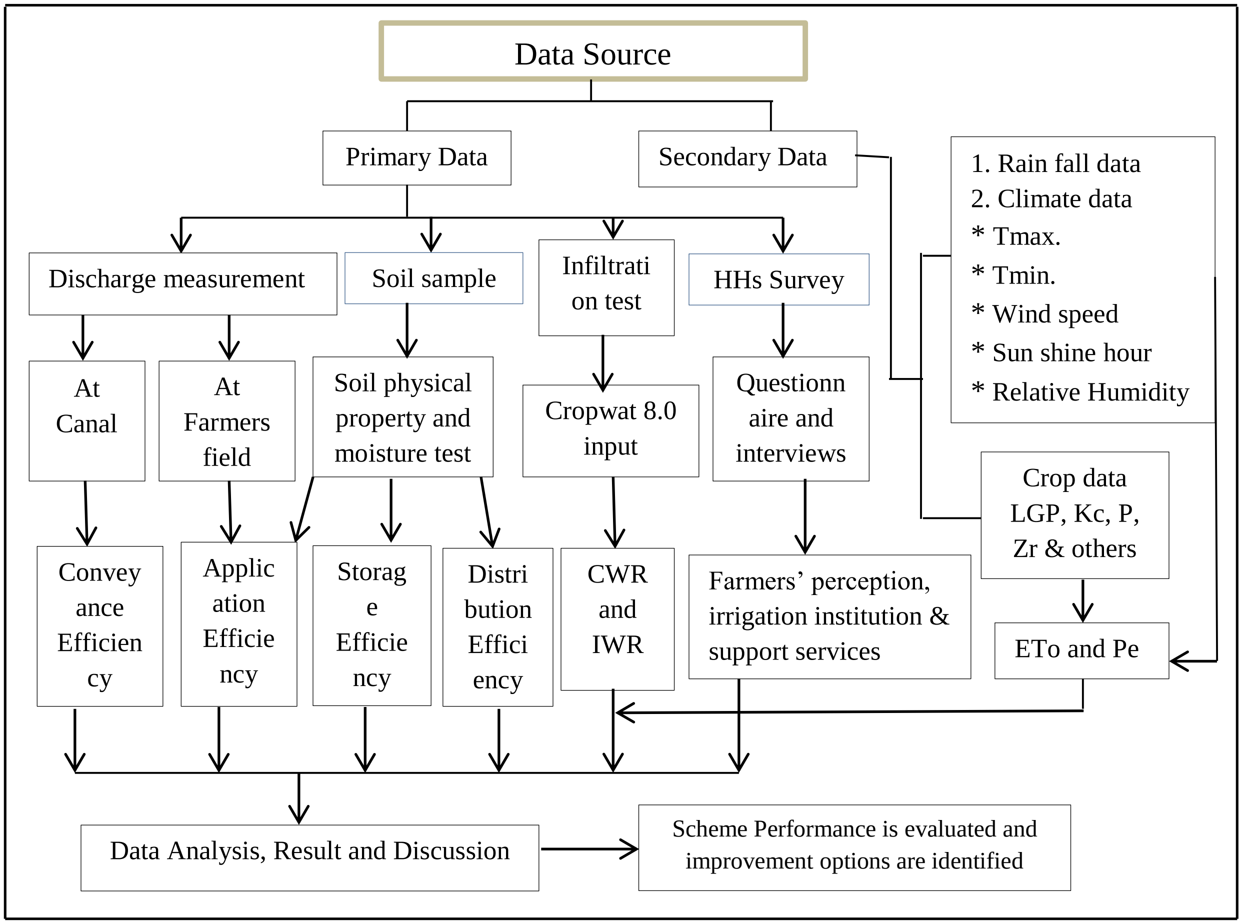

Figure 8 Methodological data collection flow chart

4. RESULTS AND DISCUSSIONS

4.1. Result of Soil Data Analysis

Soil samples were taken at depths of 30 cm intervals up to 90 cm to investigate the physical properties of the irrigation scheme. After soil samples were analyzed, soil texture, bulk densities, field capacity, and permanent wilting point were determined. The analysis of laboratory results of the soil from the study site is given in Appendix Table 1.

4.1.1. Soil Physical Properties

Soil physical properties of the study area moisture content at field capacity, permanent wilting point, texture, and bulk density were determined to understand the general features of the soil type of the irrigated area. To identify the soil texture, nine farmer's fields were randomly selected from head, middle, and tail end users. A total of one hundred-eight soil samples were collected and analyzed for soil moisture content, the results are shown in appendix tables 1 and 2.

Soil laboratory results from bulk density, FC, PWP, and TAW

The soil moisture at field capacity and permanent wilting point were determined using fifty-four disturbed soil samples collected one day before and fifty-four after irrigation from nine selected farmer's plots at 30 cm intervals of soil depth up to 90 cm. To compute moisture content at FC, soil samples were taken and analyzed through the pressure plate apparatus by applying a suction of 1/3 bar, while for PWP the pressure plate apparatus was applied at 15 bar to saturated soil samples until the water was no longer leaving the soil samples. The average calculated value of TAW (mm/m) of the irrigation scheme was 167.83 mm/m, within the acceptable range suggested by (Allen, 1998). The bulk density of soil in the study area shows variation with soil depth between 1.12 to 1.36g/cm^3(Appendix Table 2). Total available water is the difference between FC and PWP of the soil in the root zone and is computed using equation (8). The net irrigation depth must be smaller than or equal to the effective root zone to avoid deep percolation losses (FAO, 2002). The study computed the depth of irrigation water and schedule using the CROPWAT 8.0 model.

4.1.2. Soil infiltration rate

The basic infiltration rate of the study area was determined using a double-ring infiltrometer test, and the experiment results are shown in (Appendix Table 3). The basic infiltration rate of the study area was 5.4 mm/hr attained after 215 minutes. The basic infiltration rate was used as input data for the CROPWAT 8.0 model to compute crop water requirements. As a result, it indicates that the value was in the range of the basic infiltration rate of clay loam soil 5-10 mm/hr suggested by (FAO, 2001) and shown in appendix table (10).

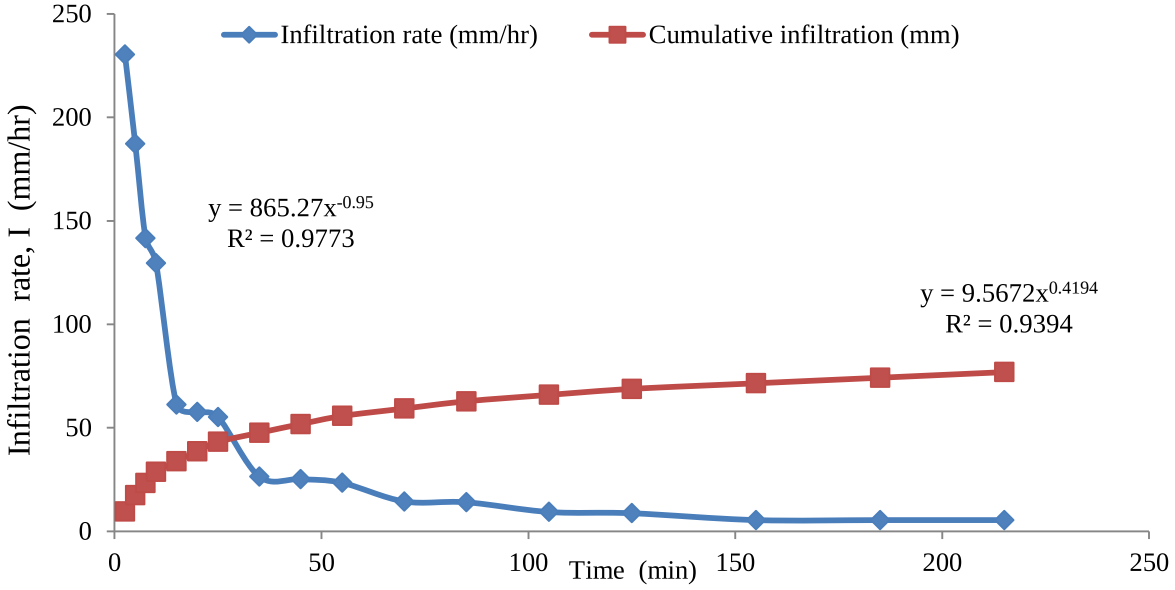

Figure 9 Curve of infiltration rate (mm/hr) Vs cumulative infiltration (mm)

Figure 10 Installation of double ring infiltrometer at farmer's field

Rainfall Data Analysis

The monthly rainfall data required for computation of crop water requirement were collected from Gurawa meteorological station, which is a nearby station. Missing rainfall and temperature data were computed with the help of XLSTAT 2022 using multiple imputation methods with self-iteration up to several times. Multiple imputed data sets can be analyzed by complete data methods and the results from these analyses are combined and overall estimates are produced.

To check the consistency of recorded data, the double mass curve was used. The accumulated total of the gauge in the study area (Girawa) is compared with the corresponding average accumulated total for a representative group of neighbor gauge stations Bedeno and Boko meteorological stations near to Girawa. If the change in the regime of the curve is observed, it should be corrected. Fortunately, the selected station in the study area was consistent; there was no need for further correction.

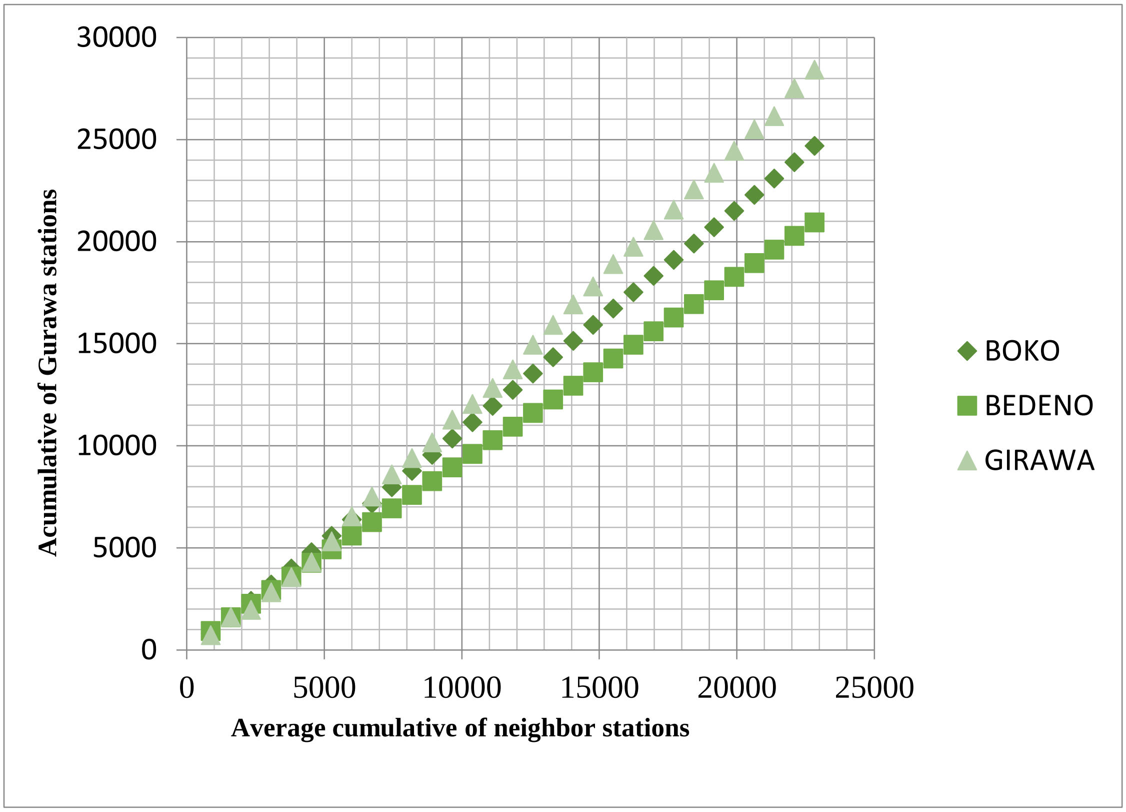

Figure 11 Double mass curve of Girawa Vs neighbour meteorological station

4.2. Determination of Reference Evapotranspiration (ETo)

Reference evapotranspiration can be calculated from the mean maximum and minimum temperatures, relative humidity, sunshine/radiation, and wind speed data (Hillel, 2004). The penman-Monteith approach was used to determine reference evapotranspiration. The result shown in (Table 1) indicates that the scheme's daily ETo values minimum and maximum were 2.85 mm/day in August and 4.11 mm/day in March, respectively. The monthly ETo values minimum and maximum were 87.6 mm/month in July and 127.4 mm/month in March (Table 2). The scheme's average daily and monthly ETo values were 3.53 mm/day and 106.86 mm/month respectively.

Table 1 Long-term climate data of the study area (1990-2019)

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo	RF	Reff
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day	(mm)	(mm)
January	10.4	27.5	73	153	7.2	18.2	3.44	13.1	12.8
February	10.8	28.2	69	152	7.5	19.8	3.88	10	9.9
March	12.1	28.3	72	163	7.3	20.5	4.11	61.3	55.3
April	11.4	27.9	79	154	6.2	19.1	3.74	131.1	103.6
May	12.2	27.5	83	174	6.1	18.5	3.57	124.3	99.6
June	10.2	27.2	86	235	5.3	16.9	3.15	75.4	66.3
July	10.9	28.5	89	218	4.2	15.4	2.92	118.7	96.1
August	12.2	27.3	92	232	4.1	15.6	2.85	153.3	115.7
September	11.1	27.8	81	154	5.9	18.3	3.58	132	104.1
October	9.8	25.6	73	141	7.8	20.4	3.75	62	55.9
November	9.7	26.9	67	149	8.1	19.7	3.71	25.9	24.8
December	9.4	26.1	62	142	8.3	19.3	3.6	10.3	10.1
Average	10.85	27.4	77	172	6.5	18.5	3.53	917.4	754.2

As shown in (Figure 12), the potential evapotranspiration of the study area is much less than the effective rainfall in July and August, with ETO values of 87.6 and 88.4 mm/month, respectively. This means that no irrigation is required through these two months, while irrigation is crucial for crops planted mainly from September to June since reference evapotranspiration is higher than effective rainfall.

Table 2 Average monthly Rainfall, Reff, and ETo of the study area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RF(mm)	13.1	10.0	61.3	131.1	124.3	75.4	118.7	153.3	132.0	62.0	25.9	10.3
Eff.RF (mm)	12.8	9.9	55.3	103.6	99.6	66.3	96.1	115.7	104.1	55.9	24.8	10.1
ETo(mm/month)	106.6	108.6	127.4	112.2	110.7	94.5	87.6	88.4	107.4	116.3	111.3	111.3

Where Reff. is effective rainfall in (mm), RF is total rainfall in (mm), and ETo is reference evapotranspiration in (mm/month).

The results of the mean monthly rainfall in the study area indicate the seasonal rainfall pattern of the study area was bimodal rainfall type distributions with peaks in August (153.3 mm) followed by September (132 mm) as shown in Figure (12).

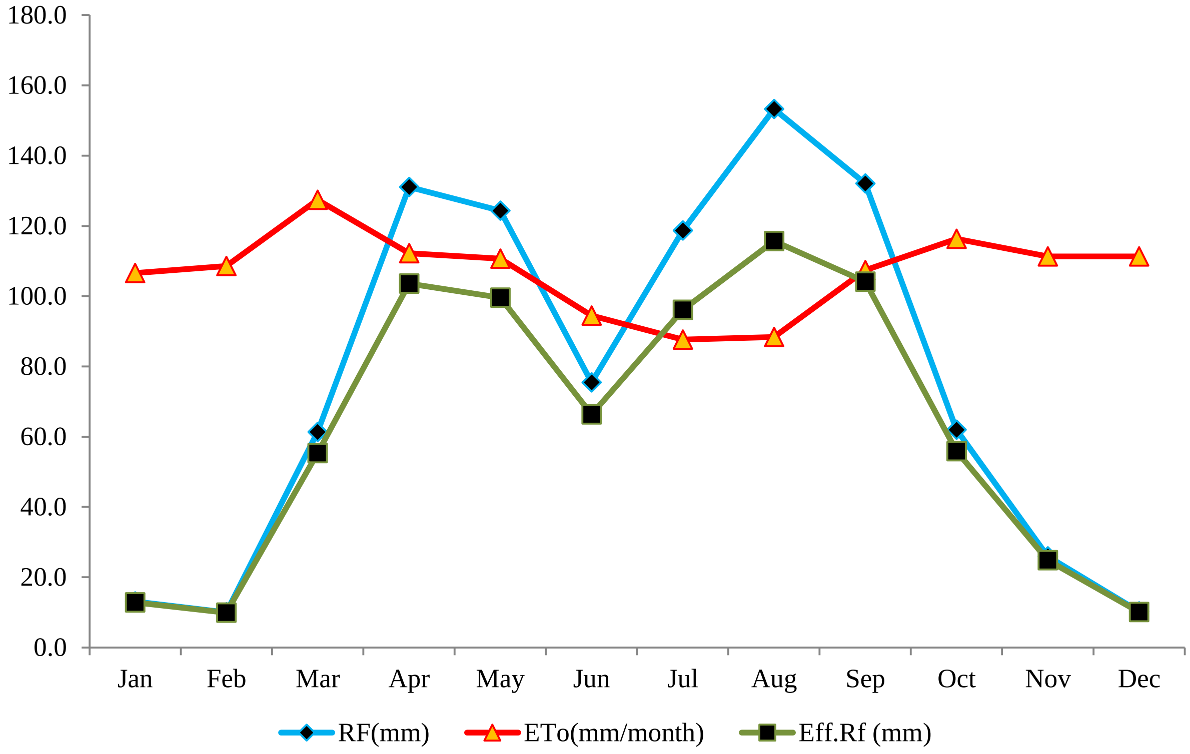

Figure 12 Average Monthly Rainfall, Reff, and ETo of the study area

4.3. Internal Performance indicator

Indicators used for the performance assessment of the Hargaya small-scale irrigation scheme were conveyance efficiency, application efficiency, storage efficiency, distribution uniformity, deep percolation ratio, and overall scheme efficiency.

4.3.1. Conveyance Efficiency

Conveyance efficiency of the left and right primary canal and four secondary canals within the scheme was computed using equation (13). Canal discharges were measured at twelve selected points through canal length as shown in (Figure 13). Flow monitoring points were benchmarked at the straight canal section for inflow and outflow discharge computation. The measurements were taken for eight months and the average discharge was computed. All data were measured repeatedly four times at the same point to gain reliable data, and an average of four values at inlet and outlet points were used.

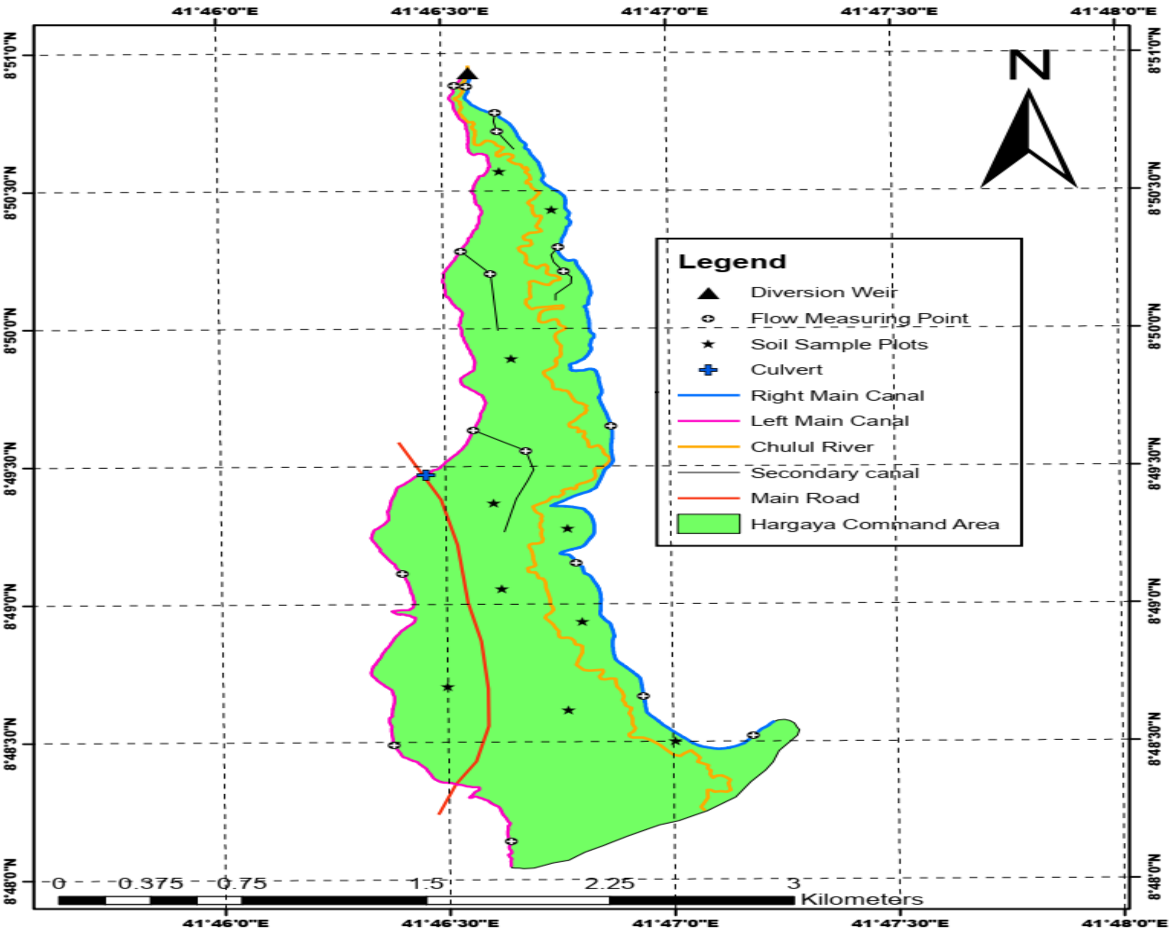

Figure 13 Command area of Hargaya small-scale irrigation scheme

As shown in Table (3), the average conveyance efficiency of the left canal at the head, middle, and tail reach was 91.4%, 58.1%, and 43.8%. In contrast, for the right canal, the values were 88.8%, 78.75%, and 49.1% (Table 4). The overall conveyance efficiency of the main canal was 68.5 percent. The result indicates that the amount of water lost at the left main canal was higher when compared to the right main canal because of the poor infrastructure designed at the left main canal. As observed from Figure (3), the left primary canal consist lack of drainage facilities. The average conveyance efficiency of the right canal was better than that of the left canal as it approached the recommended values for clay loam soil. Moreover, FAO (1989) stated that the conveyance efficiency of earthen canals for clay loam soil is 70- 80% for canal lengths greater than 2000 meters. The conveyance efficiency of the left canal ranged from 35- 85 percent for the earthen canal and 98.3 percent for the lined canal part, with a mean value of 64.5 percent.

Table 3 Conveyance efficiency of the left main canal

Canal type	Canal Reach	Segment No.	Distance b/n point	Mean discharge in flow	Mean discharge outflow	Conveyance Loss			Ec
			(m)	(l/s)	(l/s)	l/s	l/s/m	Loss (%)	(%)
	At the intake			135.3					
Lined canal	Upper head	1	100	135.3	133	2.3	0.023	2	98.3
Unlined canal	Lower head	2	600	133	113	20	0.033	15	85
	Upper middle	3	800	113	62	51	0.06	45	54.9
	Lower middle	4	800	62	38	24	0.03	39	61.3
	Upper tail-end	5	620	38	20	18	0.029	47	52.6
	Lower tail-end	6	620	20	7	13	0.021	65	35
Average conveyance efficiency								35.5	64.5

The length of the canal from main intake to upper head, upper head to lower head, lower head to the upper middle, upper middle to lower middle, lower middle to upper tail-end, and upper tail-end to lower tail-end was 100 m, 600 m, 800 m, 800 m, 620 m, and 620 m, respectively. Therefore, the discharge lost per meter length in the left primary canal from main intake to upper head, upper head to lower head, lower head to upper middle, upper middle to lower middle, lower middle to upper tail-end, and upper tail-end to lower tail-end was 0.023 l/s/m, 0.033 l/s/m, 0.06 l/s/m, 0.03 l/s/m, 0.029 l/s/m, and 0.21 l/s/m, respectively (Table 3). For right canal the discharge lost per meter length from main intake to upper head, upper head to lower head, lower head to upper middle, upper middle to lower middle, lower middle to upper tail-end, and upper tail-end to lower tail-end was 0.023 l/s/m, 0.042l/s/m, 0.029 l/s/m, 0.023 l/s/m, 0.05 l/s/m, and 0.032 l/s/m, respectively (Table 4).

The amount of water lost in the total length of the left canal was 128.3 l/s or 11085.12 m^3 per day (Table 3), whereas the amount of water lost in the right canal was 119.3 l/s or 10307.52 m^3 per day. This showed that 35.5 percent of the water diverted was lost in the left canal while 27.5 percent in the right canal. Renault (2007) accepts approximately 10 to 15 percent of water loss within the canal. Even though when the result was compared to this, the value was not within the acceptable range due to improper canal design and alignment, and lack of cross-drainage structure (Figure 17).

Table 4 Conveyance efficiency of the right main canal

Canal type	Canal Reach	Segment No.	Distance b/n point	Mean discharge in flow	Mean discharge outflow	Conveyance Loss			Ec
			(m)	(l/s)	(l/s)	l/s	l/s/m	Loss (%)	(%)
	At the intake			135.3					
Lined canal	Upper head	1	100	135.3	133	2.3	0.023	2	98.3
Unlined canal	Lower head	2	600	133	108	25	0.042	19	81.2
	Upper middle	3	800	108	85	23	0.029	21	78.7
	Lower middle	4	800	85	67	18	0.023	21	78.8
	Upper tail-end	5	620	67	36	31	0.05	46	53.7
	Lower tail-end	6	620	36	16	20	0.032	56	44.4
Average conveyance efficiency								27.5	72.5

The mean conveyance efficiency of the left and right primary canals was 64.5% and 72.5%, respectively. The overall conveyance efficiency of the Hargaya irrigation scheme was 43.28 percent using equation (15).

Table 5 Conveyance efficiency of secondary canal

Canal type	Distance b/n point (m)	Mean discharge inflow (l/s)	Mean discharge outflow (l/s)	Conveyance loss			Conveyance Effi. (%)	Average Ec(%)
				l/s	l/s/m	Loss (%)		
SC-1	105	51	34	17	0.162	33.33	66.67	
SC-2	100	47	31	16	0.160	34.04	65.96	63.18
SC-3	80	36	22	14	0.175	38.89	61.11	
SC-4	110	41	29	12	0.109	41.03	58.97	
Average					0.152	36.82		

The conveyance efficiency of the secondary canal 1, 2, 3, and 4 was approximately 66.67%, 65.96%, 61.11%, and 58.97% respectively. The discharges lost in secondary canals 1, 2, 3, and 4 were estimated to be 17 l/s, 16 l/s, 14 l/s, and 12 l/s or 1468.8 m^3, 1382.4 m^3, 1209.6 m^{3,} and 1036.8 m^3 per day respectively. As observed from (Table 5), much water loss is measured at SC-1 because of the canal is fully covered by grass and weeds due to lack of timely maintenance.

The SC-1 and SC-2 branched from the left primary canal while SC-3 and SC-4 off take from the right primary canal. Conveyance losses per meter length of the secondary canal were 0.162 l/s/m, 0.160 l/s/m, 0.175 l/s/m, and 0.109 l/s/m respectively. The volume of water lost in the total length of the secondary canal, 395m, was 59 l/s or 5097.6 m^3 per day. The average conveyance efficiency of the secondary canal was 63.18 percent, below the value suggested by (Brouwer, 1989) minimum of 75%. This loss is due to weed growth, siltation, and seepage of the secondary canal, as observed during the field survey (Figure 17).

4.3.2. Application Efficiency

To maximize the yield of crop production water applied needs to be the right amount at the right time. The application efficiency was determined at nine farmer's plots selected from the head, middle, and tail to identify the application of the irrigation scheme. The water depth applied to the field was measured by a 3-inch partial flume installed at the water inlet to the field. Water stored in the root zone was calculated by taking soil samples from each plot by auger one day before and after irrigation. Irrigation water was used up to the farmer, stating sufficient water was used to identify the information gaps of farmers about irrigation scheduling and how much water was applied to the field. Farm application efficiency of the scheme at different farm levels was determined at the head, middle, and tail using equation (17). Total moisture stored in the soil profile was determined using soil samples collected one day before and after irrigation from selected plots, and soil moisture content was computed using equation (18) and presented in (Appendix Table 4). Field application efficiency is varies from field to field in similar farming system, the reason may be on-field water management.

Table 6 Measurement of discharge applied at the selected field by 3-inch partial flume

Farm location	Field Code	Time elapsed (sec)	Respective Discharge (l/s)	Area of field (m^2)	Total volume (m^3)	Applied Depth (mm)	Stored Depth (mm)	Ea (%)
Head	HU-1	12939.38	2.52	247	32.61	132.01	53.77	40.73
	HU-2	13462.52	2.37	330	31.91	96.69	49.34	51.03
	HU-3	17723.15	2.75	473	48.74	103.04	53.07	51.51
Middle	HM-1	15807.35	3.13	396	49.48	124.94	52.71	42.19
	HM-2	18578.61	2.38	480	44.22	92.12	54.67	59.35
	HM-3	15987.03	1.91	352	30.54	86.75	45.37	52.30
Tail-end	HT-1	18445.17	2.81	512	51.83	101.23	54.48	53.82
	HT-2	14789.09	2.97	360	43.92	122.01	50.91	41.72
	HT-3	13915.18	2.26	325	31.45	96.76	47.03	48.60
Average								49.03

Where U-1, U-2, and U-3 are fields selected from upper-reach water users, M-1, M-2 and M-3 represent fields selected from middle water users, T-1, T-2, and T-3 is fields selected from tail-end water users, and H represents Hargaya.

The application efficiency of the scheme implies the volume of water stored in the crop root zone to the volume of water applied. The application efficiency of the scheme varied from 40.73% to 59.35%, with a mean value of 49.03% (Table 6). The average application efficiency of farmers' fields at the head, middle, and tail-end were 47.76%, 51.28%, and 48.05% respectively. The field application efficiency of upstream users was lower than the middle and downstream because head users apply excess water based on the assumption that more water used gives more production. The recommended value suggested by FAO (1989) is 50-60%. This implies the application efficiency of the scheme under the study was poor.

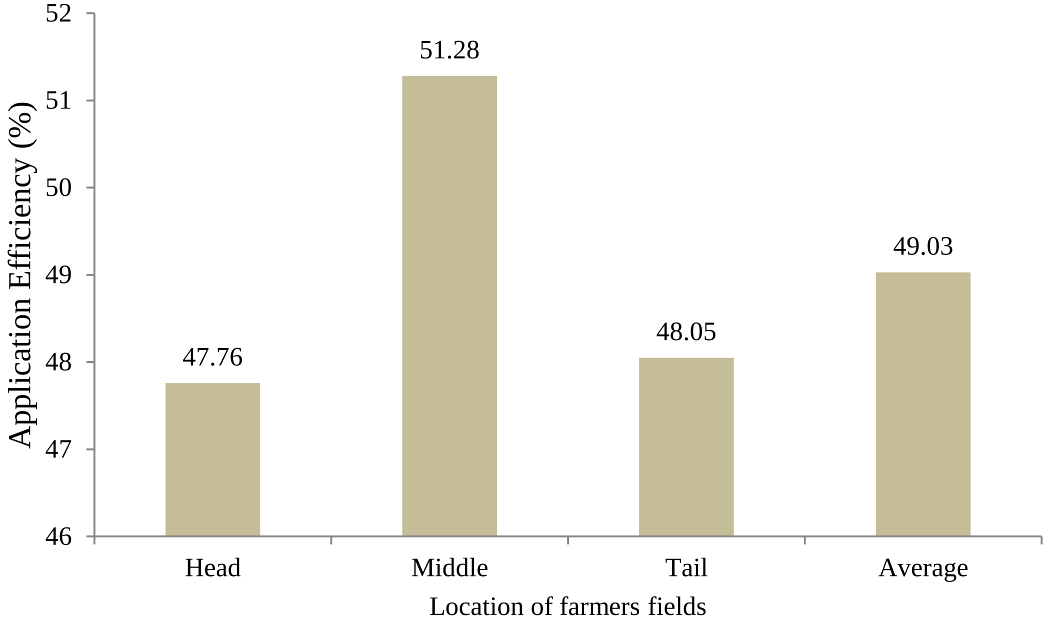

Figure 14 Application efficiency of selected farmer’s field at Hargaya irrigation scheme

4.3.3. Storage Efficiency

Storage efficiency is an index used to measure irrigation adequacy. It is the fraction or/ ratio of the quantity of water stored in the root zone during an irrigation event to that intended to be held in the root zone. It becomes important when water supplies are limited or excessive time is required to secure adequate water penetration into the soil. Mean storage efficiency was computed using equation (19), indicating that the scheme's Es was insufficient to satisfy the moisture required for crop production. Storage efficiency of the scheme ranged from 76.47% - to 91.04% with a mean value of 83.41%. Average storage efficiency at the head, middle, and tail-end water users was 82.31 %, 86.98 %, and 80.92%, respectively (Table 7). According to (Raghuwanshi, 1998), the recommended storage efficiency is 87.5%. Thus, the storage efficiency of the irrigation scheme did not satisfy the soil moisture required for good crop production. The main reason of underperformance may be on-farm water management practice.

Table 7 Computed Storage efficiency of the scheme

Field location along MC	Field code	Stored water at the root zone (mm)	Water required (mm)	Storage efficiency Es (%)
Head	HU-1	53.77	66.46	80.90
	HU-2	49.34	61.97	79.61
	HU-3	53.07	61.40	86.43
Middle	HM-1	52.71	59.97	87.89
	HM-2	54.67	60.05	91.04
	HM-3	45.37	55.33	82.00
Tail	HT-1	54.48	66.35	82.12
	HT-2	50.91	60.48	84.18
	HT-3	47.03	61.50	76.47
Average				83.41

4.3.4. Distribution Uniformity (Du)

To decide the distribution uniformity of irrigation water, soil samples were augured at regular intervals. At each selected point of the fields, soil samples were collected at depths with a gap of 30 cm up to 90 cm, and the moisture contents of the soil were computed to determine the depth of water penetration. For calculating the distribution uniformity, the root depths of the crops have been taken as the zone of distribution. The distribution uniformity of the Hargaya irrigation scheme was found to be 38.76%, 80.35%, and 65.19% at the head, middle, and tail end user fields, respectively, with an average value of 61.43 percent. As suggested by (Smith, 1992), the average distribution uniformity of 65% is enough. The result indicates the distribution efficiency of irrigation water in the selected farmers' plots were poor, the main reason is farmers were practices long size furrow.

4.3.5. Deep Percolation Ratio (DPR)

The deep percolation ratio is the amount of irrigation water applied that percolates down into the soil in the root zone. A higher deep percolation ratio suggests over-irrigation. As shown in (Table 8), the average deep percolation ratio at the head, middle, and tail test fields was 52.24%, 48.72%, and 51.95%, respectively. The furrow practiced in the scheme was blocked end furrows.

As the result indicates, a high deep percolation ratio was obtained at the head, and low values were recorded at the middle reach. This implies headwater users are irrigating with maximum deep percolation loss compared to middle and tail-end users by considering excessive water application gives high productivity.

Table 8 Computed field efficiency and losses for nine selected farmers' fields

Field Location	Field Code	Application Eff., Ea (%)	RO ratio (RR) (%)	DPR (%)	Average DPR (%)
Head	HU-1	40.73	0	59.27	
	HU-2	51.03	0	48.97	52.24
	HU-2	51.51	0	48.49	
Middle	HM-1	42.19	0	57.81	
	HM-2	59.35	0	40.65	48.72
	HM-3	52.30	0	47.7	
Tail-end	HT-1	53.82	0	46.18	
	HT-2	41.72	0	58.28	51.95
	HT-3	48.60	0	51.4	
Average					50.97

4.3.6. Overall Scheme Efficiency

According to (Shiberu and Hailu, 2011), the overall efficiency of the scheme is the ratio of water available to the crop to the amount released at the headwork. Overall, scheme efficiency was determined as the product of conveyance and application efficiency (Amsalu, 2020). The application efficiency of nine sample plots was assessed and analyzed in (Table 6). The mean conveyance efficiency of the main and secondary canals in the scheme was considered to determine the overall scheme efficiency. The overall efficiency of the scheme was found to be 21.22% equation (23). When this value was compared with the previous study, the overall efficiency of the Hargaya irrigation scheme was better than the value of the Branti small-scale irrigation scheme reported by Getachew (2018), which was 12.24%.

FAO (1989) suggests the overall scheme efficiency of 50–60% is sufficient, 40% is reasonable, and 20-30% is considered poor. Similarly, (Frenken, 2002) suggested that Eo below 40-50 percent commonly in African irrigation schemes was considered insufficient. Compared to the recommended values, the Hargaya irrigation scheme was considered poor.

The internal indicator results reveal that the scheme is totally considered as poor based on suggested values by many scholars. Indeed, the purpose of the internal process assessment is to assist irrigation mangers to improve water delivery services to users. The author suggested that, in general to enhance efficiency of the irrigation scheme these factors should have to be considered. Rehabilitation of left main canal, reducing water diverted to the scheme, mobilizing community participation in operation and maintenance, lining of main canal to minimize water loss and practical training for users based on-farm water management and farming system can improve performance of the scheme

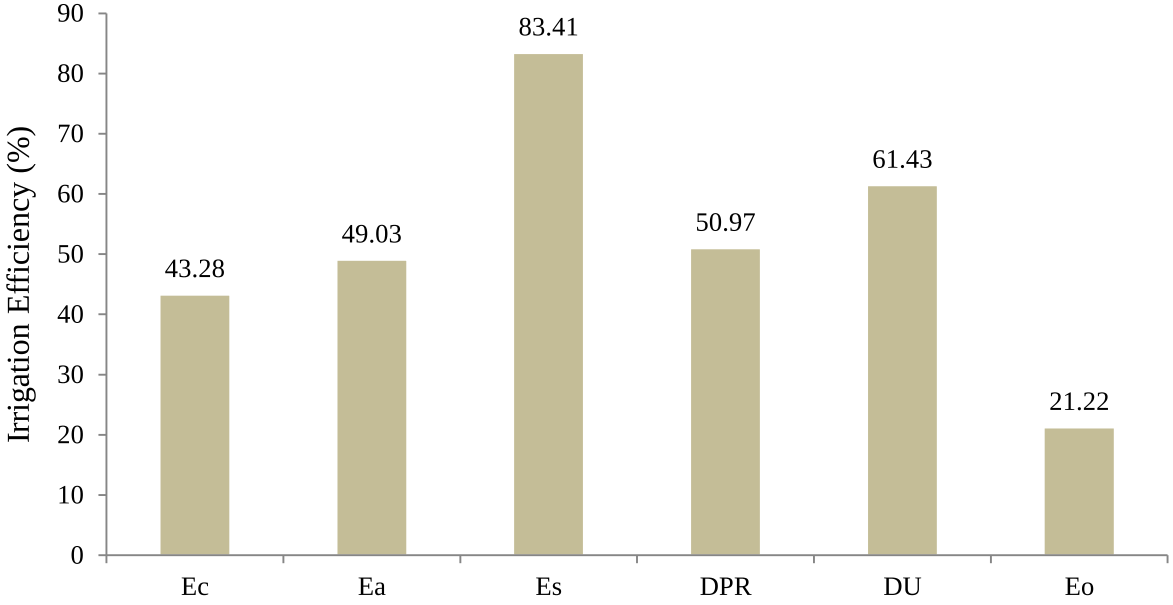

Figure 15 Average values of internal performance indicators

Table 9 Summary result of the internal process at the Hargaya irrigation scheme

Internal indicators	Efficiency (%)	Recommend value	Remark
Average conveyance, Ec	43.28	Below Brouwer (1989), 75%	Poor
Application Efficiency, Ea	49.03	Below FAO (1989), 60%	Poor
Storage Efficiency, Es	83.41	Below Markos (2021), 87.5%	Poor
Deep percolation Ratio, DPR	50.97	Depending on Ea	
Distribution Uniformity, DU	61.43	Below FAO (1992), 65%	Poor

Overall Efficiency, Eo	21.22	Below FAO (1989), 50%-60%	Poor

4.4. External indicators

4.4.1. Agricultural Output Indicators (Land and Water) Productivity

Productivity is associated with output from the system in response to the input added to the design and there are many indicators of productivity. But, it is necessary to consider the performance of the irrigation scheme over the area. This consists of performance indicators that are related to production.

Output per unit irrigated area and production per unit command area of irrigation scheme show land productivity, and also, the relation between the two is an indication of how the intended command area is irrigated or not. This means if the values of the two indicators are very similar, the intended command area is irrigated, and if the output per unit command area is much higher than the output per irrigated area, less area is irrigated than the designed area. Similarly, production per irrigation water supplied and production per water consumed are indications of water productivity.

The agricultural outputs computed from the two irrigation seasons and data required such as crop types, the area covered by each crop, average yield and price of each crop collected from field measurement, district agricultural and revenue office and locally available market price during the study period was used. The output per cropped area shows the response of each cropped area within the available water and the capacity of land productivity. The production per unit of water consumed indicates the result gained using a cubic meter of applied water. The yield values were collected through interviews with beneficiary farmers and the Meyu Muluke agricultural office's final report of 2015 E.C. as indicated in (Table 10). The irrigated cropped area of the two irrigation seasons was 110.9 ha and 102 ha, respectively. The total production values for the two irrigation seasons were 267714.50 US$ and 295691.57 US$, respectively. The result reveal that, production value of first irrigation season was less than second irrigation season; the reason may be high value crops were grown during second irrigation season. The cultivated area and area coverage for each crop of the irrigation season, intensity, yields, and values of production of the scheme are summarized in (Table 10).

Table 10 Crop yields and output values of the production year of 2022/23

Season	Irrigated crops	Area (ha)	Yield (Ql/ha)	Total Yield(Ql)	Price (ETB/Ql)	Production (ETB)	Production (U$$)
		(1)	(2)	(3)=(1)*(2)	(4)	(5)= (3)* (4)	(6)=(5)/54.08
Season -I	Maize	36	31	1116	3100	3459600	63971.89
	Pepper	7.3	24	175.2	5000	876000	16198.22
	Beans	2.8	12	33.6	4500	151200	2795.86
	Tomato	18.9	56	1058.4	3500	3704400	68498.52
	Onion	12.4	60	744	3500	2604000	48150.89
	Wheat	16.3	12	195.6	3000	586800	10850.59
	Cabbage	17.2	60	1032	3000	3096000	57248.52
	Total	110.9				14478000	267714.50
Season - II	Maize	42.5	30	1275	3100	3952500	73086.17
	Pepper	10.7	25	267.5	5000	1337500	24731.88
	Tomato	15.1	60	906	4000	3624000	67011.83
	Onion	19.7	60	1182	3500	4137000	76497.78
	Potato	14	70	980	3000	2940000	54363.91
	Total	102				15991000	295691.57

Ql is quintal and 1 US$ = 54.08, Ethiopian Birr rate, 9 April 2023

The average discharge measured at the intake of the main canal was 0.135m^3/sec, and the total volume of water diverted into the system in the season was calculated using the total flow time of irrigation water multiplied by a recorded discharge at the head system of the main canal was 2822688 m^3.

Table 11 Agricultural performance indicators for the cropping season of 2022/23

Season	Command Area (ha)	Irrigable Area (ha)	Total production value (US$)	Irrigation water diverted (m^3)	Crop water Consumed (m^3)
Season-I	200	110.9	267714.50	1423008	411139.57
Season-II	200	102	295691.57	1399680	413100
Total			563406.07	2822688	824239.57

Table 12 Computed values of land and water productivity indicators

Season	Output per Cropped Area (US$/ha)	Output per Command Area (US$/ha)	Output per water diverted (US$/m^3)	Output per water consumed (US$/m^3)
Season-I	2414.02	1338.57	0.19	0.65
Season-II	2898.94	1478.46	0.21	0.72
Total	5312.95	2817.03	0.4	1.37

Land productivity indicators

Land productivity was evaluated using two indicators output per unit irrigated area and output per command area.

I. Output per unit irrigated area (OPUIA)

This type of land productivity indicator shows how much hectare of land is covered by crops. The value was computed using equation (24) as the ratio of the total value of production per irrigated cropped area and expressed in the unit of US$/ha, and the result is presented in (Table 12). Irrigated area is the sum of the areas under crops during the analysis period. From the result analysis, the output per unit irrigated area of two irrigation seasons was found to be 2414.02 US$/ha and 2898.94 US$/ha, respectively. This implies that there is contraction of initially irrigated land at the scheme.

II. Output per unit command area (OPUCA)

The type of land productivity indicator which indicates how many hectares of land are covered by the crop is output per unit command area. The value was computed by equation (25) as the ratio of the total production value per command area and expressed in the unit of US$/ha. Output per unit command area indicates whether all the command areas generate returns. As a result, the production per unit command area of two irrigation seasons was 1338.57 US$/ha and 1478.46 US$/ha, respectively.

Water productivity indicators

I. Output per unit irrigation delivered (OPUID)

Output per unit irrigation delivered is a water productivity indicator that indicates how much water is diverted for irrigation. This indicator shows the revenue from the agricultural output for every cubic meter of irrigation water supplied. This kind of external indicator is excellent as it addresses the output per unit drop of irrigation water surely introduced to the user. The output per irrigation delivered was calculated using equation (26), and the result was 0.4 US\$/m^{3,} as indicated in (Table 12). Water diverted to the scheme was higher in first irrigation season due to number of days in the first irrigation season. Out of water diverted to the scheme in 8 months; only 29.2% was consumed by crops (productive) while 70.8% of water diverted to the scheme was un-productive. This implies water productivity at the scheme under the study was poor. To improve water productivity of the scheme insignificant water loss should be minimized.

II. Output per unit of water consumed (OPUWC)

This type of external indicator describes how much water is consumed by crops. This indicator gives due attention to the water consumed by the scheme and tells us how the scheme, from an economic point of view, efficiently utilizes water. The values for this indicator were found to be 1.37 US\$/m^3, as shown in (Table 12). Water consumed by ETc was higher in second irrigation season due to high crop water demand observed in February month. The result indicates that the water use efficiency of the Hargaya irrigation scheme was poor compared to the Deremo small-scale irrigation scheme of 2.88 US\$/m^3, as reported (Alemie, 2021).

Water supply performance indicator

For this research, RWS and RIS were used as parameters to evaluate and characterize the irrigation scheme's performance and to see the variation of the indicators spatially with the intended values. The study considered two irrigation seasons. The first irrigation season started at the beginning of September to December, while the second cropping season includes the period of early January to April.

Table: 13 Results of RWS and RIS during irrigation season.

Study	Irrigation	Crop	Total	Total RF.	NCWR	NIWR	WD	RWS	RIS

period	Season	ped Area	diverted water				PR		
		Ha	m^3/season	m^3/season	m^3/season	m^3/season			
Sept-Dec	Season-I	110.9	1423008	255291.8	411139.57	259140			
Jan- April	Season-II	102	1399680	219810	413100	277674.6			
Total		212.9	2822688	475101.8	824239.57	536814.6	3.2	4	5.3

Where RWS is relative water supply, RIS is relative irrigation supply, WDPR is water delivery performance ratio, NCWR is net crop water requirement and NIWR is net irrigation water requirement.

4.4.2. Relative Water Supply (RWS) and Relative Irrigation Supply (RIS)

The computed values of RIS and RWS of the scheme have been 5.3 and 4, respectively, which was greater than unity (Table 13). As a result, this indicates, that the higher value of irrigation supply observed at the Hargaya irrigation scheme was due to the absence of water fees. Farmers applied more water than the required amount without considering crop water requirements. To maximize the water use efficiency, it is better to have RIS near 1, and the volume of water supplied must be reduced as recommended (Molden, 1998).

4.4.3. Water Delivery Performance Ratio (WDPR)

The scheme irrigation requirement was calculated with CROPWAT 8.0 using the climate data; cropping data and area coverage of individual crops were shown in (Table 14). The peak irrigation requirement in February was 0.41 l/s/ha (Appendix Table D) and Figure (16). The peak irrigation demand for the month obtained by multiplying the peak irrigation requirement by the cropped area was 41.82 l/s.

The average discharge measured at the head system of the main canal was 135 l/s. The peak irrigation requirement and the peak consumptive demand at the Hargaya irrigation scheme were 0.41 l/s/ha and 41.82 l/s, respectively. The water delivery capacity of the system is the ratio of canal capacity at the system head to the peak consumptive demand equation (30). The computed value of the WDPR of the scheme was 3.2, which was greater than one; this means that the capacity of the main canal at the peak time of crop demand was greater than the peak crop water requirement. This shows that the capacity of the main canal at the head system was not a constraint to meeting peak crop water demands (Molden, 1998).

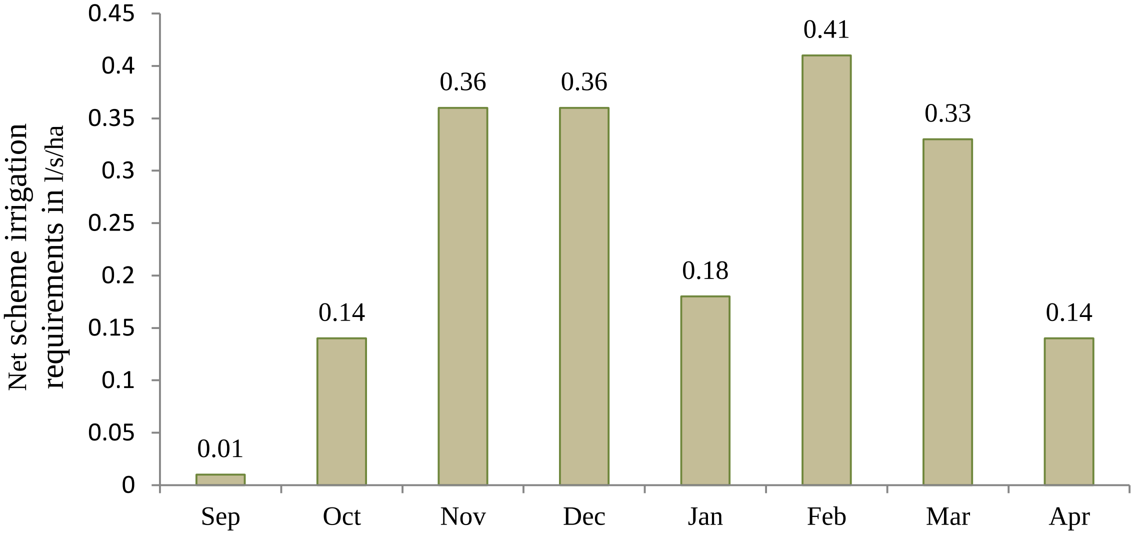

Figure 16 Net scheme irrigation requirements

4.5. Computation of Crop Water and Irrigation Water Requirement

The crop water requirement of different crops in the study area was determined using the CROPWAT 8 model. The crop and irrigation water requirements were calculated by considering growth stages (initial, development, mid-season, and late season) for each crop grown in the study area. Crop water requirement, ETc. can be calculated using equation (10).

Table 14 Crop water and irrigation water requirement of the Hargaya irrigation scheme.

Season-I					Season-II				
Crop type	Area (ha)	CWR (mm/season)	RFeff. (mm)	IWR (mm/season)	Crop type	Area (ha)	CWR (mm/season)	RFeff. (mm)	IWR (mm/season)
Maize	36	358.3	126.9	231.2	Maize	42.5	376.9	110.7	266.2
Pepper	7.3	400.8	178	222.7	Pepper	10.7	402.8	148.6	254.3
Beans	2.8	269.3	84.4	184.7	Tomato	15.1	409.1	148.5	260.6
Tomato	18.9	387.9	149.2	238.4	Onion	19.7	442.2	148.6	293.6
Onion	12.4	422.1	186.5	235.3	Potato	14	435.2	148.6	286.7

Wheat	16.3	303.4	101.4	201.7					
Cabbage	17.2	408.4	132.8	275.4					
Total	110.9				Total	102			

Table 15 Net Crop water and Net irrigation water requirement of the cropping season

Season-I					Season-II				
Crop type	Area (%)	NCWR (mm/season)	NIWR (mm/season)	Eff. RF (mm)	Crop type	Area (%)	NCWR (mm/season)	NIWR (mm/season)	Eff. RF (mm)
Maize	32	116.31	75.05	41.19	Maize	42	157.04	110.92	46.13
Pepper	7	26.38	14.66	11.72	Pepper	10	42.25	26.68	15.59
Beans	3	6.80	4.66	2.13	Tomato	15	60.56	38.58	21.98
Tomato	17	66.11	40.63	25.43	Onion	19	85.41	56.71	28.70
Onion	11	47.20	26.31	20.85	Potato	14	59.73	39.35	20.40
Wheat	15	44.59	29.65	14.90					
Cabbage	15	63.34	42.71	20.60					
Total	100	370.73	233.67		Total	100	405.00	272.23	

The total crop and irrigation water demand for the two irrigation seasons were calculated by equation (12) and tabulated in tables (14 and 15).

CWR maize*(Area maize /Area total) + CWR pepper*(Area pepper/Area total) + CWR beans*(Area beans /Area total) + CWR tomato*(Area tomato/Area total) + CWR sorghum*(Area sorghum /Area total) + CWR wheat*(Area wheat/Area total) + CWR cabbage*(Area cabbage/Area total) + CWR potato*(Area potato/Area total)

The total amount of net crop water requirement was 370.73 mm/season in-depth and 411139.57m^3/season in volume for the first cropping season, while net crop water demand for the second irrigation season was 405 mm/season in-depth and 413100m^3/season in volume (Table 15). To change the depth of water demand to volume, multiply crop water demand by the total irrigated area. On the other hand, the entire irrigation requirement of the scheme was also calculated in the same procedure.

IWR maize*(Area maize /Area total) + IWR pepper*(Area pepper/Area total) + IWR beans*(Area beans/Area total) + IWR tomato*(Area tomato/Area total) + IWR sorghum*(Area sorghum/Area total) + IWR wheat*(Area wheat/Area total) + IWR cabbage*(Area cabbage/Area total) + IWR potato*(Area potato/Area total)

The results of the total NIWR of the two seasons were 233.67 mm/season and 272.23 mm/season in-depth, whereas 259140.03 m^3/season and 277674.6 m^3/season in volume, respectively. The total rainfall of the first and second cropping seasons at the Hargaya irrigation scheme was 230.2 mm/season and 215.5 mm/season in depth. To change rainfall depth into volume, multiply rainfall depths with the total cropped area of the season were 255291.8m^3/season and 219810m^3/season, respectively.

4.5.1. Estimation of Amount of water diverted

To estimate the amount of diverted water through the irrigation season, the average discharge of the main canal at the head system, operating hours per day, and months per year were required. The average discharge measured at the left and right main canal intake was 0.1353m^3/sec, as depicted in (Appendix Table 6). The volume of water diverted for two irrigation seasons was computed using the average discharge measured at the head system multiplied by operating hours per day. Farmers in the scheme use irrigation water for a continuous flow of 24 hours and rinse in day and night shift cycles for eight months of irrigation seasons per year. For eight months of irrigation period, the volume of diverted water is the sum of the water diverted in two irrigation seasons. Therefore, the value of water diverted at the head system of the main canal through the irrigation season per year was estimated to be 2822688 m^3.

Irrigation Scheduling

Farmers applied constant irrigation intervals in each growth stage of the irrigated crop, but crops' water needs varied from stage to stage, and irrigation intervals varied for each growth stage. Based on field measurements, the mean irrigation water applied to the fields was 110.58 mm, 101.27 mm, and 106.67 mm per application at the head, middle, and tail end water users, respectively (Table 6). The irrigation scheduling practiced by farmers' was considered to compare the irrigation interval practiced by farmers and calculated irrigation interval. This helps to show the gap in farmers’ knowledge; they do not consider soil moisture content and growth stage to schedule irrigation water application. Scheduling at farmers‘ fields considers fixed irrigation intervals and fixed water depth application techniques through the growing season because farmers are not in a position to measure and monitor the soil moisture contents before the irrigation.

Table 16 Irrigation interval practiced by farmers and average calculated values at the Hargaya irrigation scheme

S.No	Crop	Farmers practiced irrigation interval (day)	Average calculated irrigation intervals (day)	Irrigation frequency/season
1	Maize	8	14	7
2	Pepper	10	15	8
3	Beans	8	18	5
4	Tomato	5	12	7
5	Onion	5	14	8
6	Wheat	8	16	7
7	Cabbage	10	16	7
8	Potato	10	12	10

4.6. Physical Performance Indicator

Physical indicators are related to the expansion or contraction area of irrigated land for different reasons, including lack of irrigation scheduling, landholding size, loss of land productivity, and lack of sustainability, causing essential problems in the community-managed small-scale irrigation scheme (Kidane, 2015). The irrigation ratio, sustainability of the irrigation area, and effectiveness of infrastructure have been calculated using equations (34, 35, and 36) respectively. Irrigation ratio and sustainability of irrigated area was used for cross-comparison of irrigation performance over time.

A) Irrigation ratio (IR)

The irrigation ratio shows the utilization level of a given irrigable area in the specific production season. The irrigation ratio of the study scheme was found to be 51% (Table 17), and this elaborates that about 49 % of the command area of the irrigation scheme was not under irrigation during the study period. Thus, the reduction of irrigated areas is related to the lack of properly designed irrigation infrastructure, especially at the left canal, which causes excessive water loss.

Table 17 Computed Values of IR and SIA for the selected scheme

Scheme	Command Area (ha)	Initial irrigable land (ha)	Currently irrigated land (ha)	Irrigation ratio (IR)	Sustainability of irrigation Area (SIA)
Hargaya	200	196	102	0.51	.0.52

Source: Design document and field GPS survey.

B) Sustainability of irrigated area (SIA)

This indicator is used to investigate the change in the area irrigated against the intended in terms of ratio and it also provides valid reasons for such variation (Mekonnen, 2018). The designed command area of the scheme was 200 ha but initially irrigated was 196 ha. However, the actual irrigated area of the second irrigation season was 102 ha. The sustainability of the irrigation scheme was computed by equations (35), and the result was found to be 0.52, as depicted in table (17). Initially irrigated area of the scheme was reduced to 52 percent while 48 percent of irrigable area was not under irrigation due to the reason discussed under section 4.10.

Generally, values of IR and SIA of the Hargaya irrigation scheme show the irrigated area became contracted due to excessive water loss at the left primary canal. As observed in (Figure 2) vehicles pass the canal without structure. Thus, the irrigated area was reduced from 140 ha to 38 ha at left canal. This means that only 27% of the irrigable area was irrigated, and service continuity of the scheme became difficult unless urgent protection was carried out.

Figure 17 Silt deposited and vegetation growth at the main canal

C) Effectiveness of Infrastructure

The effectiveness of infrastructure was predicted using equation (36), and the value of the effectiveness was found to be 61.54%. This value indicates more than 38.46% of initially installed structures were damaged over time due to the absence of regular maintenance of the irrigation scheme.

Table 18 Effectiveness of infrastructure

No	Name of structure	Initially installed	Functional	Non-functional	Effectiveness infrastructure (%)
1	Diversion Weir	1	1	0	100
2	Intake gate	2	2	0	100
3	Drop structures	2	1	1	50
4	Division box	2	2	0	100
5	Road crossing culvert	3	1	2	33.3
6	Division box gates	4	2	2	50
7	Turnout	12	7	5	58.3
	Total structure	26	16	10	61.54

4.7. Evaluation of users' perception of the irrigation scheme

Farmer's perspective concerning the scheme performance was conducted by interviewing 71 beneficiary farmers selected from the head, middle, and tail end users. As interviewed farmers believe, excessive water loss in the conveyance system contributed to water shortage at the tail users. During the field survey, interviewed beneficiary farmers said that to improve the efficiency of the scheme rehabilitation of the conveyance system, lining the earthen canal, and mobilizing community participation is engaged to enhance water delivery capacity.

Moreover, the active participation of users during the planning and construction period positively contributed to creating a sense of ownership and assuring sustainability. To gain the intended capacity of the scheme, both government and farmers have the responsibility to manage the scheme including its operation and maintenance. To ensure the long-term sustainability of the scheme, labor work was done by beneficiary farmers. However, the government has been making huge investments in irrigation scheme design and construction of irrigation projects without community participation. This leads to dependency on the government, which decreases farmers' sense of ownership and responsibility for operation and management.

Table 19 Response of households on community participation in planning and construction

Have you participated in the planning and design of the scheme	Frequency	Percent
No	71	100
Yes	0	0
Total	71	100

The irrigation user's participation during the planning phase positively impacted creating a sense of ownership and sustainability of the irrigation scheme (Alemie, 2021). According to HH survey results, beneficiary farmers did not participate in the scheme planning and design phase. This shows the government body planned and designed the scheme by itself without community participation. Similarly, (Tahir, 2020) reported that the sustainability of the irrigation scheme is not achieved without community participation in all stages of the project.

Table 20 Responses related to maintenance activity

Have you ever participated in canal clearing and	Frequency	Percent

other maintenance of the irrigation scheme?		
Yes	59	83.1
No	12	16.9
Total	71	100

To gain sustainability of the irrigation scheme, one of the most vital steps is enhancing community participation in all stages of the project cycle. However, in the Hargaya irrigation scheme, there is no community participation in the planning phase. The engineers select diversion weir sites and canal routes without considering users' interests. The major problems identified in the scheme were related to the project planning phase and poor design. Farmers who participated in canal clearing and other maintenance activities were 83.1% (Table 20). However, canal-clearing activities cannot minimize water loss at the left canal because it needs rehabilitation to overcome the existing problem.

4.7.1. Assessment of irrigation institution and Support services of the irrigation scheme

The institutional and support services were assessed with the help of a questionnaire, and interviews with beneficiary farmers, DAs, WUA leaders, and zonal agricultural office experts. Institutional performance indicators, including the working condition of the WUA and the attitude of the farmers to WUA, were studied through HH surveys of randomly selected beneficiary farmers from the head, middle, and tail.

4.7.2. Support Service

A) Extension and Training

There are organizations at the woreda level, but they are not committed to providing necessary training and extension services for farmers. As the household survey result indicates, 91.5% of beneficiary farmers have not received adequate capacity-building training on the overall operation, maintenance, utilization, and management of the irrigation scheme. Frequently, capacity-building training on comprehensive water management should be given to beneficiary farmers to achieve sustainability of the scheme.

Table 21 Response of households to capacity-building training

Is there any training given to you?	Frequency	Percent
Yes	6	8.5
No	65	91.5
Total	71	100

B) Enhance community participation in the long-term sustainability of the Scheme

The sustainability of the irrigation scheme requires community participation in all stages of the project cycle, which is important (Ayana, 2021). However, most of the time, the government has been making a huge investment in irrigation schemes during design without considering community participation. This leads to dependency on the government which decreases farmers' sense of ownership and responsibility for operation and management. Enhance the long-term sustainability of irrigation systems by strengthening local management (Mekonnen, 2018). As household surveys indicate, 54.93% of respondents accepted water loss in the scheme was related to design problems (Table 22). To enhance the scheme's efficiency, rehabilitation of the left primary canal is needed. Regular training must be given by the experts to raise awareness and build the capacity of users to manage the scheme for sustainable development.

Table 22 Response of households related to the current status of the scheme

What is the main cause of water loss in the scheme	Frequency	Percentage
Structural failure	3	4.22
Design problem	39	54.93
Seepage	12	16.9
Sediment	17	23.95
Total	71	100

C) Conflict and conflict resolution mechanisms

Conflicts were raised among individual irrigation water users, between WUA, and among upstream and downstream users because water theft was the main source of conflict. Therefore, the HH survey result indicates that 88.7 % of respondents confirmed conflict in the scheme.

Table 23 Frequency of household respondents on conflict

Have you ever faced any conflict over irrigation water?	Frequency	Percent

Yes	63	88.7
No	8	11.3
Total	71	100

The sources of conflicts at the Hargaya irrigation scheme were water theft and unlawful water abstraction. Out of respondents interviewed 35.21% of the respondents believe that more disputes raised due to water theft in the scheme, 47.89% of respondents replied illegal water abstraction was the source of conflict, and 16.90% of respondents were confirmed competition due to the increasing number of water users was the source of conflict. Disagreements had been solved using arbitration in most cases, and the remaining was solved through the legal procedure law.

Table 24 Response related to sources of conflict at Hargaya irrigation scheme

What are the main sources of conflict?	Frequency	Percent
Water theft	25	35.21
Illegal water abstraction	34	47.89
Competition due to the increasing number of water users	12	16.90
Total	71	100

4.8. Organizational setup and performance of irrigation water management

Based on the fact that collected using questionnaires from HHs survey technical support given to beneficiaries by the authorities side how to implement activities such as effective water use, soil management, scheme operation and maintenance, use of modern inputs, and adopt new technology in agricultural practices, organizing and strengthening water users associations had been no longer given for the scheme customers. There were three WUAs in the scheme responsible for managing and distributing irrigation water among users.

The organizational structure of WUAs

The beneficiaries of the Hargaya irrigation scheme live in three villages (Hargaya, Challa, and Musa) organized for management purposes. Each of the three villages consists of one water users association with a total of 32-59 members. Out of 148 farmers organized under the three water user associations, 127 and 21 were males and females, respectively. This indicates that the total number of females who participated in WUAs was only 14.2%, and to enhance scheme efficiency, female participation should be strengthened in irrigation water management. The structure of WUAs was Chairman, Vice-chairman, and Secretary from top to bottom. They were organized to arrange water allocation among users and conflict management with the help of the kebele administration. All WUAs were not doing their activities properly. They need training because more WUA members do not have a concept of irrigation water management.

Comparison of left and right main canal based on conveyance loss

A canal is a conveyance system that transports and delivers irrigation water from the source to the point of use. The Hargaya irrigation scheme consists of two main canals and four secondary canals. As a result, the conveyance efficiency of the left and right primary canals was 64.5% and 72.2%, respectively. The volume lost within the left main canal was 11145.6 m^3 per day, while the volume of water lost in the right main canal was 10540.8 m^3 per day (Table 3 and 4). This implies that the conveyance efficiency of the right canal was better than the conveyance efficiency of the left canal. Even if an equal volume of water was diverted and transported for the same distance, the amount of water delivered to tail-end users at the left and right canals varies due to canal conditions. This causes a shortage of water at the tail end users of the left canal.

4.9. Main Causes of Underperformance Identified

i. Poor design and construction Problem

As interviewed beneficiary farmers randomly selected from the head, middle, and tail users during field survey shows there is no community participation in the project planning phase. Household survey and field data indicate due to excessive water loss in the conveyance system farmers at the tail end users of the left canal were challenged by a shortage of water. To upgrade the efficiency of the Hargaya irrigation scheme rehabilitation of the left canal including lining the earthen canal, drainage facilities, and modification of the left canal alignment were required to enhance the water delivery of the scheme.

ii. Improper irrigation water use

The computed values of RIS and RWS of the irrigation scheme have been 5.3 and 4, respectively. These values indicate that at the Hargaya irrigation scheme, farmers applied more water than the required amount. The amount of water supplied to the scheme must be reduced to maximize water use efficiency. As reported by (Solomon, 2016), the value of RIS of more than one suggests that the irrigation supply was beyond the irrigation demand. If it is less than one, the irrigation supply is less than the irrigation demand. Accordingly, the result indicated that canal capacity did not constrain water supply for crop production. From an economic point of view, it is possible to irrigate the additional area with the supplied amount of irrigation water.

iii. Weak organizational and management of WUAs of the scheme

Weak organization between water committees that fails to effective water distribution, poor coordination between WUAs, unequal water distribution among users, lack of awareness about crop water requirements, and poor participation in scheme management were among the factors that account for the decrease in the sustainability of the scheme. Generally, losses within the scheme under the study related to seepage, overflow, water theft, canal breaching, and illegal water abstractions. These losses affect the equity of water allocation throughout the systems particularly; tail-end users did not get equitable shares within the required time at Hargaya irrigation scheme.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary and Conclusions

The study was conducted to assess the performance of the Hargaya small-scale irrigation scheme in the Oromia Regional State East Hararghe zone, Meyu Muluke district. In this study, performance of the irrigation scheme is assessed using internal processes, external performance, physical performance, farmers' perception, institutional setup, and support services were used.

The study collected primary and secondary data to get the research findings. Double ring infiltrometer, auger, core sampler, tape meter, weight balance, partial flume, floating material, GPS, digital camera, and peg interval have been used. The velocity area method was used to measure the discharge at the main and secondary canals. Primary data were collected through HH surveys, interviews with respective stakeholders, and group discussions. Soil samples were collected to determine various soil physical properties and infiltration rate tests were taken at head, middle, and tail fields to get input data for the CROPWAT 8 model. Secondary data were collected from the district and zonal agricultural offices, national meteorological agencies, design documents, and literature.

Internal performance indicators used in this study were conveyance efficiency, application efficiency, storage efficiency, distribution uniformity, deep percolation ratio, and overall efficiency. As the result of the internal process indicates, conveyance efficiency, application efficiency, storage efficiency, distribution uniformity, deep percolation ratio, and overall efficiency of the Hargaya irrigation scheme was 43.28%, 49.03%, 83.41%, 50.97%, 61.43%, and 21.22%, respectively. The result shows that, in all internal processes the scheme performance is below the recommended values suggested by FAO (1989).

External performance indicators used in the study were agricultural output, water use, water delivery capacity, and physical performance indicators. The results of agricultural output (land and water) indicate; that output per unit irrigated area, production per unit command area, output per unit irrigation supply, and output per unit water consumed were 5312.95 US$/ha, 2817.03 US$/ha, 0.4 US$/m^3 and 1.37 US$/m^3 respectively. Similarly, the results of water use efficiency WDPR, RWS, and RIS were 3.2, 4.0, and 5.3, respectively. These values indicate that at the Hargaya irrigation scheme, farmers applied more water than the required amount. Physical performance indicators IR, SIA, and effectiveness of infrastructures were found to be 0.51, 0.52, and 0.615, respectively. This result indicates that 38.5% of initially installed infrastructures at the scheme were non-functional. As interviewed beneficiary farmers indicated water user associations, organizational setup, and legal enforcement bylaws were inefficient due to this illegal water abstractions were expanded.

Problems identified in the scheme were a poor design, absence of timely maintenance of conveyance systems, poor irrigation water management, lack of community participation during project planning, implementation, and evaluation phases, and lack of strong WUAs are the main problems identified in the scheme.

5.2. Recommendations

Based on the performance assessment of the irrigation scheme, improvement options are made to achieve the intended potential and sustainability of the irrigation scheme. The following recommendations should be considered as better alternatives.

- Rehabilitation of the left main canal with close supervision is highly recommended to ensure fair water distributions because of 38% of initially installed infrastructures at the scheme were damaged.
- Mobilizing community participation in the scheme operation and maintenance and prepare schedule for maintenance activities.
- Regular training practically based on-farm water management and practical training on farming system that would help to improve the efficiency of the irrigation scheme should be given to users which upgrade the yield of crops.
- Organizing and strengthening WUAs of the scheme since they had management gaps. Therefore, organizing WUAs is essential for ensuring effective water management, equitable water distribution, and efficient use of irrigation water.
- Illegal water abstraction and water theft is expanded at the scheme; to control these WUAs proclamation should be implemented.
- Monitoring and evaluating the scheme performance frequently is required to know the problems and identify best alternatives to improve efficiency of the scheme.
- Main canal should be lined to minimize conveyance losses and increase available water to beneficiaries because most of the canal length is unlined.
- Water supplied to the scheme should be reduced to maximize water use efficiency.

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7. APPENDICES

Appendix Table I: Soil moisture, texture, and infiltration rate of the study area

Appendix Table 1 Soil laboratory result of Hargaya SSI Scheme

Farms Location	Field code	Sample code	Soil depth (cm)	Particle size Distribution (%)			Textural class
				Sand	Silt	Clay	
Head	HF-1	HF1$_{0-30}$	0-30	42	25	33	Clay loam
		HF1$_{30-60}$	30-60	41	27	32	Clay loam
		HF1$_{60-90}$	60-90	43	21	36	Clay loam
	HF-2	HF2$_{0-30}$	0-30	41	24	35	Clay loam
		HF2$_{30-60}$	30-60	40	29	31	Clay loam
		HF2$_{60-90}$	60-90	42	20	38	Clay loam
	HF-3	HF3$_{0-30}$	0-30	31	23	46	Clay
		HF3$_{30-60}$	30-60	40	27	33	Clay loam
		HF3$_{60-90}$	60-90	35	34	31	Clay loam
Middle	MF-1	MF1$_{0-30}$	0-30	32	40	28	Clay loam
		MF1$_{30-60}$	30-60	42	28	30	Clay loam
		MF1$_{60-90}$	60-90	38	26	36	Clay loam
	MF-2	MF2$_{0-30}$	0-30	36	35	29	Clay loam
		MF2$_{30-60}$	30-60	35	41	24	Clay loam
		MF2$_{60-90}$	60-90	33	27	40	Clay
	MF-3	MF3$_{0-30}$	0-30	42	21	37	Clay loam
		MF3$_{30-60}$	30-60	43	25	32	Clay loam
		MF3$_{60-90}$	60-90	49	28	23	Clay loam
Tail	TF-1	TF1$_{0-30}$	0-30	29	36	35	Clay loam
		TF1$_{30-60}$	30-60	30	37	33	Clay loam
		TF1$_{60-90}$	60-90	31	32	37	Clay loam
	TF-2	TF2$_{0-30}$	0-30	27	37	36	Clay loam
		TF2$_{30-60}$	30-60	23	52	25	Clay loam
		TF2$_{60-90}$	60-90	38	33	29	Clay loam
	TF-3	TF3$_{0-30}$	0-30	21	47	32	Clay loam
		TF3$_{30-60}$	30-60	36	36	28	Clay loam
		TF3$_{60-90}$	60-90	33	28	39	Clay loam
Average				36	31	33	Clay loam

Where H represents the head, M is mid, T is the tail and F is the field along the irrigation canal respectively.

Appendix Table 2 Average soil moisture FC, PWP, TAW, and Bulk density.

Field location	Field Code	Soil depth (cm)	FC (vol.%)	PWP (vol.%)	Bulk density (g/cm^3)	TAW (%)	TAW (mm/m)	Moisture desired to be Stored (Wn), (mm)

Head	HU1	0-30	39.71	21.73	1.22	17.98	179.8	66.46
		30-60	39.93	22.21	1.29	17.72	177.2	
		60-90	39.62	23.33	1.33	16.29	162.9	
	HU2	0-30	35.53	19.25	1.26	16.28	162.8	61.97
		30-60	37.61	21.01	1.21	16.6	166	
		60-90	39.26	22.56	1.28	16.7	167	
	HU3	0-30	37.19	20.72	1.23	16.47	164.7	61.40
		30-60	39.58	23.05	1.26	16.53	165.3	
		60-90	39.98	24.47	1.31	15.51	155.1	
Middle	HM1	0-30	38.51	20.81	1.13	17.7	177	59.97
		30-60	39.62	22.65	1.21	16.97	169.7	
		60-90	39.92	23.31	1.17	16.61	166.1	
	HM2	0-30	38.47	21.21	1.19	17.26	172.6	60.05
		30-60	39.61	24.11	1.2	15.5	155	
		60-90	40.83	23.83	1.23	17	170	
	HM3	0-30	39.96	25.12	1.14	14.84	148.4	55.33
		30-60	38.47	20.67	1.19	17.8	178	
		60-90	39.81	25.57	1.21	14.24	142.4	
Tail	HT1	0-30	36.17	18.63	1.23	17.54	175.4	66.35
		30-60	39.23	21.81	1.26	17.42	174.2	
		60-90	38.51	20.68	1.28	17.83	178.3	
	HT2	0-30	38.35	22.31	1.16	16.04	160.4	60.48
		30-60	36.94	19.64	1.2	17.3	173	
		60-90	38.4	21.51	1.25	16.89	168.9	
	HT3	0-30	36.31	19.33	1.12	16.98	169.8	61.50
		30-60	36.91	18.93	1.18	17.98	179.8	
		60-90	37.43	20.28	1.24	17.15	171.5	
Average							167.83	

Appendix Table 3 Experimental Result of determination of infiltration rate

Site: Hargaya			Soil type: Clay loam		Date: 23-November-22	
Time recorded		Time Interval	Cumulative Time	Infiltration Depth	Infiltration rate	Cumulative Infiltration
(hr)	(min)	(min)	(min)	(mm)	(mm/hr)	(mm)
2	30	0	0			
2	32.5	2.5	2.5	9.6	230.4	9.6
2	35	2.5	5	7.8	187.2	17.4
2	37.5	2.5	7.5	5.9	141.6	23.3
2	40	2.5	10	5.4	129.6	28.7
2	45	5	15	5.1	61.2	33.8

2	50	5	20	4.8	57.6	38.6
2	55	5	25	4.6	55.2	43.2
3	05	10	35	4.4	26.4	47.6
3	15	10	45	4.2	25.2	51.8
3	25	10	55	3.9	23.4	55.7
3	40	15	70	3.6	14.4	59.3
3	55	15	85	3.5	14	62.8
4	15	20	105	3.1	9.3	65.9
4	35	20	125	2.9	8.7	68.8
5	05	30	155	2.7	5.4	71.5
5	35	30	185	2.7	5.4	74.2
6	05	30	215	2.7	5.4	76.9

Appendix Table: 4 Soil moisture content one day before and after irrigation at Hargaya irrigation scheme

Field code	Soil depth (cm)	Avg. Bulk density (g/cm^3)	Moisture before irrigation (%)	Moisture after irrigation (%)	Moisture stored in depth (%)	Moisture stored in depth (mm)	Total moisture stored in depth (mm)
HU-1	0-30	1.22	38.03	40.10	2.07	7.58	53.77
	30-60	1.29	29.53	36.61	7.08	27.40	
	60-90	1.33	33.41	38.12	4.71	18.79	
HU-2	0-30	1.26	32.01	39.12	7.11	26.88	49.34
	30-60	1.21	36.34	40.91	4.57	16.59	
	60-90	1.28	39.71	41.24	1.53	5.88	
HU-3	0-30	1.23	30.80	36.58	5.78	21.33	53.07
	30-60	1.26	36.62	39.30	2.68	10.13	
	60-90	1.31	29.71	35.21	5.50	21.62	
HM-1	0-30	1.14	29.71	36.12	6.41	21.92	52.71
	30-60	1.21	32.56	36.23	3.67	13.32	
	60-90	1.26	33.19	37.81	4.62	17.46	
HM-2	0-30	1.19	30.68	35.45	4.77	17.03	54.67
	30-60	1.30	32.43	36.23	3.80	14.82	
	60-90	1.27	31.17	37.16	5.99	22.82	

HM-3	0-30	1.16	30.34	35.08	4.74	16.50	45.37
	30-60	1.33	32.81	36.33	3.52	14.04	
	60-90	1.18	33.98	38.17	4.19	14.83	
HT-1	0-30	1.25	32.47	36.38	3.91	14.66	54.48
	30-60	1.34	31.41	36.84	5.43	21.83	
	60-90	1.36	32.63	37.04	4.41	17.99	
HT-2	0-30	1.20	32.58	35.22	2.64	9.50	50.91
	30-60	1.13	30.71	35.91	5.20	17.63	
	60-90	1.31	32.64	38.69	6.05	23.78	
HT-3	0-30	1.29	31.12	34.37	3.25	12.58	47.03
	30-60	1.30	32.61	36.82	4.21	16.42	
	60-90	1.13	32.83	38.15	5.32	18.03	

Where, U-1, U-2, and U-3 are codes of fields selected from upper-reach water users, M-1, M-2 and M-3 are codes of fields selected from middle water users and T-1, T-2, and T-3 are codes of fields selected from tail-end water users and H is Hargaya.

Appendix Table II: Discharge measurement

Appendix Table 5 Average flow measured at canal intake in the left main canal

	Average section				Flow	
Date of measurement	Width (cm)	Depth (cm)	Flow area (m^2)	Flow velocity (m/s)	Flow discharge (m^3/s)	Flow discharge in l/s
18/9/2022	100	50	0.5	0.302	0.15100	151.00
21/10/2022	100	49	0.49	0.283	0.13867	138.67
13/11/2022	100	48	0.48	0.286	0.13728	137.28
9/12/2022	100	43	0.43	0.288	0.12384	123.84
11/01/2023	100	45	0.45	0.291	0.13095	130.95
10/02/2023	100	42	0.42	0.273	0.11466	114.66
29/03/2023	100	47	0.47	0.292	0.13724	137.24
16/04/2023	100	50	0.5	0.298	0.14900	149.00
Average					0.1353	135.3

Appendix Table 6 Average flows measured at intake of the right main canal

Date	Average section				Flow	
	Width (cm)	Depth (cm)	Flow area (m^2)	Flow velocity (m/s)	Flow discharge (m^3/s)	Flow discharge in l/s
18/9/2022	100	50	0.5	0.2973	0.14865	148.65
21/10/2022	100	49.5	0.495	0.2735	0.13538	135.38
13/11/2022	100	47	0.47	0.2847	0.13380	133.80
9/12/2022	100	44.7	0.43	0.2551	0.10969	109.69
11/01/2023	100	45.3	0.453	0.2826	0.12801	128.01
10/02/2023	100	48.6	0.486	0.2838	0.13792	137.92
29/03/2023	100	49.5	0.495	0.2782	0.13770	137.70
16/04/2023	100	50	0.5	0.303	0.15150	151.50
Average					0.13533	135.33

Appendix Table III: Crop characteristics data from FAO and field survey

Appendix Table 7 Crop type, planting, and harvesting date at Hargaya irrigation scheme.

Season-I			Season-II		
Crop type	Planting date	Harvesting date	Crop type	planting date	Harvesting date
Maize	10-Sep	23-Dec	Maize	1-Jan	15-Apr
Tomato	1-Sep	29-Dec	Tomato	1-Jan	30-Apr
Paper	1-Sep	30-Dec	Potato	1-Jan	30-Apr
Wheat	21-Sep	8-Jan	Paper	1-Jan	30-Apr
Cabbage	21-Sep	18-Jan	Onion	1-Jan	30-Apr
Beans	1-Oct	29-Dec			
Onion	1-Sep	29-Dec			

Appendix Table 8 Characteristics of major crops in the Hargaya irrigation scheme

Crop type	Factors	Growth stages				
		I	D	M	L	Total
Maize	Kc	0.43	-	1.2	0.35	
	LGP	15	30	45	15	105
	Ky	0.4	0.4	1.3	0.5	
	Z(m)	0.3		0.9	0.9	
	P	0.3	0.3	0.3		
Tomato	Kc	0.45		1.15	0.8	

	LGP	25	35	40	20	120
	Ky	0.3	1.1	0.8	0.4	
	Z(m)	0.45		1	0.7	
	P	0.3		0.3	0.3	
	Kc	0.5		1.15	0.95	
	LGP	20	35	45	20	120
Potato	Ky	0.4	0.8	1	0.7	
	Z(m)	0.6		0.6	0.6	
	P	0.4		0.4	0.7	
	Kc	0.35	0.75	1.05	0.9	
	LGP	30	35	40	20	120
Pepper	Ky	1.4	0.6	1.2	0.6	
	Z(m)	0.25		0.8		
	P	0.25	0.25	0.30	0.25	
	Kc	0.45		1.15	0.75	
	LGP	15	25	40	40	120
Onion	Ky	0.45	1	0.3	0.3	
	Z(m)	0.2			0.6	
	P	0.2	0.25	0.3	0.3	
	Kc	0.5		1.15	0.9	
	LGP	20	30	30	10	90
Beans	Ky	0.2	0.6	1.0	0.2	
	Z(m)	0.3		0.7	0.9	
	P	0.45		0.45	0.6	
	Kc	0.3		1.15	0.3	
	LGP	25	35	30	20	110
Wheat	Ky	0.4	0.6	0.8	0.4	
	Z(m)				0.6	
	P	0.55		0.55	0.55	
	Kc	0.7		1.05	0.95	
	LGP	25	30	45	20	120
Cabbage	Ky	0.2	0.8	0.7	0.6	
	Z(m)	0.45	0.45	0.45	0.45	
	P	0.45		0.45	0.45	

Source: FAO I & D 24(1992) and 56 (1998) papers and household survey.

Where Kc - Crop coefficient, LGP - Length of growing period, I- initial, D-developmental, M - mid-stage, L - late, Ky - yield response factor, Z(m) - crop root depth (m), H(m) - crop height (m), Rdz (m) - Root depth and P - critical depletion (fraction).

Appendix Table 4.9 Basic infiltration rate of soil types

Soil Type	Basic infiltration rate (mm/hr)
Clay	<5

Clay loam	5-10
Silt loam	10-20
Sandy loam	20-30
Sand	>30

Source: (Savva and Frenken, 2002b)

Appendix Table A: Crop water requirement of the first irrigation season of 2022/23

Appendix Table A1: Crop Water Requirement of Pepper

ETo Station		Girawa	Crop type		Peppers	Planting date	1-Sep
Rain Station		Girawa	Soil		Clay loam	Harvesting date	30-Dec
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	1	Init	0.6	2	20	35.1	0
Sep	2	Init	0.6	2.15	21.5	35.6	0
Sep	3	Init	0.6	2.18	21.8	30.6	0
Oct	1	Deve	0.67	2.49	24.9	15.1	0
Oct	2	Deve	0.81	3.63	36.3	12.6	13.7
Oct	3	Deve	0.95	4.05	40.5	10.9	17.3
Nov	1	Mid	1.06	4.07	40.7	10.7	24.6
Nov	2	Mid	1.47	4.07	40.7	9.5	29.8
Nov	3	Mid	1.57	3.93	39.3	7.3	31.7
Dec	1	Mid	1.1	3.89	38.9	4.6	34.3
Dec	2	Late	1.05	3.89	38.9	3.2	35.9
Dec	3	Late	0.98	3.73	37.3	2.8	35.4
					400.8	178	222.7

Appendix Table A2: Crop Water Requirement of Wheat

ETo Station		Girawa	Crop type		Wheat	Planting date	21-Sep
Rain Station		Girawa	Soil		Clay loam	Harvesting date	08-Jan
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr.Req. mm/dec
Sep	3	Init	0.3	1.09	10.9	28.6	0
Oct	1	Init	0.3	1.11	11.1	18.1	0
Oct	2	Deve	0.34	1.27	12.7	14.6	0
Oct	3	Deve	0.57	2.14	23.6	12.7	4.9
Nov	1	Deve	0.83	3.11	31.1	10.9	16.2
Nov	2	Mid	1.08	4.01	40.1	6.5	28.6
Nov	3	Mid	1.17	4.3	43	4.3	35.6
Dec	1	Mid	1.17	4.26	42.6	2.6	37.9

Dec	2	Late	1.17	4.2	42	2	40
Dec	3	Late	0.87	3.07	33.8	0.8	31
Jan	1	Late	0.45	1.58	12.6	0.3	7.5
					303.4	101.4	201.7

Appendix Table A3: Crop water requirement of Cabbage

ETo Station		Girawa	Crop type		Cabbage	Planting date	21-Sep
Rain Station		Girawa	Soil		Clay loam	Harvesting date	18-Jan
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	3	Init	0.7	2.55	25.5	30.6	0
Oct	1	Init	0.7	2.59	25.9	21.1	0.7
Oct	2	Deve	0.72	2.7	27	18.6	8.3
Oct	3	Deve	0.83	3.12	34.3	15.5	18.6
Nov	1	Deve	0.96	3.58	35.8	12.9	22.9
Nov	2	Mid	1.06	3.92	39.2	9.5	29.8
Nov	3	Mid	1.07	3.91	39.1	7.3	31.8
Dec	1	Mid	1.07	3.87	38.7	4.6	34.1
Dec	2	Mid	1.07	3.84	38.4	2	36.3
Dec	3	Late	1.06	3.77	41.5	2.8	38.7
Jan	1	Late	1.03	3.59	35.9	4.2	31.8
Jan	2	Late	0.98	3.39	27.1	3.7	22.4
					408.4	132.8	275.4

Appendix Table A4: Crop water requirement of dry beans

ETo Station		Girawa	Crop type		Dry beans	Planting date	01-Oct
Rain Station		Girawa	Soil		Clay loam	Harvesting date	29-Dec
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	1	Init	0.4	1.48	14.8	20.1	0
Oct	2	Init	0.4	1.5	15	16.6	0
Oct	3	Deve	0.55	2.07	20.7	12.7	7
Nov	1	Deve	0.82	3.06	30.6	10.6	17.7
Nov	2	Mid	1.07	3.98	39.8	8.5	28.4
Nov	3	Mid	1.17	4.28	42.8	7.3	35.5
Dec	1	Mid	1.17	4.24	42.4	4.3	37.7
Dec	2	Late	1.16	4.17	41.7	2.0	39.6
Dec	3	Late	0.68	2.4	21.6	2.3	18.8
					269.3	84.4	184.7

Appendix Table A5: Crop Water Requirement of Tomato

ETo Station		Girawa	Crop type		Tomato	Planting date	01-Sept
Rain Station		Girawa	Soil		Clay loam	Harvesting date	29-Dec
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	1	Init	0.45	1.5	15	39.1	0
Sep	2	Init	0.45	1.61	16.1	39.3	0
Sep	3	Deve	0.48	1.75	17.5	22.3	3.3
Oct	1	Deve	0.67	2.46	24.6	10.4	7.7
Oct	2	Deve	0.87	3.27	32.7	10.7	15.9
Oct	3	Mid	1.09	4.06	40.6	8.4	28.9
Nov	1	Mid	1.17	4.35	43.5	6.6	30.6
Nov	2	Mid	1.17	4.34	43.4	5.5	31.9
Nov	3	Mid	1.17	4.29	42.9	4.3	32.6
Dec	1	Late	1.17	4.24	42.4	2.6	33.8
Dec	2	Late	1.05	3.79	37.9	0	31.9
Dec	3	Late	0.89	3.14	31.3	0	21.8
					387.9	149.2	238.4

Appendix Table A6: Crop water requirement of Maize

ETo Station		Girawa	Crop type		Maize	Planting date	10-Sept
Rain Station		Girawa	Soil		Clay loam	Harvesting date	23-Dec
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	1	Init	0.4	1.34	1.3	4	1.3
Sep	2	Init	0.4	1.43	14.3	35.6	0
Sep	3	Deve	0.45	1.65	16.5	28.6	0
Oct	1	Deve	0.7	2.58	25.8	20.1	0.6
Oct	2	Deve	0.96	3.59	35.9	12.6	14.3
Oct	3	Mid	1.16	4.34	47.8	9.7	29.1
Nov	1	Mid	1.18	4.38	43.8	7.9	30.9
Nov	2	Mid	1.18	4.36	43.6	4.5	33.2
Nov	3	Mid	1.18	4.32	43.2	2.3	35.8
Dec	1	Late	1.17	4.25	42.5	1.6	38.8
Dec	2	Late	0.97	3.51	35.1	0	35.1
Dec	3	Late	0.8	2.84	8.5	0	12.1
					358.3	126.9	231.2

Appendix Table A7: Crop Water Requirement of Onion

ETo Station		Girawa	Crop type		Onion	Planting date	10-Sept

Rain Station		Girawa	Soil		Clay loam	Harvesting date	23-Dec
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	1	Init	0.7	2.34	23.4	38.5	0
Sep	2	Deve	0.72	2.58	25.8	37.6	0
Sep	3	Deve	0.85	3.1	31	30.6	0
Oct	1	Deve	1	3.69	36.9	22.1	11.7
Oct	2	Mid	1.06	3.99	39.9	16.6	18.2
Oct	3	Mid	1.06	3.97	43.7	11.7	23
Nov	1	Mid	1.06	3.96	39.6	10.9	26.7
Nov	2	Late	1.06	3.94	39.4	7.5	29.9
Nov	3	Late	1.05	3.84	38.4	4.3	31.1
Dec	1	Late	1.02	3.71	37.1	3.6	32.5
Dec	2	Late	1	3.59	35.9	1.8	33.9
Dec	3	Late	0.97	3.45	31.1	1.3	28.3
					422.1	186.5	235.3

Appendix Table B: Crop water requirement of the Second irrigation season of 2022/23

Appendix Table B1: Crop water requirement of Maize

ETo Station		Girawa	Crop type		Maize	Planting date	01-Jan
Rain Station		Girawa	Soil		Clay loam	Harvesting date	15-Apr
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.4	1.4	14	4.2	9.8
Jan	2	Deve	0.44	1.51	15.1	4.7	10.4
Jan	3	Deve	0.68	2.46	27	4.2	22.8
Feb	1	Deve	0.96	3.57	35.7	2.1	33.7
Feb	2	Mid	1.16	4.51	45.1	0.9	44.1
Feb	3	Mid	1.18	4.66	37.3	6.8	30.5
Mar	1	Mid	1.18	4.75	47.5	14.3	33.2
Mar	2	Mid	1.18	4.84	48.4	19.8	28.6
Mar	3	Mid	1.18	4.69	51.6	21	30.6
Apr	1	Late	1.03	3.97	39.7	21.3	18.4
Apr	2	Late	0.83	3.09	15.5	11.4	4.1
					376.9	110.7	266.2

Appendix Table B2: Crop Water Requirement of Tomato

ETo Station		Girawa	Crop type		Tomato	Planting date	01-Jan
Rain Station		Girawa	Soil		Clay loam	Harvesting date	30-Apr

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.45	1.57	15.7	4.2	11.6
Jan	2	Init	0.45	1.55	15.5	4.7	10.8
Jan	3	Deve	0.49	1.76	19.3	4.2	15.1
Feb	1	Deve	0.69	2.56	25.6	2.1	23.5
Feb	2	Deve	0.89	3.46	34.6	0.9	33.6
Feb	3	Deve	1.08	4.26	34.1	6.8	27.3
Mar	1	Mid	1.17	4.71	47.1	14.3	32.8
Mar	2	Mid	1.17	4.8	48	19.8	28.2
Mar	3	Mid	1.17	4.65	51.2	21	30.2
Apr	1	Mid	1.17	4.51	45.1	21.3	23.7
Apr	2	Late	1.07	4	40	22.8	17.2
Apr	3	Late	0.9	3.3	33	26.5	6.5
					409.1	148.6	260.5

Appendix Table B3: Crop water requirement of Potato

ETo Station	Girawa	Crop type	Potato	Planting date	01-Jan
Rain Station	Girawa	Soil	Clay loam	Harvesting date	30-Apr

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.5	1.75	17.5	4.2	13.3
Jan	2	Init	0.5	1.72	17.2	4.7	12.5
Jan	3	Deve	0.61	2.2	24.3	4.2	20.1
Feb	1	Deve	0.81	3.04	30.4	2.1	28.3
Feb	2	Deve	1.01	3.9	39	0.9	38.1
Feb	3	Mid	1.15	4.57	36.5	6.8	29.8
Mar	1	Mid	1.17	4.71	47.1	14.3	32.8
Mar	2	Mid	1.17	4.8	48	19.8	28.2
Mar	3	Mid	1.17	4.65	51.2	21	30.2
Apr	1	Mid	1.17	4.51	45.1	21.3	23.8
Apr	2	Late	1.11	4.16	41.6	22.8	18.8
Apr	3	Late	1.01	3.73	37.3	26.5	10.8
					435.2	148.6	286.7

Appendix Table B4: Crop Water Requirement of Pepper

ETo Station	Girawa	Crop type	Pepper	Planting date	01-Jan
Rain Station	Girawa	Soil	Clay loam	Harvesting date	30-Apr

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec

Jan	1	Init	0.6	2.1	21	4.2	16.8
Jan	2	Init	0.6	2.06	20.6	4.7	16
Jan	3	Deve	0.6	2.16	23.7	4.2	19.5
Feb	1	Deve	0.69	2.57	25.7	2.1	23.6
Feb	2	Deve	0.82	3.19	31.9	0.9	30.9
Feb	3	Deve	0.94	3.73	29.8	6.8	23
Mar	1	Mid	1.05	4.23	42.3	14.3	28
Mar	2	Mid	1.07	4.39	43.9	19.8	24.1
Mar	3	Mid	1.07	4.26	46.8	21	25.8
Apr	1	Mid	1.07	4.12	41.2	21.3	19.9
Apr	2	Late	1.06	3.95	39.5	22.8	16.7
Apr	3	Late	0.99	3.64	36.4	26.5	10
					402.8	148.6	254.3

Appendix Table B5: Crop water requirement of Onion

ETo Station		Girawa	Crop type		Onion	Planting date	01-Jan
Rain Station		Girawa	Soil		Clay loam	Harvesting date	30-Apr
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.7	2.45	24.5	4.2	20.3
Jan	2	Deve	0.72	2.48	24.8	4.7	20.2
Jan	3	Deve	0.86	3.09	34	4.2	29.8
Feb	1	Mid	1.01	3.78	37.8	2.1	35.8
Feb	2	Mid	1.07	4.14	41.4	0.9	40.4
Feb	3	Mid	1.07	4.22	33.8	6.8	27
Mar	1	Mid	1.07	4.3	43	14.3	28.7
Mar	2	Mid	1.07	4.38	43.8	19.8	24
Mar	3	Late	1.05	4.2	46.2	21	25.1
Apr	1	Late	1.03	3.96	39.6	21.3	18.3
Apr	2	Late	1	3.74	37.4	22.8	14.6
Apr	3	Late	0.98	3.59	35.9	26.5	9.4
					442.2	148.6	293.6

Appendix Table C: Net Scheme Irrigation Requirement of First Irrigation Season 2022/23

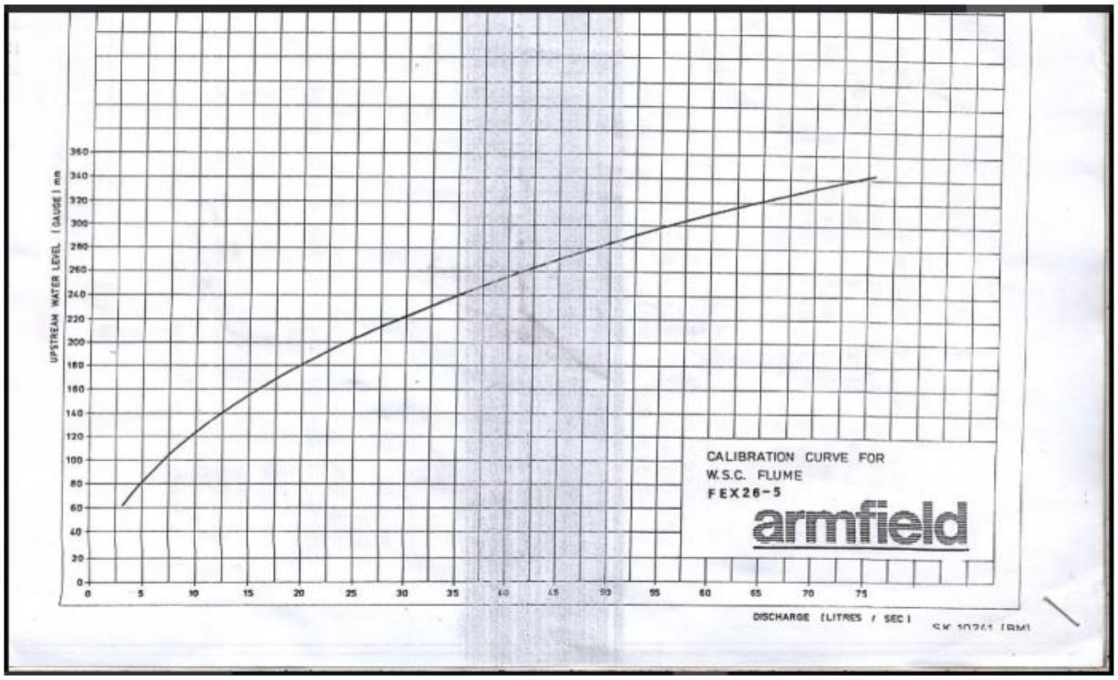
Season -I	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Maize	0	0	0	0	0	0	0	0	1.3	50	101	78.1
2. Peppers	7.6	0	0	0	0	0	0	0	0	34.9	88.6	105.4
3. Dry beans	2.7	0	0	0	0	0	0	0	0	3.4	75.8	110
4. Tomato	0	0	0	0	0	0	0	0	0	42.9	99.9	99.2

5. Onion	0	0	0	0	0	0	0	0	0	61.3	88	94.8
6. Wheat	8.5	0	0	0	0	0	0	0	0	7.9	84.5	108.9
7. Cabbage	54.1	0	0	0	0	0	0	0	0	27.6	84.5	109.2
Net scheme irr. req.												
in mm/day	0.3	0	0	0	0	0	0	0	0	1.2	3	3
in mm/month	9.9	0	0	0	0	0	0	0	0.4	37.5	91.2	93.5
in l/s/h	0.04	0	0	0	0	0	0	0	0	0.14	0.35	0.35
Irrigated area (% of total area)	38	0	0	0	0	0	0	0	32	98	98	98
Irr. req. for actual area (l/s/h)	0.1	0	0	0	0	0	0	0	0.01	0.14	0.36	0.36

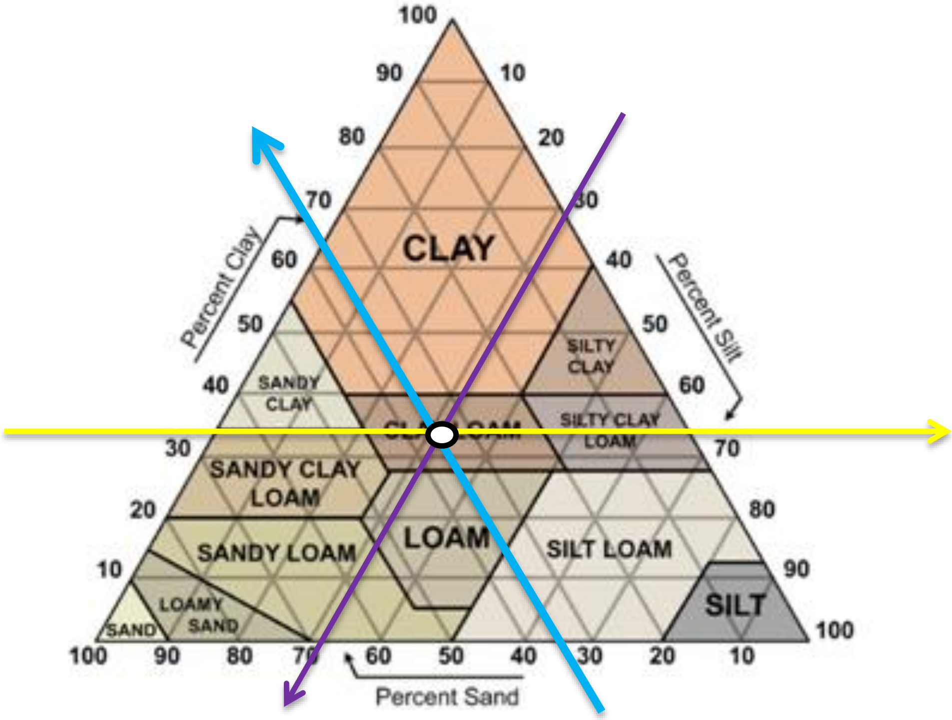
Appendix Table D: Net Scheme Irrigation Requirement of Second Irrigation Season 2022/23

Season-II	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Maize	43.1	108.3	92.4	22.5	0	0	0	0	0	0	0	0
2. Peppers	52.3	77.5	78	48	0	0	0	0	0	0	0	0
3. Tomato	37.5	84.5	91.2	47.5	0	0	0	0	0	0	0	0
4. onion	70.3	103.2	77.9	42.3	0	0	0	0	0	0	0	0
5. Potato	45.9	96.2	91.3	53.3	0	0	0	0	0	0	0	0
Net scheme irr. req.												
in mm/day	1.6	3.5	2.8	1.2	0	0	0	0	0	0	0	0
in mm/month	48.7	99	87.9	36.7	0	0	0	0	0	0	0	0
in l/s/h	0.18	0.41	0.33	0.14	0	0	0	0	0	0	0	0
Irrigated area (% of total area)	100	100	100	100	0	0	0	0	0	0	0	0
Irr. req. for actual area (l/s/h)	0.18	0.41	0.33	0.14	0	0	0	0	0	0	0	0

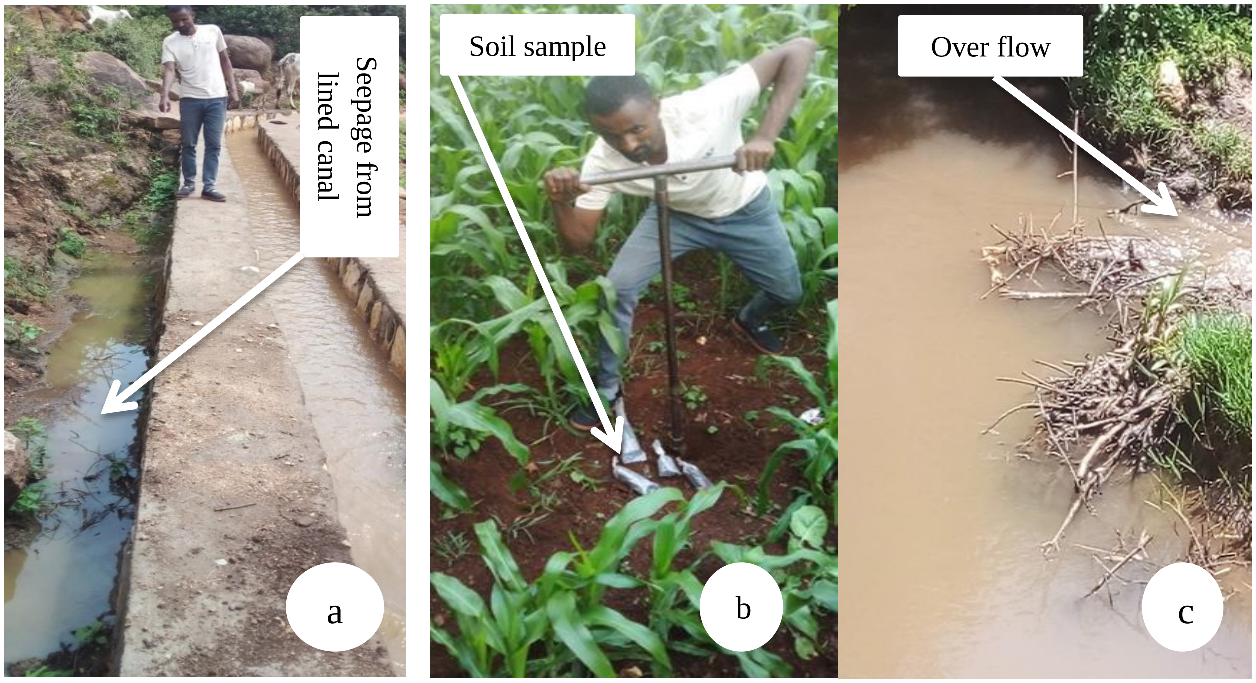
Appendix Figure



Appendix Figure 1 Calibration curve of water level vs. discharge graph



Appendix Figure 2 Determination of soil textural class triangle



Appendix Figure 3. Primary data collection at the field

Appendix Figure 4 Canal condition and seepage loss

Questionnaire for the Performance Evaluation of Hargaya Small-Scale Irrigation Scheme

Scheme Name:_______ Region: _______ Zone: _____ Woreda:________ Kebele:_______

Farmer’s Name:______________ Location of the plot: head/mid/tail Date:___________

i. Household characteristics

1. Household head : Male: _____ Female: _____ Age:_____ Educational Level:_______

2. Family size: F:______ M:_______

☐<15yrs ☐ 15-65yrs ☐ > 65yrs

3. Marital status of the respondent: ☐ Married ☐ Widowed ☐ Divorced ☐Unmarried

4. Literacy level of the household: ☐ illiterate ☐ Elementary ☐Diploma and above

ii. Irrigation scheme infrastructure

1. What is the main cause of water loss in the scheme?

A. Seepage B. Deep percolation C. Structural failure C. Design problem D. Sedimentation E. All

2. Who has responsibility for water allocation?

A. The community as a whole B. DA C. Representatives of the community D. Others ____

iii. Evaluation of project planning, design/ layout/ and construction

1. Have you participated in the planning and construction of the scheme? A. Yes B. No

2. Who designs the layout of the structure?

A. DAs B. Zonal expert C. Woreda expert

3. Have you ever participated in canal clearing and other maintenance of the irrigation scheme?

A. Yes B. No

iv. Institutional setup and support services

1. Is there a water user association in the scheme? A.Yes B. No

2. Are you a member of WUAs? A. Yes B. No

If yes; what benefits do you get from being a member?

A. Gain irrigation water on a scheduled basis B. Social accountability and responsibility C. Irrigation water use in a wise manner D. All E. Others ______

3. What type of institutional support do you need related to the scheme?

A. Water management B. Operation and maintenance D. Organization D. All

4. Do you have access to different input supplies for irrigation? A. Yes B. No

5. Did you use improved seed, fertilizer, chemicals, and hand tools? A. Yes B. No

V. Water management

1. What criteria should you use to decide when to irrigate crops?

A. Wait until see signs of wilting on the leaves B. Check the soil near the roots C. When it is dry, I irrigate D. Every day E. Others (specify____________

2. What is the system of water allocation in the scheme? A. As the size of land holding. B. Equal division among all members C. Can irrigate any time D. Specify if any other system_________

3. Is there any training given to you? A. Yes B. No

4. Have you ever faced any conflict over irrigation water? A. Yes B. No

If yes; What are the main sources of conflict?

A. Water theft B. Competition due to increasing number of water users C. Ilegal water abstraction