PERFORMANCE EVALUATION OF WOSHA AND WERKA IRRIGATION SCHEMES IN WONDO GENET DISTRICT, SNNPRS, ETHIOPIA

MSC THESIS

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PERFORMANCE EVALUATION OF WOSHA AND WERKA IRRIGATION SCHEMES IN WONDO GENET DISTRICT, SNNPRS, ETHIOPIA

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APPROVAL SHEET

As members of the Examining Board of the Final MSc. Open Defense, we certify that we have read and evaluated the thesis prepared by HENOK TESFAYE CHARINET entitled " Performance Evaluation of Wosha and Werka Irrigation Schemes in Wondo Genet District, SNNPRS, Ethiopia ", and recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in Water Resource Engineering and Management.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the School of Graduate Council (SGC) of the candidate's major department.

DEDICATION

I dedicate this thesis manuscript to my father TESFAYE CHARINET and my mother MULATUWA H/MARIAM for nursing me with affection and love and for their dedicated partnership in the success of my life.

STATEMENT OF AUTHOR

I declare that this thesis is my bona fide work and all sources of materials used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Name: …………………………………………. **Signature:** ………………
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BIOGRAPHY

The author was born on July 22, 1991 at Goba, from his father Mr. Tesfaye Charinet and his mother Mulatuwa H/Mariam. He attended his elementary at Urji Berisa elementary school, secondary education at Negade Sefer high school and preparatory at Batu Terara preparatory school in Goba. After completing his preparatory school education in 2009, he joined Bahir Dar University in October 2010 and graduated with BSc degree in Water and Irrigation Management in July 2013.

After graduation, he was employed at Alage ATVET College in the position of Irrigation Instructor, and worked there for six months. Then he joined Wondo Genet Agricultural Research Center of Ethiopian Institute of Agricultural Research in August 2014 and worked there until he joined the School of Graduate Studies of Hawassa University in October 2016 to pursue his MSc Degree study in Water Resource Engineering and Management.

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LISTS OF ABBREVIATIONS AND ACRONYMS

BD	Bulk Density
CROPWAT	Crop Water Requirement Model
Ea	Application Efficiency
Ec	Conveyance Efficiency
Ed	Water Distribution Uniformity
Es	Water Storage Efficiency
ET	Evapotranspiration
ET_O	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
GDP	Gross Domestic Product
GPS	Global Positioning System
Ha	Hectare
IR	Irrigation Ratio
IS	Irrigation Scheme
IWMI	International Water Management Institute
M ha	Million hectares
m.a.s.l	Mean Above Sea Level
MoWIR	Federal Democratic Republic of Ethiopia Ministry of Water, Irrigation and Energy

MoA	Federal Democratic Republic of Ethiopia Ministry of Agriculture
O & M	Operation and Maintenance
OPUCA	Output per Unit Command Area
OPUIA	Output per Unit Irrigated Area
OPUWC	Output per Unit Water Consumed
OUPIS	Output per Unit Irrigation Supply
PWP	Permanent Wilting Point
RH	Relative Humidity
RIS	Relative Irrigation Supply
RIW	Relative Water Supply
RR	Runoff Ratio
RWH	Rain Water Harvesting
RWS	Relative Water Supply
SIA	Sustainability of Irrigated Area
SNNPRS	South Nation, Nationality, and People Regional State
WGCFNR	Wondo Genet College of Forestry and Natural Resource
WGDAO	Wondo Genet District Agricultural Office

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PERFORMANCE EVALUATION OF WOSHA AND WERKA IRRIGATION SCHEMES IN WONDO GENET DISTRICT, SNNPRS, ETHIOPIA

ABSTRACT

Expanding efficient irrigation development on various scales is one of the best alternatives to provide reliable and sustainable food security. However, many irrigation schemes in developing countries in general and particularly in Ethiopia are performance below capacity. Performance evaluation of irrigation schemes plays a fundamental role in improving irrigation system of a scheme by identifying where the critical problems occurred. Evaluation of irrigation schemes carried out at Wondo Genet SNNPRS, Ethiopia. The primary objective of evaluating Wosha and Werka irrigation schemes using internal and external indicators were to evaluate their performance and suggest possible interventions to enhance their capacity. Internal indicators including conveyance, application, water storage, water distribution uniformity efficiency, and deep percolation ratio were used at the head, middle and tail reach of each scheme. Moreover, external indicators of agriculture output, water supply, water delivery capacity and physical indicator were used for evaluating the schemes. The results showed that the conveyance, application, storage, distribution efficiency of 55.6, 48.2, 89.8 and 91.7%, respectively were found at Wosha irrigation scheme whereas 43.0, 59.0, 87.2 and 91.4%, respectively at Werka irrigation scheme. The agricultural output performance such as OPUIA, OPUCA, OPUIS, and OPUWC were 4213.97 US$/ha, 8732.29 US$/ha, 1.18 and 0.32, respectively at Wosha irrigation scheme and 5840.34, 8534.19, 1.77 and 0.42 respectively for Werka irrigation scheme. Water supply indicators such as RIS and RWS were 0.64 and 0.71, respectively for Wosha 0.48 and 0.55, respectively for Werka irrigation scheme. The result indicates that water delivery capacity of Wosha and Werka irrigation schemes were 1.56 and 1.32, respectively. Physical indicators revealed that irrigation ratio of 0.89 and 0.78 and sustainability of irrigated area of 2.07, and 1.46 were found at Wosha and Werka irrigation schemes. Among the internal indicators, application efficiency was very low especially at Wosha irrigation scheme due to higher water loss through deep percolation. The overall efficiency was also below the desired level, where 26.8 and 25.4 %, respectively realized at Wosha and Werka irrigation schemes. Based on the above observation, adoption of water saving practices such as deficit irrigation, surge and cutoff application to improving application, conveyance and distribution systems can enhance crop productivity per unit irrigation water.

Keywords: Irrigation scheme, internal indicators, external indicators, efficiency

1. INTRODUCTION

1.1. Background and Justification

Water is the most limited resource, which is widely used by different sectors like agriculture, water supply and industrial. Due to rapid increasing of world population in the world the food demand also increased as well. The competition for this scarce resource is increasing from time to time due to increasing food demand from the highly consuming agricultural sector, which makes less water available for crop production (Ingle *et al.*, 2015; Pereira *et al*., 2009).

Many of developing countries particularly in Africa, Asia, and the Middle East are located in hotspots of water-related stress area. Worldwide, the cost of water insecurity to the irrigation sector is estimated about US$94 billion per year, and hence the total value of water insecurity to the global economy is about US$500 billion annually (Sadoff *et al*., 2015). In addition, increasing stress on water resources could inhibit an adaptation effort that increases irrigation development through maintaining the current level of the irrigation system. Global climate change, water scarceness, and variability have a direct impact on the key sector outputs and ultimately on the overall economy of most African countries (WWAP, 2016).

Irrigation in Ethiopia dates back several centuries through producing subsistence food crops. However, modern irrigation systems started in the 1960s with the objective of producing industrial crops in Awash Valley (Seleshi *et al*., 2007). The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climatic instability in any country. Although Ethiopia has abundant rainfall and water resources but agricultural system does not yet fully benefit from the technologies of irrigation water management (Seleshi, 2010).

Ethiopia has 112 Mha of land among which, cultivable land area estimates vary between 30 and 70 Mha. Currently, reports show that out of the total country land only 15 Mha of land is under cultivation. From the existing cultivated area of the country, only about 4 to 5 percent is cultivated under irrigation, with existing equipped irrigation schemes covering about 640,000 hectares. The total irrigable land area in the country is estimated as 5.3 Mha.

Which implies that based on the irrigable land potential, only 12% is under irrigation currently (Seleshi, 2010).

With the naturally endowed water resources, annual surface runoff estimated to be about 122 Bm³ (Seleshi, 2010). In addition to this, the preliminarily estimated amount of annual groundwater recharge of the country is about 28 billion m^3, which is mainly used for domestic and industrial water supply (MoWIE, 2014). However, about 90% of the irrigation potential in terms of land and water resources has not been developed so far. In recent years, there are many irrigation development progresses in medium and large-scale. Whereas about 47% of the developed area is under large-scale public irrigation schemes, mainly industrial crops like cotton, sugarcane, and fruits were grown (Zeleke *et al.*, 2012).

According to FAO (2011) report, irrigated agriculture is the most inefficient and much water consuming sector, which contributes globally about 70% of water withdrawal from different sources like aquifers, streams, and lakes and it is over 90% in most of the least developed countries. Without improved efficiency measures, agricultural water consumption is expected to increase by about 20% globally by 2050 (WWAP, 2012).

Due to, the acceleration of population and changes in nutritional habits, food consumption are increasing in most regions of the world. It is expected that by 2050 an additional a billion tons of cereals and 200 million tons of meat will need to be produced annually to satisfy growing food demand (FAO, 2012). Currently, irrigated agriculture contributes to producing 40% of world food and agricultural commodities within 16% of cultivated land (Bos *et al*., 2008).

Irrigation in Ethiopia is a basic strategy to alleviate poverty and food security. It is helpful to modernize the rain-fed agricultural system that depends on precipitation into the combined rain-fed and irrigated agricultural system. This is supposed to be the most outstanding way of sustainable development in the country (Gebremedhin, 2015). However, irrigated agriculture faces several challenging problems. One of the major concerns is its poor efficiency, which water resources have been used for irrigation. The comparative estimate is 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff (FAO, 1989). Irrigation science in the future, it will certainly expected to maximize efficiency through assessments of water resources and attention on wasteful practices (FAO, 1989).

Various terms are used to describe how efficiently irrigation water is applied and used by crop. The efficiency of irrigation water use varies from scheme to scheme. In schemes where water is limited, an available water is used more carefully. Whereas, in areas of abundant water, the value put on conserving water is less and the tendency to over-irrigate is exists. Efficient use of water is also influenced by the cost of labor, ease of water controlling, crops being irrigated, types of irrigation system, and soil characteristics (Ramulu, 1998).

Performance evaluation allows to verify the degree of those targets and objectives are being accomplished. It additionally provides different stakeholders (system managers, farmers, and policymakers) with a far better understanding of how a system operates. It can help to determine issues and identify ways in which and suggests options for enhancing system performance (Cakmak *et al*., 2004). In this respect, irrigation water management needs various types of performance measurements to determine and reflect different desires and expectations of stakeholders.

Irrigation water manager is usually desired the successful balance of competing demands in various users. Especially, farmers are among the strategic users of the irrigation water resource. Paying attention to farmers could give economic and social advantages to the irrigation system. More significantly, if an irrigation system committed to farmers satisfaction it will provide additional and better sustainability information (Kuscu *et al.*, 2009).

The performance of irrigation schemes in developing countries is also questioned due to low performances. In order to improve performance, measures are needed to develop the capacity of the actors to design realistic infrastructure, support irrigation users and develop capabilities to improve system management (Seleshi and Mekonnen, 2011). Evaluating the current condition of irrigation systems, introducing improved techniques and manage water resources efficiently are crucial for improving irrigation efficiencies, sustainability, and productivity of irrigated agriculture (McCornick *et al*., 2003).

1.2. Statement of the Problem

Most irrigation schemes are performing below capacity with an estimated average performance of about 30 percent below design capacity. This implies that about 230 thousand hectares of irrigated land is a loss, from these small-scale schemes account for 90 percent of the gap (Seleshi, 2010).

In Wondo gent district, three modern irrigation schemes and several traditional irrigation systems are operating from rivers, hand-dug wells and springs water sources. Totally, the irrigated land estimated about 8246 ha. From the total irrigated area 865, 5612, 982 and 787 ha of land irrigated by modern irrigation schemes, traditional river diversion, hand dug well and spring water source, respectively. However, there are conflicts among irrigation water users due to water shortage.

Inappropriate irrigation practices lead to inefficient water distribution, non-uniform crop growth and excessive leaching losses in some areas and insufficient irrigation in others part of the field, all of these decreases the yield per unit of irrigated area against per unit water applied. As a result, performance evaluation of irrigation schemes plays a fundamental role in improving the productivity of irrigation schemes by identifying where the critical problem occurred. Therefore, it is reasonable to evaluate the performance of Wosha and Werka Irrigation Schemes found in Wondo Genet District of SNNPRS having the following general and specific objectives.

1.3. General Objective:

The general objective of this study was to evaluate the performance of Wosha and Werka Irrigation schemes located at Wondo Genet SNNP, Ethiopia.

1.3.1. Specific Objectives:

- To evaluate the performance of the schemes using internal and external performance indicators.
- To identify the main technical constraints responsible for lowering the performance of each scheme.

1.4. Scope of the Study

The study was conducted on two irrigation schemes, which is found in Wondo Genet district. The study aimed to identify technical constraint causing poor performance of the schemes and suggest their mitigations.

1.5. Significance of the Study

The study will provide water management options, which can improve the irrigation system and sustainability in these schemes. The water management recommendation can be extended to other similar small-scale schemes in Ethiopia. It will provide 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. Irrigation Development in the World

Irrigated agriculture produces nearly 40% of food and agricultural commodities in the world with only 16% of cultivated land (Bos *et al*., 2008). It uses about 70% of water withdrawn from global systems. Over the last forty years, the irrigation has been a major contributor to the growth of food and fiber supply for a global population that has more than doubled, from 3 to over 7.3 billion people.

Global irrigated area increased by about 2% a year in the 1960s and 1970s, slowing down to about 1% in the 1980s, and lower until 1990s. World's irrigated land grows from 150 to 260 million ha between 1965 and 1995. Currently, it is increasing at a very slow rate because of the significant slowdown in new investments, combined with the loss of irrigated areas due to salination and urban encroachment (De Wrachien and Goli, 2015).

Many countries depend on surface irrigation to produce food and fiber. Estimation of surface irrigation accounts for some 80 to 90 percent of the total 260 million hectares of irrigated land worldwide, mainly in developing countries in the tropics and sub-tropics, where hundreds of millions of farmers depend on surface irrigation to grow their crops (Jurriens et al, 2001).

2.2. Irrigation Development in Ethiopia

Irrigation development in Ethiopia can be considered as a basis of food security to meet the growing food demands and poverty reduction tool as it has the power to stimulate economic growth and rural developments. Increasing food demand can be met in one or a combination of three ways: increasing agricultural yield, increasing the area of arable land, and increasing cropping intensity (Seleshi *et al*., 2007; Fisum *et al*., 2009). Therefore, increasing arable land or attempting to increase agricultural yield by, for instance, growing higher yielding varieties of crops offers limited scope to provide food security in Ethiopia. The solution for food security will be provided by a combination of these factors, enhancing water availability for production and expansion of irrigation that can lead to security by reducing variation in harvest, as well as the intensification of cropping by producing more than one crop per year (Seleshi *et al*., 2005).

The country has cultivated land only 4 to 5 percent is irrigated, with current irrigation schemes, which covers about 640,000 hectares across the country moreover output from this irrigated agriculture covers only 3% of the total national food production (Bacha *et al*., 2011). In addition to the existing irrigation, development in Ethiopia is not significant to the potential (MoA, 2011a).

The country has an estimated total irrigable land potential of 5.3 Mha assuming use of existing technologies, including 1.6 M ha through rainwater harvesting and groundwater. Significant irrigation potential from the twelve-river basin surface water is about 3.7 Mha and an additional 1.1 from groundwater and 0.5 Mha rainwater harvesting. From the total surface water, small, medium and large-scale irrigation potential have a share of 5, 9 and 86 % respectively. From the total basin surface, only five basins have a potential for small-scale irrigation scheme is 91,281 hectares (Seleshi, 2010).

Ethiopia has significantly expand its irrigation sector to reach the full irrigable potential of over 5 Mha. Medium and large-scale schemes will be an important strategy to achieve this aspiration, in combination with exploring and developing groundwater potential, especially given that an estimated 85 percent of Ethiopia's total surface water irrigation potential estimated to be in large-scale schemes (Seleshi, 2010).

Small-scale irrigation schemes consist of 19 percent of the total irrigation schemes developed in the country. Hence, efforts are being made to involve farmers progressively in various aspects of management in small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture (Seleshi *et al.*, 2007). However, as compared to its potential and rain-fed farming, the contribution of irrigation to the national economy is quite limited, which contributes about 2.5% of the overall gross domestic product (GDP) (MoA, 2011b; Fisum *et al.*, 2009).

2.2.1. Irrigation Development in Wondo Genet District

Irrigation practice in Wondo Gent District has a longer period story through cultivation of chat and sugarcane using traditional river diversions. However, moder irrigtion practice started since in 1980 by deveping Werka river for about 200 ha of irrigabale land in Wetera Kechema Kebele by non governmental organazation fund. Other modern irrigation schemes also constructed in Wosha River, which is designed for 180 ha at Wosha Soyama Kebele in 2000 by governmetal support. Resa Irrigation Scheme developed in 2008 by diverting Ressa River designed for 200 ha irrigable land. Currently, in Wondo Genet District those three modern irrigation scheme are developing about 865 ha of irrigable land. The district has riches in water resource, having this advantage farmers develop about 5612 ha through traditional river diversion and more than 1769 ha of hand irrigated using ground water source and local springs (WGDAO).

2.3. Irrigation Typology in Ethiopia

Many irrigation schemes in Ethiopia classified in two way. According to Seleshi (2010) and Makombe *et al*. (2011) irrigation schemes in Ethiopia is classified based on the size of the command area in three categories as below.

1. Small-scale irrigation systems (<200 ha),
2. Medium-scale irrigation systems (200-3,000 ha),
3. Large-scale irrigation systems (>3,000 ha).

Based on this classification, 46% of the total currently estimated and planned irrigation development is in the small-scale irrigation category (Makombe *et al*., 2011).

The second classification uses a mix of the history of establishment, time of establishment, management system and nature of the structures, those irrigation schemes range in size from about 50 to 85,000 ha and are organized in 4 different ways (Makombe *et al*., 2011; MoWR, 2002) as follows.

1. Traditional schemes: These are small-scale irrigation systems up to 100 ha in the area, which usually uses diversion weirs made from local material and needs annual maintenance. The canals are usually earthen, and the community manages the schemes.
2. Modern schemes: These are small-scale irrigation systems up to 200 ha with more permanent diversion weirs made from concrete that do not require annual maintenance. They are mostly community-managed, and the primary and secondary channels are made of concrete.

3. Public: These are large-scale up to 2,000 ha which operations constructed and managed by the government. Sometimes these schemes support out-growers (smallholder farmers who have farms near the large-scale schemes).
4. Private: These are privately owned systems over 3,000 ha in mechanized farms which need a highly intensive operation

2.4. Challenge and Opportunity of Irrigation in Ethiopia

Now a day's Ethiopian population increasing with an alarming rate which increases food demand. An ultimate solution for food security is enhancing productivity by expanding irrigation development. However, Ethiopian irrigation development faces different challenges. According to the MoWIE (2013) and MoA (2011, a), the main challenges and opportunities for the development of irrigation in Ethiopia are listed below.

2.4.1. Challenges

The technical constraints and knowledge gaps are identified as:-

1. Inadequate awareness of irrigation water management as in irrigation scheduling techniques, water saving irrigation technologies, water measurement techniques, operation and maintenance of irrigation facilities,
2. Inadequate knowledge of improved and diversified irrigation agronomic practices,
3. Shortage of basic technical knowledge on irrigation pumps, drip irrigation system, sprinkler irrigations, surface, and spate irrigation methods,
4. Scheme based approach rather than area/catchments-based approach for the development of SSI Schemes,
5. Inadequate baseline data and information on the development of water resources,
6. Lack of experience in design, construction, and supervision of quality irrigation projects,
7. Low productivity of existing irrigation schemes,
8. Inadequate community involvement and consultation in scheme planning, construction, and implementation of irrigation development,
9. Poor economic background of users for irrigation infrastructure development, to access irrigation technologies and agricultural inputs, where the price increment is not affordable to farmers.

2.4.2. Opportunities

The basic opportunistic considerations regarding irrigation developments in Ethiopia are

1. Emphasis and priorities are given to irrigation in the growth and transformation plan of the country,
2. Indigenous knowledge and the introduction of promising household water harvesting and micro-irrigation technologies,
3. Government’s strong political commitment and encouragement of the private sector and public enterprises involvement in irrigation development,
4. Abundant water resources, climate, and land suitability,
5. Availability of inexpensive labor,
6. Availability of suitable lands for irrigation developments especially in arid areas of the country.

2.5. Irrigation Water Management

Irrigation management majorly is concerned about water needs to be gauged and properly utilized, both excessive and inadequate water applications have negative effects (Mihret, 2013). Water management is the integrated process of intake, conveyance, regulation, measurement distribution, application and use of irrigation water at the farmer's field and drainage of excess water from farmer’s field with proper amounts and at the right time for increasing crop production and water economy in conjunction with other improved agricultural practices. It also includes various steps of investigations, planning, designing, construction, operation, maintenance and rehabilitation of irrigation and drainage facilities (Ahmed, 2005).

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

A good management, proper and timely application of water may result in better yield and reduction in drainage problems (Vidhya *et al.*, 2002). Farmers are not sure when and how much water they can applied, which leads to very little cooperation and involvement in irrigation management and limited contribution to operation and maintenance costs (Wil and Vander, 1994). Managing an irrigation system is not a simple task. Many different parties are involved; each with their own interests, however information on irrigation water management in a detailed scale like at country level is not common due to the lack of data, reliability, and accessibility of the data (Merdun and DeIrmenci, 2004).

2.6. Evaluation of Irrigation Scheme Performance

Performance evaluation of irrigation schemes is meaningful if related to certain management objectives that are defined for a given situation (Walker and Skogerobe, 1987). Numerous performance evaluation indicators have been developed, that is used for evaluating the performances of individual irrigation systems and for comparing the performances of different irrigation systems as well as farms. The type and number of indicators used for a particular situation depend on the level of details required for quantification, and on the number of disciplines selected for assessment. These may include, agricultural, water use, economics, environment, management, physical indicators, which are, regarded as external indicators (Bos, 1997).

2.7. Purpose of Irrigation Schemes Evaluation

Performance evaluation assessed for a variety of reasons: to improve system operations, assess progress against strategic goals, as an integral part of performance-oriented management, assess the general health of a system, assess impacts of interventions, diagnose constraints, better understand of performance determinants and to compare the performance of a system with others or with the same system over time. The type of performance measures chosen depends on the purpose of the performance assessment activity (Molden *et al.*, 1998). Performance evaluation practices are very much essential because of their central role in effective management (Prasad and Jayakumar, 2003).

Schultz and De Wrachien (2002) described that the aim of performance assessment is to select a small number of powerful, easily observable indicators that allow reliable conclusions to be drawn. The performance assessment should be a regular, short-duration process for investigating suspected critical shortfalls in performance. According to Bos (2000), the wider objectives of performance evaluation is to upgrade management capabilities in both public and private sector irrigation and drainage projects with a view to improving the efficiency with which available resources are used. As such, the assessment should become part of the routine management procedures of the irrigation institution.

In addition, evaluating surface irrigation systems is to identify management practices and system configurations that can be feasible and effectively implemented to improve the irrigation efficiency. The evaluation may also show opportunities for improving performance through changes in the field size and topography. Evaluations are useful in several analyses and operations, particularly those that are essential to improve management and control (FAO, 1989). Improvement of irrigation method requires the considerations of the factors influencing the hydraulic process, the water infiltration and uniformity of water application to the entire field (Hlavek, 1992).

2.8. Performance Indicators

Performance indicators measure the value of a particular item such as yield or canal discharge and must include a measure of quality as well as of quantity and be accompanied by appropriate standards or permissible tolerances (Rust and Snellen, 1993). Performance indicators can be broadly categorized into internal and external indicators. However commonly efficiency terms used for on-farm irrigation system evaluation (internal process indicators) include application efficiency, uniformity, storage efficiency, and adequacy, and recently complementary terms such as runoff ratio, deep percolation ratio, are being applied (Jurriens *et al.,* 2001).

Internal indicators, which relate performance to internal management targets, external indicators enable comparison between different regions, different infrastructure, and management types, and different environments. Moreover, the trend in performance of a specific scheme can be compared over time. Internal irrigation performance is also linked to farmers' level of satisfaction by some authors (Ghosh *et al.*, 2005). Much of the work to date in irrigation performance assessment has been focused on internal processes of irrigation systems. Many internal process indicators relate performance to management targets such as timing, duration, and flow rate of water; area irrigated and cropping patterns.

A major purpose of this type of evaluation is to assist irrigation managers to improve water delivery service to users. Targets are set relative to objectives of system management, and performance measures tell how well the system is performing relative to these targets

(Molden *et al*., 1998). Internal indicators do not lend themselves well to cross-system comparison. This is due to several reasons. First, internal processes of irrigation systems vary widely from system to system, so that performance indicators are tailored to meet system-specific needs. Second, indicators related to irrigation processes tend to be data intensive and it is often difficult, time-consuming, and expensive to obtain complete data sets. Third, assumptions about relations between internal processes and outputs may not be valid. It is often assumed that meeting a target will improve output in terms of agricultural production or net benefit to farmers.

2.8.1. Internal Performance Indicators

Internal performance indicators describe the effectiveness of the physical system and operating decisions to deliver irrigation water from a water source to the crop. Several efficiency terms are used to evaluate irrigation system performance. These include water conveyance efficiency, water application efficiency, soil water storage efficiency, irrigation efficiency, overall irrigation efficiency, and effective irrigation efficiency (Irmark *et al*., 2011). Generally, internal indicators enable a comprehensive understanding of the processes that influence water delivery service and the overall performance of a system (Renault and Wahaj, 2007).

Internal process indicators relate performance to management targets such as timing, duration, and flow rate of water; area irrigated and cropping patterns. A major purpose of this type of assessment is to assist irrigation managers to improve water delivery service to users. Targets are set relative to objectives of system management, and performance measures tell how well the system is performing relative to these targets. When the performance is not adequate, either the process must be changed to reach the target, or the target itself must be changed. Generally, internal indicators aid for checking the accuracy of activities related to irrigation management (Murray-Rust and Snellen, 1993).

I. Conveyance Efficiency

Conveyance efficiency is an indicator which measures irrigation water is normally conveyed from a water source to the farm or field through natural drainage ways, constructed earthen or lined canals, or pipelines. Many conveyance systems have transmission losses, meaning that water delivered to the farm or field is usually less than the water diverted from the source. Water losses in the conveyance system include canal seepage, canal spills, evaporation losses from canals, and leaks in pipelines (Irmark *et al*., 2011).

Conveyance loss consists mainly of operation losses, evaporation and seepage into the soil from the sloping surfaces and bed of the canal. Evaporation loss in irrigation networks is generally not taken into consideration (Xie *et al.*, 1993). The seepage loss in the irrigation canals accounts for the major portion of water conveyance loss, for example, Badenhorst *et al.* (2002) reported that 98.4 % was due to conveyance loss and only 0.3 percent is from evaporation.

High seepage in canals leads to an increase in the water table of the irrigated area resulting in yield reduction. Moreover, the loss of irrigation water through seepage in canals reduces the share of water availability for the newly irrigated area. Under such conditions, improving irrigation canals by lining minimize the water loss through seepage (Kumar *et al.*, 2008). In addition to this with proper soil compaction techniques, steady states loss rates in earthen channels can be reduced even more than 50 %.

Jadhav *et al.* (2014) reported that overall conveyance efficiency of the lined, unlined section of the main canal and field channel was 75.1, 52.3 and 34.8 % respectively at Panchnadi Minor Irrigation Project. Moreover, it has been reported that management interventions of converting the unlined canal network sections into lined sections could improve conveyance efficiency by up to 75 %. Conveyance efficiency at main unlined canal of Selgie irrigation scheme, which is ranges from 69 % to 81 % as reported by Menelik (2008).

II. Application Efficiency (Ea)

Water application efficiency (Ea) provides a general indication of how well an irrigation system performs its primary task of delivering water from the conveyance system to the crop (Irmark *et al*., 2011). It is the most important in terms of design and management since it reflects the overall beneficial use of irrigation water (FAO, 1989).

Lesley (2002) suggested that it could be in the range of 50 to 80 %. Gashaye and Tena (2008) reported that the application efficiency was 57.4, 44.4 and 49.3 % at the head, middle and lower end of Geray irrigation scheme respectively. Similarly, Dessalew *et al*, (2016) reported that application efficiency in Bedene Alemtena small-scale irrigation scheme ranges from 53.6 % at the head to 57.2 % tail of the scheme. According to Dinka (2017), application efficiency was between 57.2 and 65.5% at Ketar medium scale irrigation scheme.

Poor irrigation water management can result inefficient use of water and reduce the application efficiency. Over-irrigation may result in leaching chemicals below the crop root zone, cause yield reduction, and result in wasting water resources. Improper timing and inadequate irrigation applications that do not meet the crop water requirement may impose stress on the crop, reduce grain yield, and yield quality (Irmark *et al*., 2011).

III. Storage Efficiency (Es)

The value of storage efficiency is important when either the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced using precipitation as it occurs, and storage efficiency become important when water supplies are limited (FAO, 1989). The water storage efficiency refers to how completely the water needed prior to irrigation has been stored in the root zone during irrigation (Roger *et al*., 1997).

The main goal in most irrigation applications is to maximize water storage in the soil root zone to satisfy crop water requirement while minimizing deep percolation and surface runoff. The maximum amount of water that should be applied to achieve high storage efficiency for a given irrigation event is the difference between the field capacity and average water content in the soil root zone prior to the irrigation event. In most cases, it is suggested not to refill the soil profile to the field capacity, but rather to leave some storage capacity for a potential rainfall event. Thus, refill the soil profile to about 90 percent of the field capacity can be a good strategy (Irmark *et al*., 2011).

Water storage efficiency has a significant impact on the crop yields and thus on the economic return on water use. The Natural Resource Conservation Service of UK recommends water storage efficiency for a homogeneous soil condition to be 87.5% (Raghuwanshi and Wallender, 1998). Menelik (2008) reported that storage efficiency varies between 94.51% and 100%.

Iv. Distribution Uniformity (DU)

Distribution uniformity is one indicator used to represent the pattern of the infiltrated depths along the field length, which is defined as the minimum infiltrated depth divided by the average infiltrated depth (Jurriens *et al.*, 2001). This can be computed as the ratio of average infiltrated depth in the low quarter of the field to the average infiltrated depth over the whole field (Merriam and Keller (1978).

When a field with a uniform slope, soil and crop density receives steady flow at its upper end, a waterfront will advance at a monotonically decreasing rate until it reaches the end of the field (FAO, 1989). According to Roger *et al.* (1997) water lost to percolation below the root zone due to the non-uniform application or over-application of water as run-off from the field, all reduce irrigation efficiencies.

Distribution efficiency of 30 and 65 % as poor and sufficient respectively (FAO, 1992). Different reports also revealed the distribution efficiency failed in this range as reported by Pitts *et al.* (1996). However, Bayan (2017) reported that the distribution efficiency was 96.4, 91.0 and 91.8 % at the upper, middle and lower end of Mada Batu small-scale irrigation scheme, respectively. Similarly, Dessalew (2016) found the average distribution efficiency of 90.2 % at Bedene Alemtena small-scale irrigation scheme.

V. Deep percolation ratio (DPR)

A part of the irrigation applied to a field percolates into the soil below the root zone. Part of the water is intentionally added to the irrigation water to maintain the salt balance of the soil through leaching additional, salt brought by the irrigation water itself or through the capillary process from saline groundwater (Smedema and Rycroft, 1983). Deep percolation ratio can quantify the ratio between the percolated water beyond the root zone to the volume of water applied to the field (Feyen and Dawit, 1999).

Higher Deep percolation ratio values are indications of over-irrigation. The volume of percolated water more than the leaching requirement is considered as lost water and is used to define the efficiency of irrigation. Bayan (2017) reported that deep percolation ratio was 25.4, 27.1 and 17.4 % at upper, middle and lower end of Mada Batu small-scale irrigation scheme respectively.

2.8.2. External Performance Indicators

External indicators are used to relate outputs from a system derived from the inputs into an irrigated agricultural system (Molden *et al*., 1998). Many indicators of external performance are computed by using secondary data rather than primary data. The indicators tell general concept about the relative health of the irrigation system, yet they are not too data-intensive to discourage widespread and regular application. This is important to identify whether the scheme is performing in economic manner related to the consumption of scarce water resource (Molden *et al*., 1998).

The International Water Management Institute proposed a minimum number of external (comparative) indicators of four, two, one and two for agricultural outputs, water supply, delivery capacity and financial cases, respectively (Molden *et al*., 1998).

Agricultural Output Indicators

Those indicators relate the output to unit land and water, in addition, agricultural output indicators provide the basis for comparison of irrigated agriculture performance where water is a constraining resource. Output per unit water may be more important, whereas if the land is a constraint relative to water, output per unit land may be more important. It includes four basic comparative indicators those are described below (Molden *et al*., 1998).

I. Output per Cropped Area

The output per unit irrigated cropped area quantifies the total value of agricultural production per unit of area harvested during the period of analysis. The annual harvested area depends on the cropping intensity. The area is the sum of all the areas under crops during the year in this case. This indicator is not affected by the intensity of cropping (irrigation). However, it can also indirectly indicate the degree of irrigation water availability. In addition to water availability, soil type and fertility, land suitability, crop variety, and agricultural inputs do have a significant impact on output and hence on land productivity. It is given as the ratio of production at local or world price to irrigation cropped area (Molden *et al*., 1998).

II. Output per Unit Command Area

The output per unit command area is the value of agricultural production per unit of nominal area, which can be irrigated. Smaller values of this indicator can also imply, less intensive irrigation and vice versa. It is particularly important where land is a constraining resource for production, which is a ratio of total value of production at local, or world price (Molden *et al.*, 1998).

Uçar (2011) reported that output per area unit command at 10 irrigation schemes in Isparta, Turkey was range 4,289 to 41,060 US$ per ha during the study year between 2004 and 2008. According to Değirmenci *et al*. (2017) output per area unit command of 14, irrigation scheme found in turkey was range from 2387 to 10129 US$/ha during the irrigation season between 2011 and 2014.

III. Output per Unit Irrigation Water Supply

The output per unit irrigation water supply tells on how well the total annual diverted irrigation water from a source is productive. Irrigation water supply includes conveyance (seepage) losses in canals, and hence it is generally measured at the intake from the source or at diversion. In areas where water is scarce, water management aims to increase the output per drop of irrigation water that is a ratio of total value of production at local or world price to the volume of surface irrigation water diverted to the command area (Zeleke *et al.,* 2012; Molden *et al.,* 1998).

IV. Output per Unit Water Consumed

The output per unit of water consumed informs on the output per unit annual volume of water consumed by actual evapotranspiration (ET). Its value is highly dependent on climate. Moreover, less consumptive use coefficient due to water losses do not affect its value; as only the water consumptively used by the crops is considered (Molden *et al*., 1998):

Water Supply Indicators

Water supply indicator includes as (Molden *et al.*, 1998) cited, relative water supply as presented by (Levine,1982) and relative irrigation supply as developed for this indicator set (Perry,1996) are used as the basic water supply indicators. There are two water supply indicators as illustrated below.

I. Relative water supply (RWS)

Relative water supply relates the total water supply to demand and gives some indication as for the condition of water abundance or scarcity, how tight supply and demand are matched (Molden *et al.*, 1998). According to Şener *et al.,* (2007 report relative water supply in Hayrabolu Irrigation Scheme in Turkey was 1.91. Ingle *et al.* (2015) reported that relative water supply at Kalwande Minor Irrigation Scheme was 2.49 this indicates the condition of water abundance.

II. Relative irrigation supply

Relative irrigation supply can identify the supply irrigation water is enough to meet the irrigation requirements of the crop during the entire growth stage. Şener *et al.* (2007 reported relative irrigation supply in Hayrabolu Irrigation Scheme was 1.55. Relative irrigation supply varies from 0.39 to 1.38 at Okyereko irrigation scheme in Ghana as reported by Alordzinu *et al*. (2017).

Water Delivery Capacity Indicator

Water delivery capacity is meant to give an indication of the degree to which irrigation infrastructure is constraining cropping intensities by comparing the canal conveyance capacity to peak consumptive demands. Again, a lower or higher value may not be better but needs to be interpreted in the context of the irrigation system, and in conjunction with the other indicators (Molden *et al.*, 1998).

Physical performance indicators

Physical indicators are related to the changing or losing irrigated land in the command area for different reasons. Among these, water scarcity and input availability are the main reason why lands in command area are not fully under irrigation in a particular season. From physical performance irrigation ratio and sustainability of irrigated area are the two main indicators as illustrated by Yercan *et al.* (2004) and Şener *et al.* (2007).

I. Irrigation Ratio

Irrigation ratio is the ratio of currently irrigated area to irrigable command area. It tells the degree of utilization of the available command area for irrigated agriculture at a particular time. Shortage of irrigation water, lack of irrigation infrastructure, lack of interest on irrigation due to less return, reduced productivity due to problems such as salinization and waterlogging, etc., could result in underutilization of land. On the other hand, cropping intensity, a ratio of annual cropped area to nominal area is indicative of annual land utilization. According to Burton *et al.* (2000), cropping intensities from 100 to 200% are considered good; whereas an inferior figure is low.

II. Sustainability of Irrigated Area

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

Financial Indicators

This indicator considers the production and the total cost of infrastructure for each scheme. It deals with the total revenues from the scheme, the total cost spent on running the project and initial investment costs. Economic indicators deal with how much investment cost is spent on the project in comparison with total production and how much fee collected from water users for yearly maintenance and operation expenditure and whether the system is self-sufficient or not (Vermillion, 2000).

According to Molden *et al*. (1998) two financial indicators, which can evaluate the gross, return (investment) and financial self-sufficiency of irrigation schemes. The values of gross return on investment of 18 different irrigation schemes in the world show a wide variation between 7 to 75% (Molden *et al.*, 1998). Rice-based irrigation systems with less abundant water give a low 6 to 30% return on investment, while private pump irrigation systems provide the highest rate of return on investment of 75%.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study irrigation schemes are found in Wondo Genet, Sidama zone, SNNPR, Ethiopia which is located at about 263 km south of Addis Ababa, and 13 km to the south-west of Shashemene town on the eastern escarpment of the Ethiopian Rift Valley in the South Nation Nationalities and Peoples Regional (SNNPR) state (Figure 1). The study area Wondo Genet is surrounded by a green chain of mountains up steam with better vegetation geographically, it is located from 6°54′0″ to 7°7′45″ N and 38°31′33″ to 38°41′20″ E. It covers an area with a wide altitudinal range of 1600 to 1950 m. a.s.l.

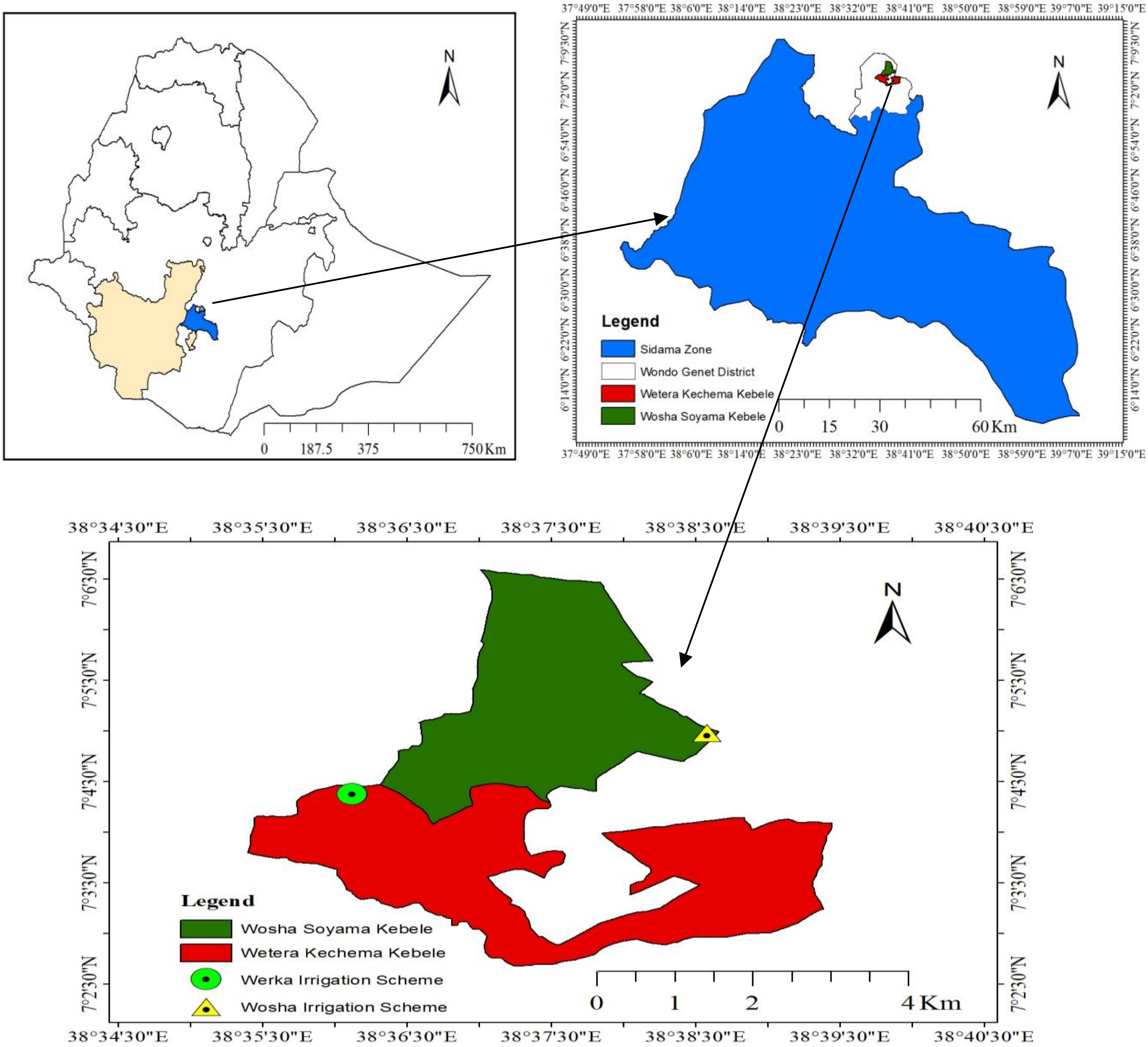

Figure 1. Map of the study area

3.1.1. Climatic Characteristics of the Study Area

Long-term (1986 – 2015) climatic record of Wondo Genet College of forestry and natural resources meteorological station, average annual rainfall in the area is 1069.2 mm. The area reaches more than 70% of the total annual rainfall between Aprils and September. The mean monthly maximum and minimum rainfall values are 147.0 mm and 18.3 mm occurs in the month of August and December, respectively. The mean maximum temperature is 22.6 ^{O}C while the mean minimum temperature is 13.4 ^{O}C.

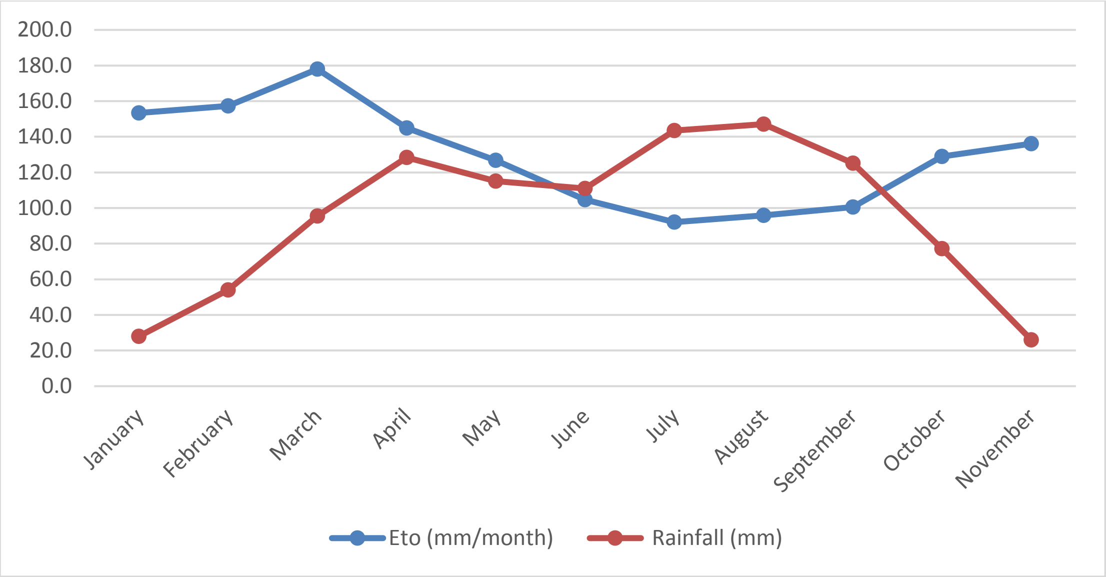

Figure 2. Long-term climatic data of the study area

According to the climatic condition of the study area, irrigation is appreciably important from Mid of September to Mid of May as evapotranspiration exceed monthly rainfall (Figure 2).

Wosha Irrigation Scheme

Wosha Small irrigation scheme is found at Wondo Genet district Wosha Soyama Kebele geographically, it is from 7^0 4′0″ to 7°6′3″ N and 38°36’18″ to 38^0 38′38″ E. It is located within the altitudinal range from 1,788 m.a.s.l at the green chain of mountains to 1,929 m.a.s.l at the low-lying areas. The scheme area and the diversion are accessed through asphalt road at 272, 25, and 12 km away from Addis Ababa, Shashemene and Wondo Genet town, respectively. The scheme is 2 km away from the main asphalt road.

The Wosha small-scale irrigation scheme constructed to use the source of Wosha River and the abstraction is through gravity system that of the diversion designed to develop about 180 ha of irrigable land, particularly in Wosha Soyama Kebele (Design Document).

The scheme is composed of a simple intake structure with diversion constructed by stone and plant debris. Whereas, the main canal designed to carry a capacity of 388.8 l/s with the length of 1.3 km masonry lined canal, 5.3 and 2.3 km of secondary and tertiary canals respectively. The scheme also comprises division boxes, road culverts, drainage, and other hydraulic structures (Design Document).

The major irrigated crops grown in the area are sugarcane, chat, maize and vegetables like tomato, potato and cabbage. The frequency and depth of irrigation event practiced in the area vary with according to crop types. The vegetables get more frequent than sugar cane and chat. Sugarcane irrigated with longer irrigation intervals, which ranges from 15 days to 30 days.

Werka Small Scale Irrigation Scheme

Werka Small-scale irrigation scheme is found in Wondo Genet district, Wetera Kechema Kebele, geographically located between latitude 7°2′8″ to 7^0 4′30″ N and longitude 38° 35′24″ to 38^0 35′24″ E. The scheme site is accessed through concrete asphalt road at 292, 24, and 13 km away from Addis Ababa, Shashemene and Wondo Genet town, respectively. The scheme is 1.5 km away from the main asphalt road.

Werka irrigation scheme is constructed in Werka River with modern aged weir with a masonry-embanked reservoir. The abstraction is through a gravity system that of the diversion head designed to irrigate 200 ha of irrigable land, particularly in Wetera Kechem Kebele. However, currently the scheme increased to 292.2 ha on 2017/18 irrigation season. The scheme has longer than 1.5 km main unlined earthen canal and other secondary and tertiary canals. The average discharge the at the intake is 75 l/s with the none functioning metal sheet gate.

Different crops are grown in the scheme, sugarcane being the major irrigated crop about 41 % or 118.25 ha. Other dominant crops include chat, potato, and cabbage with 27, 23 and 6 ha areal coverage, respectively. The number of irrigation event practiced in the area varies with according to crop types. Vegetables get more frequent than sugarcane and chat. Sugarcane irrigated with longer irrigation intervals, which ranges from 30 days to 60 days.

3.2. Data Collection

The study was carried out in 2017/18 from November to March during the dry season when the crops are being cultivated under irrigation on both schemes. The water application method, irrigation schedule, water conveyance system, as well as application depth and the adequacy of the irrigation water, were observed. In this study, quantitative and qualitative primary and secondary data were collected accordingly for the study objective and purpose.

3.2.1. Secondary Data

Secondary data were collected from the Wondo Genet District Agricultural and Rural Development Office and Water Resource and Irrigation Offices at Regional and Zonal levels. The secondary data included total yields, farm gate prices of irrigated crops, area irrigated per crop per season and cropping pattern. Long-term climatic data (maximum and minimum temperature, RH, sunshine hour, wind speed at 2m height from the earth surface of the irrigation schemes were collected from Wondo Genet College of Forestry and Natural Resources Metrological Station (Table 1).

Table 1. Secondary data

Data Type	Source
Climatic	WGCFNR Metrological Station
Yield	Wondo Genet Agricultural Office
Farm Gate Price	Wondo Genet Agricultural Office
Irrigated Area	Wondo Genet Agricultural Office
Design Document	Wondo Genet Water Resource Office

3.2.2 Primary Data

Those primary data collected through a continuous field visit to assess and evaluate physically at water diversion headwork, farm fields and details of structures to understand the water conveyance and distribution systems, to measure water applications depth and practices related to water management techniques through measuring different parameters using an appropriate device.

3.2.3. Field Layout and Crop Selection

To evaluate the irrigation application, storage and distribution uniformity of farmers at field level, six farmers' fields were selected three from each scheme at the head, middle and tail end water users with respect to the water source. The selection of fields was done in considering similarly crop and growth stage and willingness of the farmers to collaborate. Six sugarcane farmer fields were selected. The reason for the selection of sugarcane was that it was the dominant crop, which most of the schemes land is covered with it.

3.3. Data Analysis

3.3.1. Soil Texture and Bulk Density

For textural analysis of the soil, disturbed soil samples were collected from each scheme at three locations along diagonal of the selected fields of each scheme (head, middle, and tail end) using soil auger with the depths 0-30cm, 30-60 cm, 60-90 cm, and 90-120 cm. Hydrometer method was used for analyzing particle size distribution at Wondo Genet College of Forestry and Natural Resources Laboratory and the textural class was assigned using USDA textural triangle.

The soil bulk density (BD) was determined from undisturbed soil samples using a core sampler of size 5 cm internal diameter and 5 cm height. The soil sample was collected from 0-30 cm, 30-60cm, 60-90 cm and 90-120 cm at three locations along the diagonal of each selected field and oven dried at 105°C for 24 hours. The bulk density was determined using the following equation (Jaiswal, 2003).

$$BD = \frac{W_s}{V_c} \tag{3.1}$$

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

W_s is mass of dry soil (g) and

V_c is volume of soil in the core (cm ^{3})

3.3.2. Field Capacity and Permanent Wilting Point

Soil sample for determination of moisture content at field capacity (FC) and permanent wilting point (PWP) was collected at 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm from three locations along the diagonal of the selected field of each scheme. The soil sample was saturated before keeping it in the pressure plate apparatus with plastic rings at Oromia Water Works and Supervision Enterprise, Soil and Water Laboratory. Then, the pressure plate was locked and the gauge from the compressor was adjusted at 1/3 and 15 bars for field capacity and permanent wilting point, respectively. When no more drop of water is observed, the samples were collected from the pressure plate apparatus, weighed and oven dried for 24 hours at 105 ^{O}C. The dry weight is recorded and the moisture content at FC and PWP were calculated using equation 3.2 (Jaiswal, 2003).

$$\theta_m = \frac{(W_{w-W_d})}{W_d} \times 100 \tag{3.2}$$

Where: -

θ_m is mass-based moisture content at FC or PWP (%)

W_d is weight of oven dried soil (g), and

W_w is weight of wet soil from the pressure plates (g)

The volumetric total available water (TAW) was calculated based on the data of FC, PWP and root depth using the following equation *(*Allen *et al*., 1998).

$$\mathrm{TAW} = 1000 \sum (\theta_{\mathrm{FC}} - \theta_{\mathrm{PWP}}) * Z_{\mathrm{d}} \tag{3.3}$$

Where TAW is volumetric total available water in the root zone (mm/m),

Z_d: - root depth (m),

θ_{FC}: - volumetric moisture content at field capacity (m^3/m^3), and

θ_{PWP}: - volumetric moisture content at permanent wilting point (m^3/m^3).

3.3.3. Soil Moisture Determination

Determine the moisture content of the soil was carried out during the research to determine application efficiency, storage efficiency and distribution uniformity using the gravimetric method. Many soil samples were collected from each scheme with 30 cm interval up to 120 cm. Samples were taken before and after irrigation events and weighted using sensitive balance and oven dried for 24 hours at 105 ^{O}C. Then the oven-dried sample was weighed to determine the water content of the soil. The water content in the soil was determined in volume base using the following equation (Jaiswal, 2003).

$$\theta_v = \theta_m \times BD \tag{3.4}$$

Where: -

θ_v: - volumetric moisture content in (%),

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

3.3.4. Determination of Crop Water and Net Irrigation Water Requirement

The crop water requirement (CWR) of the major irrigated crops grown in the irrigation scheme was estimated by using CROPWAT 8.0 windows computer program. The determination of the CWR by the model depends on the determination of the reference evapotranspiration value using the available five climatic data. This includes minimum and maximum temperature, relative humidity, wind speed and sunshine hours. Metrological data was collected from Wondo Genet College of Forestry and Natural Resources Metrology Station. The CropWat model calculates ETo based on the following formula, which is known as FAO Penman-Monteith equation (FAO, 2009).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{3.5}$$

Where: -

ET_o: - reference evapotranspiration (mm/day)

R_n: - net radiation at the crop surface (MJ/m^2/day)

G: - soil heat flux density (MJ/m^2/day)

T: - mean daily air temperature at 2 m height (^{o}C)

e_s:- saturation vapor pressure (kPa)

e_a:- actual vapor pressure (kPa)

e_s - e_a: - saturation vapor pressure deficit (kPa)

Δ: - slope vapor pressure curve (kPa/^{o}C)

γ: - psychrometric constant (kPa/^{o}C)

The evapotranspiration of the crop was determined by multiplying the crop coefficient (K_C) of the crop by the reference evapotranspiration (ET_O).

$ET_C = K_C \times ET_O$ (3.6)

Where: -

ET_C: - crop evapotranspiration (mm/day),

K_C: - crop coefficient, which is a function of crop type and stage of growth (decimal),

ET_O: - reference evapotranspiration (mm/day)

The crop coefficient values for respective growth stages, length of growth stages, and soil moisture depletion level and root depth of each crop were collected from Allen *et al.* (1998). However, due to unavailability Kc value and depletion fraction for chat, it was taken from citrus crop as it similar in physiology with chat (Shimelis *et al.*, 2011).

The net irrigation water requirement (IR_n) was computed after estimation of effective rainfall by the CROPWAT model using the water budget equation.

$$IR_n = [(F_C - PWP) \times P \times \rho_d \times R_d] - R_e \quad (3.7)$$

Where: -

IR_n: - net irrigation water requirement (mm)

F_C: - Mass base moisture content at field capacity (decimal)

PWP: - Mass base moisture content at permanent wilting point (decimal)

P: - Allowable soil moisture depletion level for each crop (decimal)

ρ_d:- Soil bulk density (g/m^3)

R_d: - Root depth (mm)

R_e: - Effective rainfall (mm)

3.3.5. Irrigation scheduling

Irrigation scheduling helps to optimize the limited water resource and maximize crop production. Irrigation scheduling was determined for sugarcane in order to compare farmer practice and computed irrigation interval.

Irrigation interval was computed using the following equation (Michael, 2008).

$$I = \frac{RAW}{ETc} \quad (3.8)$$

Where:-

I: -Irrigation interval [day]
RAW:- Readily Available Water [mm]
ETc:- Evapotranspiration of the crop [mm/day]

3.3.6. Determination of Effective Rainfall

Effective rainfall is the portion of rainfall that is available in the plant root zone beyond the loss of runoff and deep percolation, which allows the plant to maintain its growth. The effective rainfall was determined by using CROPWAT 8.0 computer model based on the following formula of 'dependable rainfall' (FAO formula) using rainfall data (FAO, 2009).

$R_e = 0.6 * P - 3.33$ for monthly precipitation less or equal to 23.3 (70/3) mm

$R_e = 0.8 * P - 8$ for monthly precipitation greater than 23.3 (70/3) mm

3.3.7. Flow Measurement

Flow during field application, the measurement was made by using two-inch Parshall flumes to determine the amount of water applied by the irrigators to the field where at the head, middle and tail during an irrigation event. Parshall flume was installed at the entrance of the selected farmers' field at the part, which is straight and uniform. Five times readings of the Parshall flumes head were taken when the irrigator irrigating their field. The average flow depth of irrigation water passing through the flume and irrigation duration was recorded for the field being irrigated.

The relationship between the head of irrigation water and its discharge is based on the following equation (USBR, 2014).

$$Q = C * H^n \tag{3.9}$$

Where: -

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

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

Determination of flow velocity through man, secondary and tertiary canals was obtained by floating methods. Canal dimension was measured using tape meter and then floating material was laid upstream of measuring distance. The time it takes to cross 10 m measuring distance was recorded for calculation of flow velocity. Finally, the discharge of flow was determined by the continuity equation as follow.

$$Q = AV \tag{3.10}$$

Where:-

Q: - Discharge of the flow (m^3/s)

A: - cross-sectional area (m^2)

V: - Velocity of the flow (m/s)

The discharge then adjusted to $V_{flow} = 0.85\ V_{surface}$

Performance of the schemes was evaluated using both internal and external process indicators. To compute the performance indicators; fields were selected from head, middle and tail of each irrigation scheme.

3.3.8. Performance Indicators

3.3.8.1. Internal Indicators

For this study, five internal performance indicator was used in order to evaluate the internal system performance of each scheme, as listed below.

1. Conveyance Efficiency (Ec)

To determine the conveyance efficiency, the flow at main and secondary canals at hundred-meter interval recorded using area velocity method. Lined main canal and unlined main canal measured at Wosha and Werka irrigation schemes, respectively. The velocity was measured by floating methods; the discharges were calculated from the canals cross-sectional area, and the measured velocities. Floating material was put on the upper part (inlet) of the canal section, the time it took to reach the known distance section of the same canal was recorded in several replications, and the average time used to calculate the velocity of the flow. The cross-sectional area of the canal was determined by measuring the average depth and width of the same canal section.

The second measurement was also taken at a fixed distance above the downstream end of the main and secondary canal. The same procedure was followed to estimate the discharge at the second point (outlet) so that the amount of conveyance loss was known, and the conveyance efficiency was determined.

However, the measured velocity was multiplied by correction factor 0.85 for rough or rocky bottoms and 0.9 for smooth, muddy, sandy or smooth bedrock conditions as illustrated by Harrelson *et al*. (1994).

The conveyance efficiency was computed using the following equation (Michael, 2008).

$$\mathrm{Ec} = \left(\frac{Q_{in}}{Q_{out}}\right) \times 100 \tag{3.11}$$

The overall conveyance efficiency of the schemes was computed using the following equation.

$$Ec = Em * Es * Et \tag{3.12}$$

Where:-

Ec: - conveyance efficiency (%),

Em: - conveyance efficiency of the main canal (%),

Es: - conveyance efficiency of secondary canal (%),

Et: - conveyance efficiency of tertiary canal (%),

Losses in conveyance system were computed as;

$$\mathrm{Lc} = Q_{in} - Q_{out} \tag{3.13}$$

Where: -

Ec:- conveyance efficiency (%)

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

Q_{in} and Q_{out}=are the inflow and outflow discharge in specified canal length (m^3/sec)

2. Application Efficiency (Ea)

The application efficiency was computed as the ratio of moisture stored in the soil profile due to irrigation to the total irrigation water applied to the field. In this study, the amount of irrigation water applied to the field was determined using two-inch Parshall flume. The depth of water which is stored in the root zone of the soil was determined by collecting soil samples at different depths (0-30, 30-60, 60-90 and 90-120 cm) three days after irrigation. Finally, the moisture content stored in the root zone was determined by a gravimetric method using equation (3.14). Application efficiency was computed as follows (Michael, 2008):

$$Ea = \frac{W_s}{W_f} * 100 \tag{3.14}$$

Where: -

Ea:- application efficiency

W_s:- average depth water stored in the root zone of the plant

W_f:- average water delivered to the field (water depth applied to the field)

3. Storage Efficiency (Es)

To determine the water stored in the soil root zone of each field, soil samples were collected from a different location within the field at a depth of the 0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm before and after each irrigation event. The moisture content was determined using the gravimetric method.

The distribution uniformity was obtained by the relationship given below (Michael, 2008).

$$E_s = \frac{W_s}{W_n} * 100 \tag{3.15}$$

Where: -

E_s: - storage efficiency (%)

W_s: - water stored in the root zone during irrigation (mm)

W_n: - water needed in the root zone prior to irrigation (mm)

The water needed in the root zone prior to irrigation was computed using the following equation (Michael, 2008).

$$W_n = \sum_{i=1}^{n} \left(\frac{M_{fci} - M_{bi}}{100}\right) * A_i * D_i \tag{3.16}$$

Where: -

D: - net amount of water to be applied during an irrigation (mm)

M_{fci}: - field capacity moisture content in the i^{th} layer of the soil (%)

M_{bi}: - moisture content before irrigation in the i^{th} layer of soil (%)

A_i: - bulk density of the soil in the i^{th} layer

D_i: - depth of the soil layer within the root zone cm, and

N: - number of soil layers in the root zone D

4. Water Distribution Uniformity (DU)

The water distribution uniformity indicates the extent to which water is uniformly distributed in the field. The water distribution was computed using equation (3.17) given by (Walker, 2003). To determine the water stored in the soil root zone each field was divided into three parts at the inlet, middle, and end of the field and in each divided part, the furrow also divided in three parts. Totally, from nine places at a depth of the 0-30cm, 30-60cm, 60-90cm, and 90-120cm soil sample were collected before and after each irrigation event.

Then after soil moisture contents of the soil samples determined gravimetrically, at the selected points, the depth of stored water at particular soil layer ($X_{(0-30)}$ or $X_{(30-60)}$) was calculated using the equation:

$$X = \left(\frac{M_{ai} - M_{bi}}{100}\right) * Ai * Di \tag{3.17}$$

Where:

M_{ai} = moisture content of the i^{th} layer of the soil after irrigation weight basis, %

M_{bi} = moisture content of the i^{th} layer of soil before irrigation weight basis, %

A_i= bulk density of the soil in the i^{th} layer

D_i = soil depth of i^{th} layer

The total depth of water stored at each point (X_1 to X_9) was determined, by sum up the values of $X_{1(0-30)}$, $X_{1(30-60)}$, $X_{1(60-90)}$ and $X_{1(90-120)}$ of that specific point.

That is:

$$X_1 = X_{1(0-30)} + X_{1(30-60)} + X_{1(60-90)} + X_{1(90-120)} \qquad (3.18a)$$

To

$$X_9 = X_{9(0-30)} + X_{9(30-60)} + X_{9(60-90)} + X_{9(90-120)} \qquad (3.18b)$$

Then finally, the distribution uniformity was determined using equation 3.20.

$$DU = \frac{\bar{X}_{Lq}}{\bar{X}_m} * 100 \qquad (3.19)$$

Where:-

DU: - Water distribution uniformity (%),

$\bar{X}_{Lq}$: - the mean of lower-quarter depth of water infiltrated and

$\bar{X}_m$: - the mean depth of all water infiltrated (or caught)

5. Deep Percolation Ratio

The Furrow that practiced in both scheme are closed-end, therefore runoff ratio also neglected, and the evaporation from the soil neglected because it is only a short period after irrigation. The loss of irrigation water beyond the root zone is only through deep percolation. Therefore, deep percolation ratio was calculated by using the following equation (Feyen and Dawit, 1999).

$$DPR = 100 - Ea - RR \qquad (3.20)$$

Where:-

DPR:- Deep percolation ratio (%),

Ea:- application efficiency (%) and

RR:- runoff ratio

Then after, the overall scheme efficiency calculated as the product of conveyance and application efficiency. It was computed using the following formula (FAO, 2002):

$$Ep = Ec \times Ea \tag{3.21}$$

Where: -

Ep: - overall scheme efficiency (%),
Ec: - conveyance efficiency (%) and
Ea: - application efficiency (%)

3.3.8.2. External Indicator

For the performance evaluation of the schemes, nine external indicators were used as illustrated by International Water Management Institute (Molden *et al.*, 1998).

Agricultural Output Indicators

To determine the external indicators of the scheme like output per cropped area, output per unit command area, and output per unit water consumed production such data crop production, irrigable-cropped area and command area were collected from Wondo Genet District Agricultural Office. Total production (US$) for the year 2017/18 was calculated by using local farm gate price and yield production of Wosha Irrigation Scheme. The following equations were used to compute some agricultural output indicators (Molden *et al.*, 1998).

It includes three basic comparative indicators listed below:

$$1. Output\ per\ unit\ irrigated\ area \left(\frac{\$}{ha}\right) = \frac{Production}{Irrigated\ cropped\ area} \tag{3.22}$$

$$2. Output\ per\ unit\ command \left(\frac{\$}{ha}\right) = \frac{Production}{Command\ area} \tag{3.23}$$

$$3. Output\ per\ unit\ irrigation\ diverted \left(\frac{\$}{m^3}\right) = \frac{Production}{Irrigation\ diverted} \tag{3.24}$$

$$4. Output\ per\ unit\ water\ consumed \left(\frac{\$}{m^3}\right) = \frac{Production}{Volume\ of\ waterconsumed\ by\ ET} \tag{3.25}$$

Water Supply Indicators

Relative irrigation and relative water supply for both irrigation schemes evaluated for five consecutive months from November to March when the months are very sensitive for the additional water to fill moisture deficit of the soil. Irrigation supply is the volume of irrigation water delivered from the river source, which is the flow of those five consecutive months measured at the headworks of both schemes. Relative water supply is the sum of delivered irrigation water and effective rainfall. Total crop water demand is the actual evapotranspiration demand of the crops, determined using CROPWAT 8.0 computer model for a given cropping pattern and irrigation intensity.

The crop requirement was calculated for each month using the following equation.

$$CWR_{monthly} = CWR_{Sugar} \times \left(\frac{area_{sugar}}{area_{total}}\right) + CWR_{chat} \times \left(\frac{area_{chat}}{area_{total}}\right) + CWR_{potato} \times \left(\frac{area_{potato}}{area_{total}}\right) + etc$$

Both relative water supply and irrigation supply were determined using the following equation (Molden *et al.*, 1998).

$$1. RIS = \frac{IWS(m^3)}{IWD(m^3)} \tag{3.26}$$

$$2. RWS = \frac{(IWS + RWS)\ (m^3)}{CWR\ (m^3)} \tag{3.27}$$

Where: -

RWS: - Relative water supply (m^3)

IWS: - Irrigation water supply (m^3)

IWD: - Irrigation water demand (m^3)

CWR: - Crop water requirement (m^3)

Water Delivery Capacity Indicator (WDC)

The water delivery capacity was computed from the design discharge capacity taken from the design document of Wosha Irrigation Scheme. However, the design document of Werka Irrigation Scheme could be not available due to its long aged. Therefore, the main offtake canal capacity computed from the canal structure cross-section at the diversion intake by measuring the area, velocity and freeboard considered. The peak monthly demand computed by CROPWAT 8.0 model.

It is calculated using equation 3.28 as recommended by Bos *et al.* (1994).

$$WDC(\%) = \frac{Canal\ capacity\ to\ deliver\ water\ at\ system\ head}{Peak\ cosumptive\ demand} \tag{3.28}$$

Physical Indicators

Physical indicators are related to the changing or losing irrigated land in the command area for different reasons. The selected indicator used for evaluation of physical performance was irrigation ratio and Sustainability of irrigated area, which can be expressed as the follows (Molden et *al*., 1998).

Irrigation Ratio (IR)

It indicates the degree of utilization of the available irrigable area at a particular time. While there are several factors contributing to the variation in IR, availability of irrigation water is the major one, but even under sufficient water supply, low figures can be caused because of misuse (Zeleke, 2015). The irrigated area during the study period and the irrigable potential of each scheme were determined from Wondo Genet district Agricultural Office.

Irrigation ratio is the ratio of currently irrigated area to the command area (Bos *et al*., 1994).

$$IR = \frac{Irrigated\ cropped\ area}{Command\ area} \qquad (3.29)$$

Where: -

- Irrigated crop area (ha) is the portion of the actual irrigated land in any given irrigation season,
- Command area (ha) is the potential scheme command area.

Sustainability of Irrigated Area (SIA)

Sustainability of irrigated area is the ratio of currently irrigable area to initially irrigated area. This important indicator mainly used to observe the status of the irrigation systems either contracted or expanded. The currently irrigable area and nominal irrigated area of both schemes were determined from Wondo Genet district Agricultural office.

Sustainability of irrigated area was computed by using the following equation (Molden *et al.*, 1998)

$$SIA = \frac{Currently\ Irrigable\ area}{Initially\ Irrigated\ area} \qquad (3.30)$$

Where: -

Current irrigable area: - the area currently irrigated (ha)

Initially irrigated area: - the designed/nominal/ irrigable area (ha)

4. RESULTS AND DISCUSSION

4.1. Soil Physical Characteristics of Study Schemes

The soil textural class of the schemes revealed that clay, sandy loam, and sand at the head, middle and tail, respectively was dominant soil textural class at Wosha Irrigation Scheme (Table 2). Whereas, at Werka Irrigation Schemes textural class varied from clay to clay loam at the head, middle and tail reach of the scheme (Table 3). The result indicates that soils of both schemes are quite different textural classes.

Table 2. Selected soil physical characteristics of Wosha irrigation scheme.

Reach	Soil depth (cm)	Particle size distribution (%)			Textural class	Bd (g/cm^3)	FC (%)	PWP (%)	TAW (mm)
		Sand	Clay	Silt					
Head	0-30	29	55	16	Clay	1.01	36.2	25.1	34
	30-60	23	60	17	Clay	1.01	37.6	23.4	43
	60-90	23	68	9	Clay	1.05	37.7	24.0	43
	90-120	17	73	10	Clay	1.09	37.4	24.8	41
		Average				1.04	37.2	24.3	161
Middle	0-30	56	19	25	Sandy Loam	1.16	26.2	14.0	42
	30-60	77	10	13	Sandy Loam	1.23	24.1	13.5	39
	60-90	65	18	17	Sandy Loam	1.24	24.1	12.3	44
	90-120	67	19	14	Sandy Loam	1.24	23.1	10.7	46
		Average				1.22	24.4	12.6	172
Tail	0-30	63	18	19	Sandy Loam	1.23	19.0	9.7	34
	30-60	89	7	4	Sand	1.24	13.4	8.4	19
	60-90	95	3	2	Sand	1.27	10.2	6.2	15
	90-120	97	1	2	Sand	1.27	9.9	5.3	18
		Average				1.25	13.1	7.4	86

Physical soil analysis of Wosha Irrigation Scheme showed that average moisture content on a mass base at field capacity (FC) was 37.2, 24.4 and 13.1% at the head, middle and tail reach, respectively. Whereas, at Werka irrigation scheme 43.7, 43.9 and 44.5% were recorded at the head, middle and tail reach, respectively (Table 1). On the other hand, the mass base moisture content at the permanent wilting point (PWP) at Wosha was 24.3, 12.6 and 7.4% at the head, middle and tail reach, respectively. At Werka 24.2, 22.3 and 23.5% were observed at the head, middle and tail reach of the scheme, respectively (Table 3).

The bulk density values ranged from 1.01 to 1.27 g/cm^3 and 1.03 to 1.16 g/cm^3 at Wosha and Werka irrigation schemes, respectively. The soil bulk density of both irrigation schemes indicates that as the depth goes down the bulk density increased, which implies the soil compactness increased as goes down to deep.

The volumetric total available water content (TAW) at 120 cm of soil depth for both irrigation scheme were ranged from 86 to 172 mm and 253 to 288 mm in Wosha and Werka Irrigation Schemes, respectively. TAWs of both schemes are with the range of FAO (1985) recommendation for the particular soil type. The soil physical analysis result revealed that soil at Werka Irrigation Scheme had higher water holding capacity than the sandy dominant soil type of Wosha Irrigation scheme. This is an important condition for Werka Irrigation Scheme that, longer irrigation interval were practiced in an area where there is high competition for irrigation water.

Table 3. Selected soil physical characteristics of Werka irrigation scheme.

Reach	Soil depth (cm)	Particle size distribution (%)			Textural class	Bd (g/cm^3)	FC (%)	PWP (%)	TAW (mm)
		Sand	Clay	Silt					
Head	0-30	39	26	35	Loam	1.03	37.0	23.3	42
	30-60	36	33	31	Clay Loam	1.09	44.6	21.8	75
	60-90	37	24	39	Loam	1.07	44.7	24.5	65
	90-120	25	48	27	Clay	1.11	48.3	27.0	71
		Average				1.08	43.7	24.2	253
Middle	0-30	43	27	30	Loam	1.08	38.8	21.7	55
	30-60	42	22	36	Loam	1.12	39.9	18.9	71
	60-90	36	30	34	Clay Loam	1.10	47.4	23.6	79
	90-120	38	29	33	Clay Loam	1.13	49.4	24.8	83
		Average				1.11	43.9	22.3	288
Tail	0-30	41	26	33	Loam	1.05	40.5	20.9	62
	30-60	39	26	35	Loam	1.07	41.7	22.7	61
	60-90	43	32	25	Clay Loam	1.14	47.0	25.7	73
	90-120	32	41	27	Clay	1.16	48.8	24.7	84
		Average				1.11	44.5	23.5	279

4.2. Crop Water and Irrigation Requirement

From the computation of the CROPWAT model, the maximum water-demanding crop was sugar cane (ratoon), which is 1551.6 mm/season, followed by chat 1071.9 mm/season. A similar trend was also observed in irrigation requirement. On the other hand, the lowest crop water requirement and irrigation requirement was obtained from cabbage as it is growing season is shorter than all the rest (Table 4).

Table 4. Crop water and irrigation requirement of Wosha and Werka irrigation scheme

Crop	Growing season (day)	Crop water requirement (mm/season)	Re* (mm/season)	Irrigation Requirement (mm/season) **
Sugarcane	420	1551.6	598.6	983.2
Chat	365	1071.9	598.6	560.7
Potato	120	511.3	32.7	481.0
Tomato	120	585.0	49.2	539.2
Carrot	110	484.2	33.9	449.4
Cabbage	90	379.5	14.0	365.9

*Re: - Effective rainfall
**Season: - Total growing season

4.3. Irrigation Scheduling

In Wosha Irrigation Scheme, farmers used 15 to 30 days interval to irrigate sugarcane. The computed irrigation interval using soil and crop data revealed that it is 31 and 33 days at the head and middle of the scheme, respectively. This indicates similar irrigation interval was currently practice at Wosha by farmers at head and middle reach of the scheme. However, in the case of tail part of the scheme, the computed interval was 17 days, which implies the sugarcane was not obtained appropriate irrigation scheduling as compared with irrigation interval of 30 days, which is practiced by farmers.

Table 5. Irrigation scheduling of sugarcane for Wosha Irrigation Scheme

Reach	TAW (mm)	Depletion fraction (P)	RAW (mm)	ETo (mm/day)	Kc	ETc (mm/day)	Irrigation interval (days)
Head	161	0.65	104.6	4.27	0.8	3.42	31
Middle	172	0.65	111.8	4.27	0.8	3.42	33
Tail	86	0.65	55.9	4.27	0.8	3.42	17

Farmers in Werka irrigation scheme was practice irrigation interval of 45 to 60 days but as computed, irrigation interval ranged from 48 to 55 days (Table 6). The application interval more or less similar but it is longer to the irrigation interval near to 60 days and more.

The study revealed that longer irrigation interval was obtained at Werka than Wosha irrigation scheme both with estimation using soil and crop data and the current farmer practice.

Table 6. Irrigation scheduling of sugarcane for Werka Irrigation Scheme

Farm location	TAW (mm/m)	Depletion fraction (P)	RAW (mm/m)	ETo (mm/day)	Kc	ETc (mm/day)	Irrigation interval (day)
Head	253	0.65	164.4	4.27	0.8	3.42	48
Middle	288	0.65	187.2	4.27	0.8	3.42	55
Tail	279	0.65	181.3	4.27	0.8	3.42	53

4.4. Irrigated Crop Coverage

Sugarcane is the most dominant crop based on area coverage at both Wosha and Werka irrigation schemes which account for 55 and 41% at Wosha and Werka, respectively. It was followed by Chat which accounts for 40% at Wosha and 27% at Werka irrigation scheme (Table 7). Due to the perennial nature of the crop, both crops used higher irrigation water than the rest of the crops. Horticultural crops in Wosha irrigation scheme accounts only 5% out of the total area coverage of the scheme. However, at Werka irrigation scheme, 32% of the total area was covered with carrot, potato, cabbage, and tomato crops. The study revealed that much emphasis for horticultural crop was given at Werka than Wosha irrigation scheme.

On the other hand, farmers in Wosha irrigation scheme are highly depended on perennial crops than horticultural crops.

Table 7. Major crop and area coverage of Wosha and Werka irrigation scheme

Crop Type	Wosha Irrigation Scheme		Werka Irrigation Scheme	
	Area Coverage (ha)	Percentage of the total area (%)	Area Coverage (ha)	Percentage of the total area (%)
Sugar cane	205	55	118.25	41
Chat	149	40	78.5	27
Carrot	5	1	3.5	1
Potato	4	1	68.5	23
Cabbage	7	2	17.5	6
Tomato	3	1	6	2
Total	373	100	292.25	100

4.6. Internal Performance Indicators

4.6.1. Conveyance Efficiency (Ec) and Losses

The result showed that the conveyance efficiency in the main canal ranged from 83.4 to 96% at Wosha Irrigation Scheme and has an average of 92.3% (Table 8). The current finding is in line with former reports of Gashaye and Tena (2008) who reported conveyance efficiency of Geray irrigation scheme as 92 %. Similarly, the conveyance efficiency of Werka irrigation scheme in the main canal varied from 70.9 to 82.2% with an average efficiency of 76.1%. The result is in line with former findings of Menelik (2008) who reported conveyance efficiency of the unlined main canal at Selgie irrigation scheme, which ranged from 69 to 81%. On the other hand, the average conveyance efficiency in the unlined secondary canal was 60.2 and 56.5% in Wosha and Worka irrigation scheme, respectively. Bayan (2017) reported a similar finding that unlined conveyance efficiency of Mada Batu small-scale irrigation scheme canals ranged from 47.1 to 88.6%. In contrary, the conveyance efficiency in the main unlined canal of Midhegdu small-scale irrigation scheme was 88.8 % as reported by Worku (2013). This might be due to the difference in soil property and structural stability of the earth canals.

Overall, the schemes have a conveyance efficiency of 55.6 and 43 % at Wosha and Werka, respectively. Low conveyance efficiency recorded at Werka irrigation schemes as compared to Wosha scheme might be due to all part of the canal is unlined with a gentle slope which can leads to high seepage loss. According to FAO (1989) reports, the conveyance efficiency for earthen canal could be 80 and 95% for the lined canal; therefore, unlined canals of both Wosha and Werka irrigation scheme were under the desired efficiency.

Losses through conveyance system, which is in the main and secondary canal at Wosha irrigation scheme, were 0.06 and 0.093 l/s/m, respectively. Whereas in Werka irrigation scheme it was 0.104 and 0.076 l/s/m in main and secondary canals, respectively (Table 8). As per the field observation during field data collection in canals, the conveyance loss in the lined canal was due to linkage through division boxes. However, loss of irrigation water in the unlined canals associated with seepage losses. This was exacerbated by the flat slope of canal, which leads to the higher contact surface and poor structural stability of earthen materials of the canals.

The current finding is greater than the loss in the unlined canal of Mada Batu small-scale irrigation scheme, which is ranged from 0.02 l to 0.04 l/s/m as reported by Bayan (2017).

Table 8. Conveyance efficiency of the irrigation schemes (lined main canal)

Canal	Conveyance Efficiency (Ec) (%)		Conveyance losses (l/s/m)	
	Wosha IS	Werka IS	Wosha IS	Werka IS
Main canal	92.3	76.1	0.06	0.104
Secondary canal	60.2	56.5	0.093	0.076
Scheme Ec	55.6	43		

4.6.2. Application Efficiency (Ea)

Average application efficiency was 48.2 and 59% at Wosha and Werka irrigation scheme, respectively (Table 9). The efficiency at Wosha scheme has a trend of decreasing as it moves from head to tail of the scheme. This might be due to the physical property of the soil, which tells us that water-holding capacity at the head is better than at middle and tail of the scheme. According to FAO (2002) reports, the application efficiency of furrow irrigation could range from 50 to 70%. However, Wosha irrigation scheme was found to be below the range.

From mean application efficiency, the least contributed from the tail reach of the scheme it was because of typically the soil categorized in sand textural class with high deep percolation loss. According to Ayele (2016) report, application efficiency of Guder irrigation scheme was nearly similar to Wosha irrigation scheme, which is 49.7%.

Werka irrigation scheme had similar application efficiency over the entire farmland, and the result gave the value within the range of FAO (2002), which is 59%. This is due to the soil property has an advantage of greater water holding capacity and the water distributed fairly over the head, middle and tail of the scheme. Generally, the scheme has better application efficiency than Wosha irrigation scheme. A similar result also found by Worku (2013) which is 58.4% application efficiency at clay soil of Midhegdu small-scale irrigation scheme. This finding also agreed with Dessalew *et al*. (2016) study in Bedene Alemtena small-scale irrigation scheme found that the application efficiency ranges 53.6% at the head to 57.2% at the tail of the scheme, which the soil was silty clay loam and clay loam at the head and tail, respectively. This finding also in the ranges from 57.2 to 65.5% as reported by Dinka (2017) which the study conducted in clay loam of Ketar medium scale irrigation scheme.

Table 9. Application efficiency of the irrigation scheme.

Wosha irrigation scheme			
Reach	Applied depth (mm)	Stored depth(mm)	Ea (%)
Head	100.2	59.9	59.7
Middle	86.9	45.17	52.0
Tail	71.29	23.4	32.8
Scheme average efficiency			48.2
Werka irrigation scheme			
Head	150.2	84.8	56.5
Middle	132.4	77.2	58.3
Tail	144.4	89.7	62.1
Scheme average efficiency			59.0

4.6.3. Storage Efficiency (Es)

Water storage efficiency at Wosha irrigation scheme was varies 92.5% from head to 83.8% at the tail of the scheme and the maximum efficiency recorded in the middle of the scheme which is 93.2% (Table 10). Whereas, at Werka irrigation scheme, more or less similar storage efficiency 87.5, 85.8 and 88.1% was recorded at the head, middle and tail reach of the scheme, respectively. The average storage efficiency was 89.8% and 87.2% at Wosha and Werka irrigation schemes, respectively. Storage efficiency has the advantage to know the applied irrigation water is satisfied the moisture deficit of the crop root zone. The result implies about 87 % of the soil moisture deficit of both irrigation schemes satisfied. At both schemes, farmers practiced water conservation techniques by mulching the soil with sugarcane straw. This helps them to stay without irrigation by minimizing evaporation loss up to one to two months. The current finding is in line with Korkmaz and Avci (2012) who reported the storage efficiency varies from 54% to 97% over the scheme at Menemen Left Bank irrigation system.

Table 10. Storage efficiency of the irrigation schemes.

Field	Wosha Irrigation Scheme			Werka Irrigation Scheme		
	Stored water at root zone (mm)	Required Water (mm)	Es (%)	Stored water at root zone (mm)	Required Water (mm)	Es (%)
Head	59.86	64.74	92.5	84.85	96.91	87.5
Middle	45.17	48.46	93.2	77.19	89.96	85.8
Tail	23.40	27.92	83.8	89.70	101.77	88.1
Scheme Storage Efficiency			89.8			87.2

4.6.4. Water Distribution Uniformity (DU)

The computed result indicated that the average water distribution uniformity of both schemes was 91.7 % and 91.4% at Wosha and Werka irrigation schemes, respectively (Table 11 & Appendix table 14). In addition, the result revealed that water distribution uniformity at both irrigation schemes has small variation from 90 to 93%, which implies that the distribution uniformity was the same. This is due to the sugar cane fields were lay-outed by keeping the farm leveled. The highest efficiency was recorded at middle and head of Wosha and Werka irrigation scheme with a value of 93.9 and 91.9 %, respectively.

According to the recommendation of FAO (1992), both the studied irrigation schemes had adequate irrigation water distribution over the entire farm field. The current finding revealed that distribution uniformity was above sufficient, in which 30 and 65% were taken as poor and sufficient, respectively (FAO, 1992). Similar findings were reported by many authors, which the water distribution uniformity was greater than 90 % (Bayan, 2017; Dessalew *et al.*, 2016; Worku, 2013; Menelik, 2008). However, Dinka (2017) also reported conflicting results that average water distribution uniformity of the Ketar medium Scale irrigation Scheme was 61.6% due to the scheme operating at flow rates below or above the design flow rates. This could lead to inefficient and non-uniform water distribution in the whole farm field.

Table 11. Water distribution uniformity of the irrigation schemes

	Wosha Irrigation Scheme			Werka Irrigation Scheme		
Farm location	Mean stored water (mm)	least quarter mean Stored water (mm)	DU (%)	Mean stored water (mm)	least quarter mean Stored water (mm)	DU (%)
Head	60.00	55.14	91.9	84.85	77.97	91.9
Middle	45.25	42.18	93.2	77.19	70.56	91.4
Tail	23.40	21.08	90.1	89.70	81.54	90.9
Scheme efficiency			91.7			91.4

4.6.5. Deep Percolation Ratio

Majority of water loss during every irrigation event was deep percolation as farmer practice ended tied furrow. The average schemes deep percolation loss was found as 51.8 and 41.0% at Wosha and Werka irrigation schemes, respectively. The highest deep percolation loss recorded at the tail of Wosha irrigation scheme as 67.2%. In which the sandy property of the soil contributes to the lion share of the loss. The deep percolation ratio at head and middle of Wosha irrigation scheme was 40.3 and 48.0% of the applied water, respectively (Table 12). According to FAO (1989), the water loss through deep percolation and surface run off could be about 40% and above.

Werka irrigation scheme had a lowest deep percolation loss as compared to the Wosha scheme. This implies that the majority of the applied irrigation water stored at the root zone of the soil rather than lost through deep percolation. In Werka irrigation scheme, the highest water loss through deep percolation recorded at the head as 43.5%. Deep percolation loss at middle and the tail end of the scheme was 41.7 and 37.9% of the applied irrigation water. Generally, the deep percolation ranged from 37.9 to 67.2% at both Wosha and Werka irrigation scheme (Table 12).

Table 12. Deep percolation ratio of the irrigation scheme.

Farm location	Ea (%)	Runoff ratio, RR (%)	Deep percolation ratio, DPR (%)
Wosha Irrigation Scheme			
Head	59.7	0	40.3
Middle	52.0	0	48.0
Tail	32.8	0	67.2
Scheme average efficiency	48.2		51.8
Werka Irrigation Scheme			
Head	56.5	0	43.5
Middle	58.3	0	41.7
Tail	62.1	0	37.9
Scheme average efficiency	59.0		41.0

4.6.6. Overall Efficiency

The study revealed that the overall efficiency of Wosha and Werka irrigation schemes were 26.8 and 25.4%, respectively (Table 13). This indicates that both schemes were performing with poor efficiency. Poor efficiency for Wosha irrigation scheme was due to its poor application efficiency. On the other hand, scheme conveyance efficiency had a great share for its poor efficiency of Werka irrigation scheme. Both schemes overall efficiency was nearly similar with the overall efficiency of Dodicha irrigation scheme, which is 28.6% as reported by Eticha (2011).

Table 13. Overall scheme efficiency of the schemes

Internal indicator	Scheme efficiency (%)	
	Wosha	Werka
Conveyance efficiency	55.6	43.0
Application efficiency	48.2	59.0
Storage efficiency	89.8	87.2
Distribution efficiency	91.7	91.4
Deep percolation ratio	51.8	41.0
Overall scheme efficiency	26.8	25.4

4.7. External Performance Indicator

4.7.1. Agricultural Output Indicators

The irrigated crop area during the study year was 373 ha at Wosha irrigation scheme whereas the designed area was 180 ha (Table 16). The total production of Wosha irrigation scheme was 1,571,812 US $ (Table 14). The cropping pattern indicated that the major part (354 ha) of the scheme was covered by sugarcane and chat, and the rest of 19 ha of land covered with high-value horticultural crops.

Table 14. Crop type and production value of Wosha irrigation scheme.

Crop	Area Coverage (ha)	Yield (ton/ha)	Total Yield (ton)	Price(US$/ton)	production (US$)
Sugar cane	205	135,00pcs/ha	2,767,500 pcs	0.33 US$/pcs	903,427.6
Chat	149	4.5	670.5	763.6	512,020.6
Carrot	5	28	140	199.5	27,928.6
Potato	4	35	140	290.2	40,623.8
Cabbage	7	36	252	154.1	38,845.8
Tomato	3	45	135	362.7	48,965.8
Total	373				1,571,812

One US$ = 27.57 ETH birr June, 2018 rate, pcs indicate single sugar cane ban

The irrigated crop area during the study year was 292.2 ha at Werka the irrigation scheme. However, the designed area was 200 ha (Table 16). The total production value of the scheme was 1,706,838.4 US $. The study revealed that the total production of Werka was better than Wosha irrigation scheme. This is because of Werka scheme has covered more lands with high-value horticultural crops than Wosha irrigation scheme.

Table 15 . Crop type and production value of Werka irrigation scheme

Crop	Area Coverage (ha)	Yield (ton/ha)	Total Yield (ton)	Price(US$/ton)	production (US$)
Sugar cane	118.25	13,500pcs/ha	1,596,375	0.33 US$/pcs	526,803.8
Chat	78.5	4.5	353.2	763.6	269,755.8
Carrot	3.5	28.0	98.0	199.5	19,550.0
Potato	68.5	35.0	2397.5	290.2	695,682.6
Cabbage	17.5	36.0	630	154.1	97,114.5
Tomato	6.0	45.0	270	362.7	97,931.7
Total	292.2				1,706,838.40

Remark: One US$ = 27.57 Ethiopian birr, June, 2018 rate pcs indicate single sugar cane ban

4.7.1.1. Output per Unit Irrigated Area (OPUIA)

The study revealed that the output per unit irrigated area of Wosha and Werka irrigation were found as 4,214.97 and 5,840.34 US$/ha, respectively (Table 16). Werka irrigation scheme has better value than Wosha scheme due to its greater production (US$) value as a result of the scheme covered with high-value horticultural crop than Wosha scheme as output per unit irrigated area indicates the response of each cropped area on generating income. The nearly similar study reported by Degirmenci *et al.* (2003) who found the output per irrigated area was varied between 308 and 5771 US$/ha for twelve irrigation schemes found in the Southeastern Anatolia Project.

4.7.1.2. Output per Unit Command Area (OPUCA)

The outputs per unit command of Wosha and Werka irrigation schemes were 8,732.3 and 8534.2 US$/ha, respectively (Table 16). The OPUCA value of both schemes is greater than the value of OPUIA due to the expansion of irrigated land increased beyond the designed or nominal command area of the schemes. The output per unit command area of Wosha irrigation scheme is better than Werka irrigation scheme. The current finding is in line with former reports of Degirmenci *et al.* (2003) who reported output per unit cropped area varies from 1223 and 9436 US$/ha for the period 1997-2001 for twelve irrigation schemes.

4.7.1.3. Output per Unit Irrigation Delivered (OPUID)

The total amount of water delivered to Wosha and Werka irrigation schemes were 2,093,656 m^3 and 2,001,734 m^3, respectively (Table 17) for five consecutive months through irrigation diverted from Wosha and Werka rivers with an average flow of 102 and 74 l/s, respectively. Output per unit irrigation delivered of Wosha and Werka irrigation scheme was 1.18 and 1.77 US$/$m^3$, respectively.

The current finding in line with a similar result with werka irrigation scheme was reported by Solomon (2016) at Jari irrigation scheme. Output per unit irrigation delivered of both schemes was found in the range of Cakmak (2003) findings who reported 0.03 to 2.21 $/$m^3$ in the study conducted on sixty irrigation schemes found in Kızılırmak Basin, Turkey. As a result, reported by Shenkut (2015) that the output per irrigation diverted at Shina-Hamusit irrigation was 0.95 $/$m^3$. The greater value of output per unit irrigation delivered recorded at Werka irrigation scheme. This is due to the greater production value gained and the lower irrigation volume of water supplied as compared to Wosha irrigation scheme.

4.7.1.4. Output per Unit Water Consumed (OPUWC)

The outputs per unit water consumed for Wosha irrigation scheme was 0.32 US$/$m^3$ and Werka irrigation scheme was 0.42 US$/$m^3$ (Table 16). Both schemes of output per unit water consumed were in the range of 0.15-1.55 US$ m^3 as reported by Çakmak (2003) where the study conducted in the Kızılırmak Basin irrigation schemes.

Table 16. Agricultural output indicators of the schemes

Parameters	Wosha IS	Werka IS
Irrigated cropped area (ha)	373	292.2
Command cropped area (ha)	180	200
Irrigation supplied (m^3)	1,330,664	964,142
Water consumed ET (m3)	4,855,628.2	4,036,680.6
Production (US $)	1,571,812	1,706,838
OPUIA (US$/ha)	4,213.97	5,840.34
OPUCA (US$/ha)	8,732.29	8,534.2
OPUID (US$/m3)	1.18	1.77
OPUWC (US$/m3)	0.32	0.42

4.7.2. Water Supply Indicators

The study showed that from the annual total irrigation water demand, more than 72 and 76% was from November to March at Wosha and Werka Irrigation Scheme, respectively.

Table 17. Water supply indicators

Irrigation scheme	Irrigation demand (m^3)	Crop water requirement (m^3)	Eff. Rainfall (m^3)	Irrigation supply (m^3)	RIS	RWS
Wosha	2,093,656	2,341,534	329,359	1,330,664	0.64	0.71
Werka	2,001,734	2,204,676	258,057	964,142	0.48	0.55

The relative irrigation supply was 0.64 and 0.48 at Wosha and Werka Irrigation Schemes, respectively. The result indicated that relative irrigation supply of both schemes were below one. This implies that both schemes diverted less than the irrigation requirement of the schemes. According to Molden *et al*. (1998), relative irrigation supply of different schemes in the world had a wide variation ranging from 0.41 to 4.81. The result indicates that Wosha Irrigation Scheme has better relative water supply than Werka irrigation scheme. However, less relative irrigation supply of both schemes associated with the expansion of irrigated land without considering the amount of irrigation water.

The relative water supply of both schemes was also less than one, which implies that the sum of irrigation water supply and effective rainfall was not adequate for the crop water requirements of the schemes. The result indicated that the relative water supply was 0.71 and 0.55 at Wosha and Werka Irrigation Schemes, respectively. Similar to relative irrigation supply, relative water supply was also higher at Wosha than Werka Irrigation Scheme. Kuscu *et al*. (2009) reported similar findings to that of Wosha Irrigation Scheme on a study conducted at Karacabey irrigation scheme in Turkey with a value of 0.75 during the period from 2002 to 2007.

4.7.3. Water Delivery Capacity Indicator

The study revealed that both schemes have a peak demand in January, which is 0.50 and 0.53 l/s/ha at Wosha and Werka irrigation scheme, respectively (Table 18).

In addition to this, water delivery capacity was 2.1 and 1.64 at Wosha and Werka irrigation scheme, respectively. The indicator of water delivery capacity was greater than one for both schemes. This implies that the canal capacity of the schemes had a capacity to deliver the irrigation water at a season of peak demand. However, during the study period, the schemes did not supply the canals to carry water at full capacity. This was due to the off-take canal gates did not functional and maintained at some opening level at both schemes. The current study in line with Yusuf (2004) who reported that water delivery capacity was 1.83 at Doni irrigation scheme in Upper Awash River Valley. Similarly finding also reported by Abel (2014) greater than one at Bullnegero irrigation scheme, which is 1.4.

Table 18. Water delivery capacity

Irrigation schemes	Peak demand (l/s/ha)	Peak demand (l/s)	Canal capacity (l/s)	WDC
Wosha	0.50	186.5	388.8	2.1
Werka	0.53	154.9	253.9	1.6

4.7.4. Physical Indicator

4.7.4.1. Irrigation Ratio

The result revealed that irrigation ratio at Wosha irrigation scheme was 0.89. This implies about 89% of the irrigable command area is currently under irrigation. The current finding was also nearly similar to Jari irrigation scheme, which is 0.92 as reported by Solomon (2016). Whereas, the result indicated that irrigation ratio of Werka irrigation scheme was 0.78. This implies that 78% of the irrigable land covered by irrigation (Table 19).

Wosha irrigation scheme has better irrigation ratio than the Werka. This might due to the scheme has an advantage of modernized infrastructures and the sloppy nature of the scheme enable the irrigation water to rich any parts of the scheme with a low flow rate. Those reasons might be lead greater irrigation ratio at Wosha Scheme than Werka irrigation scheme.

Lower irrigation ratio at Werka scheme might be associated with whole conveyance system is unlined earth material. This could contribute to water loss through seepage and the slope is not favored for irrigation water to run a longer distance with minimum flow rate as compared with Wosha scheme. Due to this reason, the expansion is less as compared to Wosha irrigation scheme.

According to Seleshi *et al*. (2005), the most similar schemes in Ethiopia performed an average of about 40%, this implies these two schemes have greater irrigation ratio. Similar finding reported by Zeleke *et al*. (2012) as the irrigation ratio of Golgota irrigation scheme and Godino and Gohaworki subsystems of Wedecha irrigation schemes ranges from 0.67 to 0.92.

Table 19. Physical performance indicator

Irrigation Scheme	Irrigable Land (ha)	Initial Irrigated Land (ha)	Currently Irrigated Land (ha)	Indicators	
				Irrigation Ratio	Sustainability of Irrigated Area
Wosha	420	180	373	0.89	2.07
Werka	375	200	292.25	0.78	1.46

4.7.4.2. Sustainability of Irrigated Area

The sustainability of irrigated area tells about the command area under irrigation is contracting or expanding as compared to the area irrigated initially. The result showed that the sustainability of the irrigated area of Wosha and Werka irrigation schemes were 2.07 and 1.46, respectively (Table 19). This implies that the current area under irrigation was increased by double at Wosha irrigation scheme. Whereas, Werka irrigation scheme increased by 46% of the initially irrigated command area. Wosha scheme was more sustainable than that of Werka scheme but both have an advantage of market accesses and most area coverage is by commercial crops like sugarcane and chat.

According to Boss (1997) if the computed irrigation ratio value was less than one shows that the irrigable area becomes contracted and vise-verse. Werka Irrigation Scheme sustainability of irrigated area was nearly similar to Golgota irrigation scheme as reported by Zeleke *et al*. (2012), which is 1.22. Shenkut (2015) that sustainably of irrigated area of Selamko irrigation scheme was 2.11 also reported similar finding to Wosha irrigation scheme.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The current study was conducted to evaluate the performance of two small-scale irrigation schemes at Wondo Genet District, South Nations, Nationality, and People Regional State of Ethiopia. The evaluation was done using internal and external performance indicators. Those internal indicators used for the assessment were conveyance efficiency, application efficiency, storage efficiency, distribution uniformity, deep percolation ratio, and overall efficiency. The standardized performance indicators established by IWMI were used for external performance assessment. This includes agriculture output, water supply, water delivery capacity and physical indicator. The internal performance evaluation of both schemes undertakes in three selected farms from each scheme. Soil physical parameters like soil bulk density, textural class, field capacity, and permanent wilting point have been done by collecting a representative soil samples.

Textural class ranges from clay to sandy soil in Wosha irrigation scheme whereas, in Werka irrigation scheme clay and loam textural class. The bulk density ranged from 1.01 to 1.27 g/cm^3 and 1.03 to 1.16 g/cm^3 at Wosha and Werka irrigation schemes, respectively. The relative water holding capacity of the soil at Werka Irrigation Scheme was ranges from 253 to 288 mm and 86 to 172 mm in Wosha Irrigation Scheme.

The overall conveyance efficiency of Wosha and Werka irrigation schemes was 55.6 and 43%, respectively. Both at Wosha and Werka irrigation schemes, main canals had a better conveyance efficiency than secondary canals, which is 92.3 and 76.1% at Wosha and Werka irrigation scheme, respectively. Secondary canals have low efficiency due to the non-lined and non-stabilized surface as well which was 60.2 and 56.5% at Wosha and Werka irrigation scheme, respectively.

Moreover, the evaluation revealed that the application efficiency at both schemes was very low which is 48.2 and 59.0% in Wosha and Werka irrigation scheme, respectively. This low efficiency is due to poor water management like applying irrigation water without considering the infiltration rate of the soil. However, the application efficiency of Werka irrigation scheme was better than Wosha Scheme due to the better water holding capacity of the soil.

On the other hand, a better and nearly similar water distribution uniformity of 89.8 and 87.2% were observed at Wosha and Werka Irrigation Scheme, respectively. In addition to this, the applied irrigation water distributions were 91.7 and 91.4% over the irrigated command area at Wosha and Werka irrigation scheme, respectively. From the applied irrigation water, deep percolation accounted for about 51.8 and 41.0% at Wosha and Werka irrigation schemes, respectively. The overall efficiency was 26.8 and 25.4% at Wosha and Werka Irrigation Schemes, respectively.

Agricultural output indicators showed that output per unit irrigated area of Wosha and Werka irrigation scheme were 4213.97 and 5840.34 US$, respectively. Output per unit command area was 8732.29 and 8534.19 US$ for Wosha and Werka irrigation schemes, respectively. As the result showed that the output per unit irrigation supply of Wosha and Werka Irrigation Scheme were 1.18 and 1.77 US$/m^3, respectively. The outputs per unit water consumed for Wosha irrigation scheme was 0.32 US$/m^3.

Relative irrigation supply was 0.64 at Wosha and 0.48 at Werka irrigation scheme. However, the ratio was less than one, which implies that the supplied irrigation water is not sufficient for both irrigation scheme. The relative water supply indicator revealed that it was 0.71 and 0.55 at Wosha and Werka irrigation scheme, respectively. The relative water supply also less than one, which implies that total water from effective rainfall and irrigation, was not enough to meet the crop water requirements of both schemes. The water delivery capacity was 1.56 and 1.32 at Wosha and Werka irrigation scheme, respectively. The result indicated that the canal has a capacity to deliver the peak water demands of both irrigation schemes.

The obsered sustainability of irrigation schemes using physical indicators revealed that irrigation ratio of Wosha and Werka irrigation schemes were 0.89 and 0.78, respectively. This implied that about 89 and 78% of the potentially irrigable land were under irrigation at Wosha and Werka irrigation scheme, respectively. In addition to this, sustainability of irrigated area of Wosha and Werka irrigation scheme were 2.07 and 1.46, respectively. This implies that the current land under irrigation exceeds by double at Wosha and by half at Werka from the area initially designed for.

According to the internal indicators, the application efficiency was very low due to losses through deep percolation during irrigation events. In addition, conveyance efficiency in the unlined section of each schemes were very low due to leakage loss. Storage efficiency and water distribution uniformity at both scheme were good. The deep percolation loss was greater in Wosha irrigation scheme than that of Werka Irrigation scheme. Because of the above observation overall efficiency of both irrigation schemes were categorized under low efficiency. Poor application efficiency was responsible for the lion share of low overall efficiency at Wosha Irrigation Scheme. On the other hand, low overall efficiency of Werka Irrigation Scheme was mainly due to poor conveyance efficiency in main and secondary canals.

The agricultural output indicators were relatively better at Wosha Irrigation Scheme. In contrary better water supply indictors and water delivery capacity were obtained at Werka Irrigation Scheme. However, both relative water and irrigation supply were not satisfy the crop water demands in both Wosha and Werka Irrigation Schemes. Both schemes were sustainable according to physical indicators. However, the irrigation command area at both scheme were expanding without considering water resource. This leads to the schemes inadequate irrigation water supply for crop production.

Generally, based on the evaluation carried out both irrigation schemes would needs improvement measures to maximize the performance. Therefore, for the improvement of water productivity, irrigation management and practice, frequent performance evaluation should be conducted to identify the critical level of the schemes.

5.2. Recommendations

Based on the result obtained from the internal and external evaluation of Wosha and Werka irrigation schemes the following recommendations were suggested:

1. The conveyance efficiency can be improve through regular maintenance of the canals and water controlling metal sheet gates in the intake structures and conveyance systems (especially in the division box of Wosha irrigation scheme)
2. The conveyance system in the secondary canal of Wosha IS as well in the main and secondary canal of Werka IS were accounts much conveyance loss, if it is possible, lined at least the main canal of Werka IS or stabilize with selected material to reduce seepage loss and leakages.
3. The application efficiency, especially in Wosha irrigation scheme is very low, therefore possible irrigation management techniques such as deficit irrigation, surge and cutoff application shall be adopted here.
4. Proper irrigation scheduling should be used because the application efficiency can be improved by applying the right depth of water in the right place at the right time.
5. There is no diversion structure in Wosha Irrigation Scheme. Therefore, the diverted water is below the capacity of the main canal and not meets the demands of the irrigable land so the diversion structure should be built across the Wosha River.
6. Expanding high value horticultural crops is very significant to increase the output production per unit-irrigated area, command area and water diverted in both scheme especially for Wosha Irrigation Scheme.
7. This study should be repeated for another irrigation season, different crop types, with another indicator like environmental and economic to confirm the validity of the present findings since the research is done in single season.

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APPENDICES

Appendix Table 1. Long-term (1986-2015) climatic data of the study area

Month	Maximum Temperature (^{O}C)	Minimum Temperature (^{O}C)	Relative humidity (%)	Wind speed (m/s)	Sunshine hour	Rainfall (mm)	Effective Rainfall (mm)
January	24.2	12.6	47.4	3.0	8.7	28.0	6.8
February	25.7	13.8	42.0	3.2	8.4	54.0	22.4
March	26.2	15.1	46.4	3.3	7.9	95.6	52.5
April	24.6	14.9	60.5	3.0	7.3	128.5	78.8
May	23.1	14.5	71.4	2.4	7.4	115.0	68.0
June	20.9	13.8	78.8	2.9	6.7	110.9	64.7
July	19.5	13.1	81.6	3.3	4.7	143.5	90.8
August	19.8	13.0	81.5	3.1	5.1	147.1	93.7
September	21.0	13.1	77.9	2.3	5.5	125.2	76.2
October	22.0	12.3	70.6	2.4	9.2	77.2	37.8
November	23.0	11.8	58.0	3.0	9.0	26.0	5.6
December	23.2	11.9	52.1	3.1	7.2	18.3	1.0

Appendix Table 2. Crop water and irrigation requirement of sugar cane

Month	Decade	Stage	Kc	Etc. mm/day	Etc. mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Mar	1	Init	0.8	4.61	4.6	1.4	27.2
Mar	2	Init	0.4	2.34	23.4	17.6	5.7
Mar	3	Init	0.4	2.2	24.2	20.5	3.7
Apr	1	Deve	0.4	2.07	20.7	24.5	0.0
Apr	2	Deve	0.5	2.43	24.3	28.0	0.0
Apr	3	Deve	0.64	2.94	29.4	26.2	3.1
May	1	Deve	0.78	3.37	33.7	23.7	10.1
May	2	Deve	0.92	3.74	37.4	22.4	15.1
May	3	Deve	1.06	4.12	45.4	22.1	23.3
Jun	1	Mid	1.2	4.42	44.2	21.0	23.1
Jun	2	Mid	1.23	4.28	42.8	20.2	22.6
Jun	3	Mid	1.23	4.07	40.7	23.6	17.1
Jul	1	Mid	1.23	3.85	38.5	28.1	10.5
Jul	2	Mid	1.23	3.64	36.4	31.3	5.1
Jul	3	Mid	1.23	3.69	40.6	31.3	9.3
Aug	1	Mid	1.23	3.74	37.4	31.5	5.8
Aug	2	Mid	1.23	3.79	37.9	32.2	5.7
Aug	3	Mid	1.23	3.89	42.8	29.9	12.9
Sep	1	Mid	1.23	4	40.0	28.0	12.0
Sep	2	Mid	1.23	4.1	41.0	26.3	14.7
Sep	3	Mid	1.23	4.43	44.3	21.8	22.6
Oct	1	Mid	1.23	4.77	47.7	16.7	31.0
Oct	2	Mid	1.23	5.1	51.0	12.3	38.6
Oct	3	Mid	1.23	5.25	57.8	8.8	48.9
Nov	1	Mid	1.23	5.41	54.1	4.6	49.5
Nov	2	Mid	1.23	5.56	55.6	0.6	55.0
Nov	3	Mid	1.23	5.52	55.2	0.5	54.7
Dec	1	Late	1.22	5.45	54.5	0.5	53.9
Dec	2	Late	1.17	5.21	52.1	0.0	52.1
Dec	3	Late	1.12	5.18	57.0	0.6	56.4
Jan	1	Late	1.07	5.14	51.4	1.3	50.0
Jan	2	Late	1.03	5.08	50.8	1.8	49.0
Jan	3	Late	0.98	5.06	55.6	3.7	51.9
Feb	1	Late	0.93	5.01	50.1	5.3	44.8
Feb	2	Late	0.88	4.96	49.6	6.8	42.7
Feb	3	Late	0.84	4.75	38.0	10.4	27.6
Mar	1	Late	0.8	4.61	41.5	12.8	27.2

Appendix Table 3. Crop water and irrigation requirement of chat

Month	Decade	Stage	Kc	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Mar	3	Init	0.73	4.04	4.00	1.90	19.90
Apr	1	Init	0.70	3.59	35.90	24.50	11.40
Apr	2	Init	0.70	3.38	33.80	28.00	5.80
Apr	3	Init	0.70	3.21	32.10	26.20	5.80
May	1	Init	0.70	3.03	30.30	23.70	6.70
May	2	Init	0.70	2.86	28.60	22.40	6.20
May	3	Deve	0.70	2.72	29.90	22.10	7.80
Jun	1	Deve	0.70	2.57	25.70	21.00	4.60
Jun	2	Deve	0.69	2.41	24.10	20.20	3.80
Jun	3	Deve	0.68	2.26	22.60	23.60	0.00
Jul	1	Deve	0.68	2.12	21.20	28.10	0.00
Jul	2	Deve	0.67	1.99	19.90	31.30	0.00
Jul	3	Deve	0.66	1.99	21.90	31.30	0.00
Aug	1	Deve	0.66	2.00	20.00	31.50	0.00
Aug	2	Deve	0.65	2.01	20.10	32.20	0.00
Aug	3	Mid	0.64	2.04	22.50	29.90	0.00
Sep	1	Mid	0.64	2.09	20.90	28.00	0.00
Sep	2	Mid	0.64	2.15	21.50	26.30	0.00
Sep	3	Mid	0.64	2.32	23.20	21.80	1.50
Oct	1	Mid	0.64	2.50	25.00	16.70	8.30
Oct	2	Mid	0.64	2.67	26.70	12.30	14.40
Oct	3	Mid	0.64	2.75	30.30	8.80	21.40
Nov	1	Mid	0.64	2.83	28.30	4.60	23.70
Nov	2	Mid	0.64	2.91	29.10	0.60	28.50
Nov	3	Mid	0.64	2.89	28.90	0.50	28.40
Dec	1	Mid	0.64	2.87	28.70	0.50	28.20
Dec	2	Mid	0.64	2.86	28.60	0.00	28.60
Dec	3	Late	0.69	3.20	35.10	0.60	34.50
Jan	1	Late	0.73	3.51	35.10	1.30	33.80
Jan	2	Late	0.73	3.63	36.30	1.80	34.50
Jan	3	Late	0.73	3.80	41.80	3.70	38.10
Feb	1	Late	0.73	3.96	39.60	5.30	34.30
Feb	2	Late	0.73	4.13	41.30	6.80	34.40
Feb	3	Late	0.73	4.15	33.20	10.40	22.90
Mar	1	Late	0.73	4.23	42.30	14.30	28.10
Mar	2	Late	0.73	4.28	42.80	17.60	25.20
Mar	3	Late	0.73	4.04	40.40	18.70	19.90

Appendix Table 4. Crop water and irrigation requirement of potato

Month	Decade	Stage	Kc	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	3	Init	0.5	2.14	15	5.6	10.6
Nov	1	Init	0.5	2.21	22.1	4.6	17.5
Nov	2	Init	0.5	2.27	22.7	0.6	22.1
Nov	3	Deve	0.62	2.79	27.9	0.5	27.4
Dec	1	Deve	0.83	3.73	37.3	0.5	36.8
Dec	2	Deve	1.05	4.67	46.7	0	46.7
Dec	3	Mid	1.17	5.39	59.3	0.6	58.7
Jan	1	Mid	1.17	5.58	55.8	1.3	54.5
Jan	2	Mid	1.17	5.78	57.8	1.8	56
Jan	3	Late	1.1	5.71	62.8	3.7	59.1
Feb	1	Late	0.97	5.23	52.3	5.3	47
Feb	2	Late	0.84	4.73	47.3	6.8	40.5
Feb	3	Late	0.77	4.36	4.4	1.3	4.4

Appendix Table 5. Crop water and irrigation requirement of tomato

Month	Decade	Stage	Kc	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.6	2.72	21.8	0.5	21.2
Nov	3	Init	0.6	2.7	27	0.5	26.5
Dec	1	Deve	0.63	2.81	28.1	0.5	27.6
Dec	2	Deve	0.8	3.56	35.6	0	35.6
Dec	3	Deve	1	4.61	50.7	0.6	50.1
Jan	1	Mid	1.16	5.54	55.4	1.3	54.1
Jan	2	Mid	1.17	5.79	57.9	1.8	56.1
Jan	3	Mid	1.17	6.05	66.6	3.7	62.9
Feb	1	Mid	1.17	6.31	63.1	5.3	57.8
Feb	2	Mid	1.17	6.58	65.8	6.8	58.9
Feb	3	Late	1.09	6.18	49.4	10.4	39
Mar	1	Late	0.93	5.38	53.8	14.3	39.6
Mar	2	Late	0.83	4.84	9.7	3.5	9.7

Appendix Table 6. Crop water and irrigation requirement of carrot

Month	Decade	Stage	Kc	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	2	Init	0.7	2.91	29.1	12.3	16.8
Oct	3	Deve	0.72	3.08	33.9	8.8	25
Nov	1	Deve	0.84	3.71	37.1	4.6	32.5
Nov	2	Deve	0.98	4.43	44.3	0.6	43.7
Nov	3	Mid	1.06	4.79	47.9	0.5	47.4
Dec	1	Mid	1.06	4.76	47.6	0.5	47.1
Dec	2	Mid	1.06	4.73	47.3	0	47.3
Dec	3	Mid	1.06	4.91	54	0.6	53.4
Jan	1	Mid	1.06	5.09	50.9	1.3	49.6
Jan	2	Late	1.04	5.14	51.4	1.8	49.5
Jan	3	Late	0.98	5.09	40.8	2.7	37.1

Appendix Table 7. Crop water and irrigation requirement of cabbage

Month	Decade	Stage	Kc	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Oct	3	Init	0.70	3.00	6.00	1.60	6.00
Nov	1	Init	0.70	3.09	30.90	4.60	26.30
Nov	2	Init	0.70	3.18	31.80	0.60	31.10
Nov	3	Deve	0.76	3.43	34.30	0.50	33.80
Dec	1	Deve	0.87	3.90	39.00	0.50	38.50
Dec	2	Deve	0.98	4.37	43.70	0.00	43.70
Dec	3	Mid	1.06	4.90	53.90	0.60	53.30
Jan	1	Mid	1.06	5.10	51.00	1.30	49.60
Jan	2	Late	1.06	5.27	52.70	1.80	50.90
Jan	3	Late	1.00	5.19	36.30	2.40	32.60

Appendix Table 8. Conveyance efficiency of main canals

	Wosha irrigation scheme				Werka irrigation scheme			
Observation Point (m)	Q_{in} (l/s)	Q_{out} (l/s)	Ec (%)	losses (ls/100m)	Q_{in} (l/s)	Q_{out} (l/s)	Ec (%)	losses (ls/100m)
100	103.4	99.2	96	4.2	85.2	68.3	80.2	16.9
200	99.2	93.7	94.4	5.5	68.3	48.4	70.9	19.9
300	93.7	88.6	94.5	5.1	48.4	33.9	70.0	14.5
400	88.6	83.7	94.5	4.9	33.9	25.9	76.4	8.0
500	83.7	75.8	90.6	7.9	25.9	19.2	74.1	6.7
600	75.8	70.1	92.4	5.7	19.2	15.2	79.2	4.0
700	70.1	66.2	94.5	3.9	15.2	12.5	82.2	2.7
800	66.2	59.7	90.1	6.5				
900	59.7	49.8	83.4	9.9				
Average			92.3	6.0			76.1	10.4

Appendix Table 9. Conveyance efficiency of secondary canals

Secondary canal	Wosha Irrigation Scheme					Werka Irrigation Scheme			
	Observation point	Q_{in} (l/s)	Q_{out} (l/s)	Ec (%)	losses (ls/100m)	Q_{in} (l/s)	Q_{out} (l/s)	Ec (%)	losses (ls/100m)
SC 1	1	31.1	19.2	61.7	11.9	25.5	16.1	63.1	9.4
	2	19.2	11.5	59.9	7.7	16.1	8.5	52.8	7.6
SC 2	1	27.3	14.7	53.8	12.6	19.2	11.4	59.4	7.8
	2	14.7	9.6	65.3	5.1	11.4	5.8	50.9	5.6
Average				60.2	9.3			56.5	7.6

Appendix Table 10. Application depth and Stored water of Wosha Irrigation Scheme

Reach	Irrigation even	Time (sec)	Head (cm)	Discharge(Q) (l/s)	Applied Depth (mm)	Stored depth (mm)	Ea (%)
Head	1	15653	9	3.6	87.7	53.59	61.12
	2	16741	10	4.3	110.4	67.37	61.02
	3	22001	8	3	102.7	58.63	57.11
		Average			100.2	59.9	59.71
Middle	1	16553	8	3	77.2	39.66	51.34
	2	25153	7	2.5	95.4	54.81	57.43
	3	23198	7	2.5	88	41.06	46.65
		Average			86.9	45.2	51.99
Tail	1	18900	7	2.5	71.7	28.28	39.43
	2	25237	6	1.9	75.4	23.36	30.98
	3	17598	7	2.5	66.8	18.58	27.83
		Average			71.3	23.4	32.83

Appendix Table 11. Application depth and stored water of Werka Irrigation Scheme

Reach	Irrigation event	Time (sec)	Head (cm)	Discharge(Q) (l/s)	Applied Depth (mm)	Stored Depth (mm)	Ea (%)
Head	1	21761	9.5	4.3	132.54	68.43	51.63
	2	24982	10	4	164.75	95.24	57.81
	3	27348	9	3.6	153.18	90.87	59.32
		Average			150.16	84.85	56.5
Middle	1	28598	8	3	133.45	79.43	59.52
	2	25310	9	3.6	141.77	96.52	68.08
	3	32157	7	2.5	122.01	55.61	45.58
		Average			132.41	77.19	58.29
Tail	1	27028	9	3.6	151.39	96.64	63.84
	2	31197	8	3	145.58	88.82	61.01
	3	35889	7	2.5	136.17	83.64	61.42
		Average			144.38	89.7	62.13

Appendix Table 12. Storage efficiency of Wosha and Werka Irrigation Scheme

Reach	Irrigation event	Wosha irrigation scheme			Werka irrigation scheme		
		Stored water at root zone (mm)	Required Water (mm)	Es (%)	Stored water at root zone (mm)	Required Water (mm)	Es (%)
Head	1	53.59	58.35	91.83	68.43	81.13	84.34
	2	67.37	72.97	92.33	95.24	107.58	88.53
	3	58.63	62.91	93.20	90.87	102.00	89.09
Average		59.86	64.74	92.46	84.85	96.91	87.55
Middle	1	39.66	42.45	93.43	79.43	92.19	86.16
	2	54.81	59.71	91.79	96.52	108.38	89.06
	3	41.06	43.22	95.00	55.61	69.31	80.24
Average		45.17	48.46	93.22	77.19	89.96	85.80
Tail	1	28.28	32.02	88.32	96.64	109.20	88.50
	2	23.36	29.40	79.45	88.82	97.73	90.89
	3	18.58	22.33	83.20	83.64	98.39	85.01
Average		23.40	27.92	83.84	89.70	101.77	88.14
Scheme Storage Efficiency				89.84			87.16

Appendix Table 13. Distribution efficiency of Wosha Irrigation Scheme

Reach	Irrigation event	Total stored water at the depth of 120 cm in root zone (mm)									Average	Ed (%)
		X1	X2	X3	X4	X5	X6	X7	X8	X9		
Head	1	52.7	58.7	55.0	55.9	50.7	49.8	53.2	57.4	52.7	54.0	93.04
	2	55.6	67.8	69.6	68.5	72.7	66.1	73.0	66.7	66.2	67.4	90.34
	3	55.6	53.5	59.6	56.3	58.5	65.0	57.4	59.6	62.2	58.6	92.69
				Average							60.0	91.91
Middle	1	40.5	37.9	39.0	39.7	42.2	46.1	38.3	35.5	39.6	39.9	92.03
	2	50.4	56.4	58.6	54.0	56.0	53.7	57.2	54.6	52.5	54.8	93.80
	3	43.6	45.2	42.3	39.3	38.5	42.1	40.2	38.4	40.0	41.1	93.62
				Average							45.2	93.23
Tail	1	26.0	27.2	31.7	25.7	32.3	27.9	28.6	27.2	28.0	28.3	91.35
	2	21.9	22.8	24.4	23.6	26.7	19.8	22.9	24.3	23.9	23.4	89.31
	3	17.0	19.4	17.6	20.3	18.8	16.1	21.3	19.1	17.6	18.6	89.07
				Average							23.4	90.07
						scheme efficiency						91.74

Appendix Table 14. Distribution efficiency of Werka Irrigation Scheme

Reach	Irrigation event	Total stored water at the depth of 120 cm in root zone (mm)									Average	Ed (%)
		X1	X2	X3	X4	X5	X6	X7	X8	X9		
Head	1	68.3	67.7	69.2	75.7	70.2	61.4	65.2	72.6	65.6	68.4	92.52
	2	91.1	99.2	112.2	90.4	92.2	83.5	94.7	98.8	95.0	95.2	91.32
	3	85.0	93.1	95.4	84.9	86.0	117.9	82.7	84.6	88.1	90.9	92.04
					Average						84.8	91.90
Middle	1	79.0	74.3	73.0	74.5	82.9	82.5	72.3	82.1	94.4	79.4	91.41
	2	97.8	101.6	94.1	83.3	96.7	95.7	94.7	101.3	103.5	96.5	91.87
	3	64.1	51.8	56.8	49.7	51.1	55.8	54.4	56.4	60.5	55.6	90.64
					Average						77.2	91.42
Tail	1	85.4	101.8	110.2	88.8	106.7	90.7	89.0	99.0	98.3	96.6	90.13
	2	83.3	97.7	86.6	101.2	88.8	82.2	81.9	87.8	90.0	88.8	92.52
	3	87.1	88.0	77.0	74.0	89.2	85.8	77.0	86.3	88.6	83.6	90.22
					Average							90.90
					scheme efficiency							91.41

Appendix Table 15. Monthly irrigation water demand of Wosha Irrigation Scheme

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NIR ,(l/s/ha)	0.50	0.42	0.19	0.05	0.14	0.16	0.10	0.10	0.12	0.33	0.49	0.50
CWR (m^3)	516471	463259	387808	304517	371489	369997	330944	335681	354928	446537	480249	493748
Eff. Rain (m3)	25364	83552	195825	293924	253640	241331	338684	349501	284226	140994	20888	3730
Irrigation demand m^3	491148	382030	271630	40676	130382	141367	51082	50057	103377	311078	459368	489480
Irrigation supply(m^3)	271590	250049	275072								255079	278875

Appendix Table 16. Monthly irrigation and water demand of Werka Irrigation Scheme

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NIR ,(l/s/ha)	0.53	0.39	0.19	0.04	0.14	0.16	0.10	0.10	0.12	0.26	0.43	0.51
CWR (m3)	556751	428018	276083	216303	267594	268206	240081	243655	257687	338479	432978	510846
Eff. Rain (m3)	19873	65464	153431	230293	198730	189086	265363	273838	222695	110471	16366	2923
Irrigation demand m^3	531208	358729	193169	27904	95018	104500	38080	37315	76905	237631	412038	506590
Irrigation supply (m^3)	181997	206140	227584								157049	191372

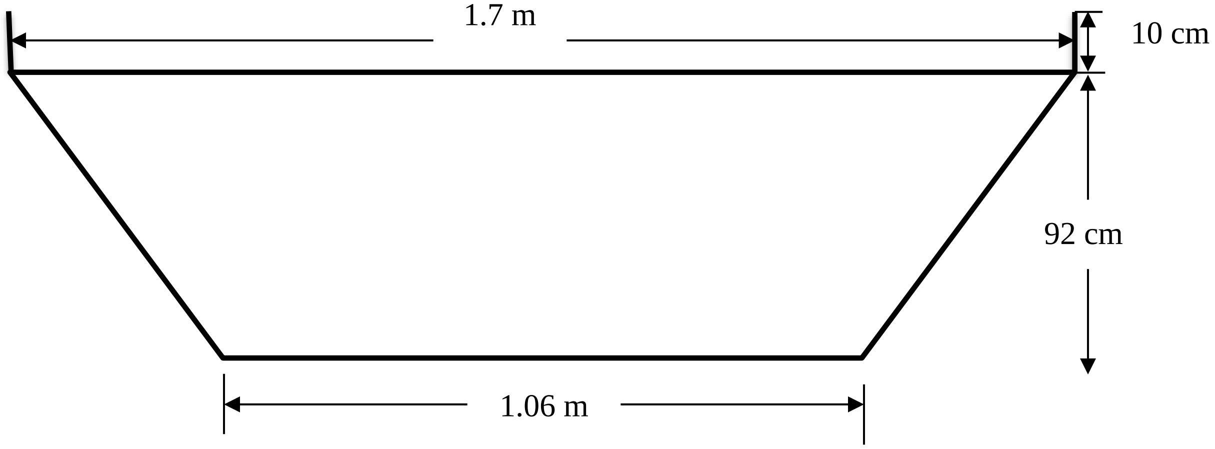
Appendix Figure 1. Intake of Wosha Irrigation Scheme

Appendix Figure 2. Werka Irrigation Scheme weir and reservoir

Appendix Figure 3. Conveyance losses in main canal of Werka Irrigation Scheme

Appendix Figure 4. During measurement in main canal of Werka Irrigation Scheme

Appendix Figure 5. Werka Irrigation Scheme canal shape and size at outlet of the weir



Appendix Figure 6. Main canals and division box in Wosha Irrigation Scheme

Appendix Figure 7. Field channel and Water measurement by parshall flume

Appendix Figure 8. Nonfunctioning metal sheet gets at Wosha and Werka Irrigation Schemes offtake canals

Appendix Figure 9. Soil sampling during fieldwork

Appendix Figure 10. Soil Textural Class Triangle