



**PERFORMANCE EVALUATION OF SEYSA IRRIGATION  
SCHEME, TIGRAY, ETHIOPIA**

**M.Sc THESIS**

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**OCTOBER, 2019**

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**A THESIS SUBMITTED TO THE DEPARTEMENT OF  
WATER RESOURCE AND IRRIGATION ENGINEERING,  
INSTITUTE OF TECHNOLOGY, SCHOOL OF  
GRADUATE STUDIES, HAWASSA UNIVERSITY,  
HAWASSA, ETHIOPIA**

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

**OCTOBER, 2019**

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## **LIST OF ACRONYMS AND ABBREVIATIONS**

|                 |   |
|-----------------|---|
| BoANR           | Bureau of agriculture and natural resource      |
| BRC             | Branch canal                                    |
| cm <sup>3</sup> | Cubic centimeter                                |
| CROPWAT8        | Crop Water Requirement Estimating Model Window8 |
| CV              | Coefficient of Variation                        |
| CWR             | Crop Water Requirement                          |
| DDR             | Delivery Duration Ratio                         |
| DPR             | Delivery Performance Ratio                      |
| DU              | Distribution Uniformity                         |
| ERHT            | Equity Ratio for Head and Tail                  |
| ET <sub>o</sub> | Reference evapotranspiration                    |
| FAO             | Food and Agricultural Organization              |
| FC              | Field Capacity                                  |
| FSL             | Full Supply Level                               |
| GIS             | Geographic Information System                   |
| g <sub>m</sub>  | Gram  |
| GPS             | Global Positioning System                       |
| ha              | Hectare   |
| IR              | Irrigation Requirement                          |
| IWMI            | International Water Management Institute        |

|                |   |
|----------------|---|
| M <sup>3</sup> | Cubic meter   |
| MDR            | Management Delivery Ratio                                   |
| Mha            | Millions of hectare   |
| PA             | Adequacy  |
| PD             | Dependability   |
| PDF            | Deficiency  |
| PE             | Equity  |
| PF             | Efficiency  |
| PIA            | Adequacy Indicator  |
| Q              | Discharge   |
| QD             | Actual Delivered Discharge                                  |
| QO             | of Taking Canal Discharge                                   |
| QR             | Actual Required Discharge                                   |
| R              | Region  |
| RWRB           | Regional Water Resource Bureau                              |
| SI             | Sustainability of Irrigable Area                            |
| STD.ER         | Standard Error  |
| T              | Time  |
| WRMEOWRA       | Water resource Mines and Energy Office of Wereda Rural Adwa |
| WSE            | Water Surface Elevation                                     |
| WSER           | Water Surface Elevation Ratio                               |
| WUAs           | Water Users Associations                                    |

## **ACKNOWLEDGEMENT**

For all his sincere, faithful and huge commitment to help me for the accomplishment of this thesis work and to bring me here from the start, much appreciation is expressed for my instructor and advisor Shemelies Asseffa (PhD) for his sweet and limitless advice that smoothen my educational journey. I also gratefully acknowledge my co-advisor Moltot Zewde (PhD) for all his assistance and unlimited support during the study. Acknowledgment is expressed to the staff of Adwa Wereda Mines and Energy Office and office of Agriculture. In addition I also gratefully acknowledge the generous support and contribution of all my colleagues, friends, families and relatives.

## **BIOGRAPHY**

Gebreabzgi Fisssha was born in 1986 in Tigray, Central administrative zone, Tahtay Maychew Wereda. He has attended his primary school at Mriena Full Elementary School and completed his secondary school at Aksum Comprehensive High School in 2006. After taking the Ethiopian School Leaving Certificate Examination (ESLCE), he joined the Hawassa University Institute of Technology 2006 and graduated with B.Sc. degree in Agricultural Engineering and Mechanization in 2009. After that, he has been working in Tigray, Central Zone, Werie Leke Wereda for two years and three months as design engineer in irrigation and water supply process. He has worked as Irrigation Engineer and Irrigation Process Coordinator in Wereda Naeder Adiet for 2 years and 8 months from February 2012 to September 2016. He was joined to the school of graduate studies of Hawassa University in October 2016 for his MSc. Study Department of Water resource and Irrigation Engineering specialized by Irrigation and Drainage Engineering.

## **ABSTRACT**

*The potential benefits of Seysa Irrigation Scheme hardly realized the required objectives due to satisfactory performance of their water delivery system and system maintenance. Hence, this study attempts to evaluate the hydraulic performance of small-scale irrigation scheme using technical performance parameters. The hydraulic performance of the system was evaluated using 10 selected process performance indicators, classified under three groups i.e. conveyance, water utility and maintenance indicators in the first way and in some selected farms technical performance indicators, application efficiency, distribution uniformity and storage efficiency were evaluated. According to the results of the study, the irrigation scheme has an average application, distribution and storage efficiency values of 65.44%, 59.42% and 73.87% respectively. Average delivery performance ratio, the value of adequacy, dependability and equity are estimated to be 0.83, 0.83, 0.18 and 0.21 respectively, which results fair water delivery performance. The equity ratio of water distribution for head to tail is fair 1.23. The head received more water than the tail. The average deficit of the system is 0.17; the main canal supplies less water than the demand to the delivery point. The value of water surface elevation ratio, delivery duration ratio and sustainability of infrastructure were found to be 86, 150 and 87.5 percent respectively, it displayed as system maintenance is required. According to the study results, the performance of the system is fair.*

***Key words: conveyance, maintenance indicators, Seysa irrigation scheme, distribution uniformity, water utility.***

# 1. INTRODUCTION

## 1.1. Background

Irrigation practices were long been in use during ancient times with unspecified beginning period. However, irrigation was not a driving force for the initiation of ancient civilization in Ethiopia. Since 1950s modern irrigation was introduced at the Rift Valley basin for production of commercial crops. Government, donors and NGOs are investing in developing irrigation systems, especially on small-scale irrigations. As a result, irrigation is developing rapidly. However, its contribution to the national economy is not significant when compared to rain-fed agriculture (Haile and Kasa, 2015). Irrigation is believed as a key for food security and poverty reduction in Ethiopia. Developments in the Ethiopian irrigation system have shown great advancements so as to assure Ethiopian livelihoods especially in the rural areas (Haile and Kassa, 2015).

The water resources of Ethiopia are enormous; amounting about 125 BCM of annual surface water potential and an estimated annual groundwater potential of 2.6 BCM (Zelege, 2015). Total irrigable land potential in Ethiopia is estimated to be 5.3 million ha, including from surface water, groundwater and rain water harvesting. Equipped irrigated area to date covers only 1958000 ha, including schemes of all scales (FAO, 2016).

Irrigation in Ethiopia plays a vital role to ensure food security and remains a high priority consideration in development strategy and prevention of food shortage. The availability of water confers opportunities to individuals and communities to boost food production, both in quantity and diversity, to satisfy their own needs and to generate income from surpluses. Improper irrigation management practices do not only waste scarce and precious water resources but also decrease marketable yield and economy (Dessalew *et al.*, 2016).

To achieve sustainable production from irrigated agriculture the utilization of the limited resources in irrigated agriculture, water and land shall be improved. The question- how is irrigated agriculture performing with limited water and land resources is not been satisfactorily answered. This is because that we are not able to compare irrigated land and

water use to learn how irrigation systems are performing relative to each other and what the appropriate targets achievement are (Molden et al., 1998).

With many variables that influence performance of irrigated agriculture, including infrastructure design, management, climatic conditions, socio-economic settings and the task of comparing performance of systems is difficult. However, if sources are on the communalities of irrigated agriculture water, land, and finance and crop production it should be possible to see, in gross sense, how irrigated agriculture is performing with various settings (Molden et al., 1998). The problem of food security is exacerbated by the rapid growth of population and hence of the demand for food. In fact, the prices of foodstuffs in the world market have recently begun to rise. Such a change could require expensive investments in modifying existing systems and establishing new ones (FAO, 1997).

The performance of existing schemes is also equally crucial. The government is currently undertaking several new irrigation developments, but the performance of existing community managed irrigation schemes are given less attention. As a result, many schemes fail to meet the objective they are established for. In many of these schemes, water management activities are performed by the farmers themselves, but they lack the technical expertise to effectively manage their water (Zeleeke, 2011). Assessing the current situation and introducing improved techniques to manage water resources efficiently are vital for improving irrigation efficiencies, sustainability and productivity of irrigated agriculture (McCornick et al., 2003).

In increased population growth and the erratic nature of rain fall, the computation of water users in the area increased from time to time, this limits the quality and quantity of agricultural productivity. There is a frequent opinion that the upstream water users of the irrigation system are gain more water than the downstream users, it might be due to failure of effective operation and management of the system. The delivery of the fair share of water to the users through the system is not clearly placed. It has been discovered that this situation could be artificially create to benefit few.

## **1.2. Statement of the Problem**

Irrigation schemes performance has now become a paramount importance not only to point out where the problem lies but also helps to identify alternatives that may be both effective and feasible in improving system performance (Mintesnot et al., 2004). Besides the poor performance of the irrigations in the country evaluation of small-scale irrigation systems is not common. This is particularly true in using the comparative performance indicators (Kloezen and Garces-Restrepo, 1998). The poor performance of irrigation system in the country is associated with little experience in irrigation is not only consequence of technical deficiencies in the design of the system, but also many of the problems stem from weaknesses in the organization and management of the system. The supplies and distribution of irrigation water is not adequate, equitable and reliable manner which is primary essential condition that will limit to achieve highest productivity (Aklilu, 2006). Seysa irrigation scheme has helped in improving the livelihood of the beneficiaries. Due to improper water use efficiency, equitable water distribution among the beneficiaries was not realized. Therefore, this study was aiming to assess the performance of the irrigation scheme for better management in order to help efficient functioning of Seysa irrigation scheme.

## **1.3. Objectives**

### **1.3.1. General Objective**

General objective of the study is to evaluate the performance of Seysa irrigation scheme.

### **1.3.2. Specific Objective**

The study has the following specific objectives

- To analyze the performance of the scheme in relation to water balance, conveyance and water utility indicators.
- To evaluate the maintenance requirement of the irrigation the scheme
- To evaluate the hydraulic performance of the Seysa irrigation scheme

#### **1.4. Research Questions**

- What is the level of the hydraulic performance of the Seysa irrigation scheme
- How is the irrigation water distributed within the irrigation system?
- What is the irrigation efficiency of the system?

#### **1.5. Significance of the Study**

Improved management of water resources is needed to ensure the equitable distribution of water for competing users. Accurate delivery of the necessary amounts of water at the correct times can both conserve water and improve the quantity and quality of agricultural products. Thus, the performances of the system described in this paper have a key role to play as we address the future system management in the study area. One possible approach to conserve the scarcity of water resource is through improving the performance of the existing irrigation scheme and improving its management and utilization level. As such development of performance indicators and accurate evaluation methodology is needed to help managers to improve their system. To be able to quantify any improvements in irrigation performance obtained either through better management or through the application of technology, it is important to measure efficiency. This study is therefore, important to measure and evaluate their success or failure objectively and identifies specific areas need for improvements, and to determine the variation in the planned and required objectives, too. It could potentially improve the irrigation efficiency of the system, understanding volumetric water control, water allocation, delivery and water charging necessity after finding. So that the purpose of this study was to forward a potential information and recommendation based on the final finding of the study, beside to give information for those who wants for further study and creating awareness to the community how the irrigation system could be sustained. It is of great interest to know how the community managed irrigation scheme are actually performing at this instance and determine whether the farmers are satisfied or not with the irrigation service, and this can be one of the measures to sustain the schemes operations.. Hence, this study provides for different stakeholders (system managers, farmers, and policy makers) with a better understanding of how the system will be operated and managed.

## **1.6. Scope of the Study**

The study focuses in Seysa irrigation scheme. The research is concerned evaluate the performance of the irrigation system using performance parameters such as application efficiency, storage efficiency, and distribution uniformity, and the output of irrigation management performance.

## **2. LITERATURE REVIEW**

### **2.1. Irrigation Development Overview**

Irrigation is the supply of water to agricultural crops by artificial means, designed to permit farming in arid regions and to offset the effect of drought in semiarid regions. Even in areas where total seasonal rainfall is adequate on average, it is poorly distributed during the year and variable from year to year. Where traditional rain-fed farming is a high-risk enterprise, irrigation can help to ensure stable agricultural production (FAO, 1997). According to (FAO,1998), small scale irrigation can be highly cost effective when simple locally adopted techniques are used and quick return can be expected as planning and design is implemented at local level with farmers directly contributing towards the construction. This also plays a vital role in poverty alleviation and improving the nutritional conditions of the rural poor who often do not receive the common benefits of economic growth.

Irrigation development helps to increase household income and reduces the incidence of poverty at the household level. It can benefit the poor through raising yields and production and nonfarm employment (Adugna et al., 2014). Well-managed irrigation development is key in helping Ethiopia to overcome major challenges including population pressure; soil and land degradation; high climate variability, and low agricultural productivity (Awulachew and Ayana, 2010).

### **2.2. Irrigation Scheme Performance Assessments**

#### **2.2.1. Performance Evaluation**

The evaluation of surface irrigation at field level is an important aspect of both management and design of the system. Field measurements are necessary to characterize the irrigation system in terms of its most important parameters, to identify problems in its function, and to develop alternative means for improving the system (FAO, 1998). The formal determination of a contribution of individual component related to outcome of a project within a particular setting or position to measure the achievements above or below the standard norms is said to be performance evaluation. Performance evaluation provides different stakeholders (system managers, farmers, and policy makers) with a better

understanding of how a system operates. It can help to determine problems and identify ways and means of improving system performance (Svendsen and Murray-Rust, 2001 and Cakmak et al., 2004).

Hence, reliable measures of system performance are very important for improving irrigation policy making and management decisions. However, experiences have shown that there are still considerable constraints and setbacks that hinder the introduction of small-scale irrigation. Irrigation performance have been assessed for a variety of reasons: to improve system operations; to assess progress against strategic goals; as an integral part of performance oriented management, to assess the general health of the system; to assess impacts of interventions; to diagnose constraints; to better understand determinants of performance of a system; 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).

### **2.2.2. Irrigation System Performance**

Bos, (1997) summarizes the performance indicators currently used in the research program on irrigation performance (RPIP). Within this program, field data was measured and collected to quantify and test about 40 multidisciplinary performance indicators. These indicators cover water delivery, water use efficiency, and maintenance, sustainability of irrigation, environmental aspects, socio economic and management. He also noted that it is not recommended to use all described indicators under all circumstances. The number of indicators should depend on the level of detail with which one needs to quantify (e.g., research, management, information to the public) performance and on the number of disciplines with which one needs to look at irrigation and drainage (water balance, economics, environment, management). Indicators have been used to measure performance. An indicator describes the level of actual achievements in respect to the objectives of irrigation. For each system, process, output, and impact measures are considered. Process measures refer to the process of internal to the system that lead to the ultimate output, whereas output measures describe the quality and quantity of the out puts where they become available to the next higher system (Molden et al., 1998).

As Msibi et al. (2014, as cited in Mudima, 2001 and Smith, 2010) irrigation system performance plays a significant role in crop performance, water use efficiency, and cost of production and income generation. The network of irrigation facilities may consist of the following four components: (1) water diversion; (2) water conveyance; (3) water use; and (4) drainage. For the complete system to work well, each must work conjunctively toward the common goal of promoting maximum on-farm production. Historically, the elements of an irrigation system have not functioned well as a system and the result has too often been very low irrigation project efficiencies (Dalton and Raine, 1999).

The scientific method to evaluate irrigation schemes have been focused on two aspects, firstly, the use of a comprehensive assessment framework and secondly the necessity of quantification of spatial and temporal comparisons within an irrigation system, which is multiple measurements (Small and Svendsen, 1990) or indicators (Bos et al, 2004).

Public agencies in many developing countries want to assist Community managed irrigation systems improve their performance through better management. And better management is dependent upon appropriate methods and measures by which system performance can be evaluated relative to the management objectives. Hence, reliable measures of system performance are extremely important for improving irrigation policy making and management decisions (Oad and Sampath, 1995).

Wide-ranging development of an irrigated agriculture production can be achieved by two ways, either new irrigation projects can be developed or existing schemes can be evaluated and their performance can be improved (Sener et al, 2007). Because, the performance of many irrigation systems is significantly under their potential due to a number of deficiency, such as poor design, construction, operation and maintenance. In recent year improving irrigation system performance is more preferable than developing new irrigation areas due to investment. Therefore improving the performance of existing scheme seems to be a sustainable and well pleased way. The poor performance of the small scale irrigation scheme existed in Ethiopia; however evaluation of irrigation systems is not common also resource management challenges to improve the performance of small scale irrigation systems (Yesuf, 2006).

### **2.2.3. Properties of Performance Indicators**

A true performance indicator includes both an actual value and an intended value that enables the assessment of the amount of deviation. It further should contain information that allows the manager to determine if the deviation is acceptable some of the desirable attributes of performance indicators suggested by (Bos, 1997) are:

Scientific basis: - the indicator should be based on the empirically quantified, statistically tested causal model of that part of the irrigation process it describes.

The indicators must be quantifiable: - the data needed to quantify the indicator must be available or obtainable (measurable) with available technology. The measurements must be reproducible.

Reference to target value: - this is of course obvious from a definition of performance indicator. It implies that relevance and appropriateness of the target values and tolerances be established for the indicator. These target values and their margin of deviation be related to the level of technology and management (Bos et al., 1991).

### **2.2.4. Features of Performance Indicators**

The application of performance indicators will provide system managers, researchers, and policy makers with information on differences in performance and, consequently, enable them to identify gaps in irrigation management policies.

Molden et al., (1998) stated generally comparative performance indicators are:

Reveal general notions about the relative health of the irrigation system, yet they are not too data intensive to discourage widespread and regular application. The indicators shall be based on relative comparison of absolute values, rather than referenced to standards or targets. The indicators relate to phenomena that are common to irrigation and irrigated agricultural systems.

Comparative performances indicators potentially have several purposes, it will allow for comparison between countries and regions between different infrastructure and management types, and between different environments, and for assessment over time of the trend in performance of the specific project, they will allow an initial screening of

systems that perform well in different environments and those that do not, they will allow for both assessing impact of intervention and managers to assess performance against strategic, long-term objectives, the set of indicators is small, yet reveals sufficient information about the output of the system. Data collection procedures are not too complicated or expensive. The indicators relate to outputs and are bulk measures of irrigation and irrigated agricultural systems, and thus provide limited information about internal processes.

### **2.2.5. Process Performance Indicators**

Process measures refer to the processes internal to the systems that lead to the ultimate output, where as output measures describe the quality and quantity of the outputs where they become available to the next higher system (Molden et al., 1998).

According to Molden et al., (1998) much of the work to date in irrigation performance assessment has 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. Kloezen and Garce-Restrep, (1998) reviewed and summarized different literatures. Process indicators help system managers to monitor the quality of daily and seasonal operational performance, but do not allow assessing the importance of irrigation in a given system, at different system levels, in a given season, and with a specific water source relative to other systems, levels, seasons, or irrigation sources. 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. Generally, process indicators have used to assess actual irrigation performance relative to system specific management goals and operational targets.

### **2.3. Performance Evaluation of Irrigation Systems**

In order to conserve water resources, close attention is required to the performance of irrigation systems. Irrigation systems should be evaluated on a regular basis to ensure that the systems are well maintained and are performing according to design. The irrigation system must also be managed correctly and effectively (Ascough and Kiker, 2004). Effective irrigation management requires reliable performance assessment. Good farm

irrigation management assures correct frequency of irrigations, correct application depth, uniform irrigation, minimum runoff, and minimum deep percolation except for that required for salt management, minimum erosion, and optimal return on irrigation investment (Renault, 1999). 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 (Kloezen and Garce, 1999).

According to Molden et al. (1998), performance is assessed for a variety of reasons: to improve system operations; to assess progress against strategic goals; as an integral part of performance-oriented management, to assess the general health of a system; to assess impacts of interventions; to diagnose constraints; to better understand determinants of performance; and to compare the performance of a system with others or with the same system over time. The type of performance measures chosen depends on the purpose of the performance assessment activity. A comprehensive performance evaluation can provide answers to the following questions (LeRoy et al., 1994):

- Is the system properly designed? In other words, are lengths, widths, and flow rates, properly designed?
- Pressures, slopes, and other design factors within acceptable ranges to permit good irrigation when the system is properly managed?
- Are the irrigations conducted at the right time and in the right amount? If not,
- What is the proper timing and amounts of typical irrigation applications
- Are the irrigations acceptably uniform? If not, how do we improve them?
- Are runoff losses acceptable? If not, how do we lower these losses?
- Is soil erosion a problem? If so, then how can the problem are eliminated?

Performance of any irrigation system is the degree to which it achieves the desired objectives. As many irrigation systems do not perform as much as they should, due to considerable constraints and setbacks, identifying the areas in which they fall short of potentials is essential (Gashaye, 2007).

### **2.3. 1. Technical Internal Performance Indicators**

Performance indicators can be broadly categorized into internal and external indicators to describe the above mentioned aspects. Internal indicators are used to assess the performance of the internal processes and irrigation services. They are concerned with operational procedures of the systems, institutional setups for management, irrigation infrastructure and water delivery services. External indicators on the other hand evaluate inputs and outputs to and from irrigation schemes. They are generally meant to evaluate the efficiency of resource use (land, water, finance) in irrigated agriculture. External indicators can be best used as part of a strategic performance assessment and benchmarking performance of schemes (Burt and Styles, 2004).

Internal indicators enable comprehensive understanding of the processes that influence water delivery service and the overall performance of a system (Renault and Wahaj, 2007). Hence, they are useful to show what would have to be done to improve the internal and hence the external performance. They relate the performance to internal management targets (equity, adequacy and reliability). Internal irrigation performance is linked to farmers' level of satisfaction by some authors (Ghosh et al., 2005 and Kuscu et al., 2008).

In order to enhance performances, it is necessary to have a comprehensive understanding of the internal processes within an irrigation scheme. Internal indicators examine the mechanisms of water control and allocation at all levels of the project and provide systematic rating of hardware, management and service throughout the entire system (Kuscu et al., 2009).

Example of internal performance indicators: Actual water delivery services to irrigation schemes are (Burt, 2002): volume measurement, flexibility and reliability etc. 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 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. These "internal" indicators aid

irrigation system managers to answer the question “Am I doing things right?” (Murry-Rust and Snellen, 1993).

Gorantiwar Smout (2005) discussed flexibility as the ability of the water delivery schedule of the allocation plan to recover from any changes caused in the schedule. It requires to reflection through planning of the irrigation water management. Flexibility is the proportionality indicator's which is named as hydraulic flexibility targets to characterize the relative variations of discharge in dependent and parental canal. It describes the degree of autonomy in accessing irrigation water (Renault, 2008). Horst (1983) stated a comprehensive approach of flexibility, in reviewing the propagation of hydraulic perturbations along a canal, and presented that perturbations would be spread equally for  $F$  equal to one, would be manipulated most strongly at the upper end when  $>$  one or at the lower end for  $F <$  one. Flexibility is defined as the water deliveries that can vary in frequency, rate, and duration (Merriam, 1991).

Bos (1997) summarizes the performance indicators currently used in the Research Program on Irrigation Performance. Within this program field data are measured and collected to quantify and test multidisciplinary performance indicators. These indicators cover water delivery, water use efficiency, maintenance and sustainability of irrigation, environmental aspects, socio- economic and management. For evaluating the hydraulic performance of the irrigation system, several performance indicators are evaluated according to the following three groups (Molden and Gates, 1990, Kloezen and Garces, 1998 and Boss, 1997): (A). conveyance of water supply(i.e. Delivery Duration ratio, efficiency and deficiency), (B) utility of water supply (i.e. Adequacy, Dependability, Equity, Delivery performance ratio and Equity ratio at head and tail) and (C) maintenance performance indicator of the system(i.e. Water surface elevation ratio, Efficiency of infrastructure, Sustainability of irrigable area, DDR and Overall reliability). Generally to quantify the extent of implemented and required objectives of the irrigation system, some of performance indicators which would be discussed in this study are: Delivery performance ratio, adequacy, deficiency, equity ,dependability, Equity ratio at head and tail with respect to MDR, Delivery duration ratio, flexibility, Efficiency, Efficiency of infrastructure water surface elevation ratio and sustainability of irrigated area.

### **2.3.2. Hydraulic Performance Indicators**

Hydraulic performance indicators are selection guide lines or criteria's to select appropriate structure and needs to review the states of established objectives of the scheme .It is stressed again that in this study the selection of structures is based purely upon the best hydraulic performance. In order to assess the performance of the irrigation water delivery, the hydraulic performance indicators such as adequacy, equity and dependability of water supply e.tc are used (Mishra, 2010).The hydraulic performance of a farm irrigation system is determined by the efficiency with which water is diverted, conveyed, and applied and by the adequacy and uniformity of the application in each field on the farm to evaluate the irrigation system. In order to judge the performance of the irrigation water delivery, the hydraulic performance indicators were used, three of the most commonly used criteria are efficiency, effectiveness, and uniformity. Singh (1998) discussed the need for improvement in hydraulic performance of conveyance system, equity, adequacy and efficiency of water supply suitable to crop production system.

### **2.4. Irrigation Water Use Efficiencies**

According to Michael, (1997) irrigation efficiency is the ratio between the volume used by plants throughout the evapotranspiration process and the volume that reaches the irrigation plots and indicates how efficiently the available water supply is being used, based on different methods of evaluation. The designs of the irrigation system, the degree of land preparation, and the skill and care of the irrigator are the principal factors influencing irrigation efficiency. Performance of a farm irrigation system is determined by the efficiency with which water is diverted, conveyed, and applied, and by the adequacy and uniformity of application in each field on the farm (James, 1988),. Mishra and Ahmed (1990) also said that irrigation efficiency indicates how efficiently the available water supply is being used, based on different methods of evaluation. The objective of these efficiency concepts is to show where improvements can be made, which will result in more efficient irrigation. Michael (1997) and Jurriens et al (2001) put as a remark that the primary performance indicators are: storage efficiency, application efficiency and distribution uniformity.

### **2.4.1. Application Efficiency**

Water application efficiency provides a general indication of how well an irrigation system performs its primary task of delivering water from the conveyance system to the crop. The objective is to apply the water and to store it in the crop root zone to meet the crop water requirement (Odhiambo and Kranz, 2011). It is defined as a measure of the fraction the total volume of water delivered to the farm or field to that which is stored in the root zone to meet the crop evapotranspiration needs. According to Roger et al. (1997) methods of determining application efficiency of a specific irrigation system is generally time consuming and often difficult because it may vary in time due to changing soil, crop and climatic condition. According to Roger et al. (1997) methods of determining application efficiency of a specific irrigation system is generally time consuming and often difficult because it may vary in time due to changing soil, crop and climatic condition.

Lesley (2002) explained and defined the situation of application efficiency with time and event specific and the equation could be used for a single irrigation event or more as a term reflecting seasonal performance. The difference in how it is used can be quite dramatic. For example, the first irrigation event using furrow irrigation can have a very low application efficiency if the length of run is long, furrows are freshly corrugated, stream size is wrong or for several other reasons. If irrigations are too close together, or the amount of water applied is too high, the application efficiency will be lower than it could be. This indicates low irrigation efficiency, showing that water is being wasted as deep percolation.

Application efficiency does not show if the crop has been under-irrigated. According to Roger et al. (1997) it is possible to have high application efficiency and 50-90% can be used for general system type comparison. FAO (1989) reported that the attainable application efficiency according to the US (SCS) ranges from 55%-70%. However, Lesley (2002) opined that it could be in the range of 50-80%. On a well-run scheme it could be as high as 80% (Adrian, 2007). FAO (1989) suggested that 60% attainable water application efficiencies for surface irrigation system. Also Norman (1999) said that a minimum value of the ratio of crop water demand to the actual amount of water supplied to the field of 0.6 or irrigation efficiency of 60% is included in the design of most surface

irrigation systems to accommodate crop water needs and anticipated losses. Value below this limit would normally be considered unacceptable.

#### **2.4.2. Distribution Uniformity**

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). Application efficiencies concerned with the distribution of water over the actual field. The same authors also suggest 'absolute distribution uniformity (DU) which is the minimum depth divided by the average depth. Thus, the evaluator can choose one that fits his / her perceptions but it should be clear as to which one is being used (FAO, 1989). Although different cases might produce the same results for application and storage efficiencies, their distribution patterns could differ. One indicator used to represent the pattern of the infiltrated depths along the field length is the distribution uniformity (DU), which is defined as the minimum infiltrated depth divided by the average infiltrated depth (Jurriens et al., 2001). Distribution uniformity describes how evenly irrigation is applied to the crop. Distribution uniformity concerns the distribution of water over the actual field. Based on the analysis of nearly 1000 properly designed irrigation system evaluations, SJVDIP (1999) puts a distribution uniformity of furrow irrigation to be 80-90%.

#### **2.4.3. Storage Efficiency**

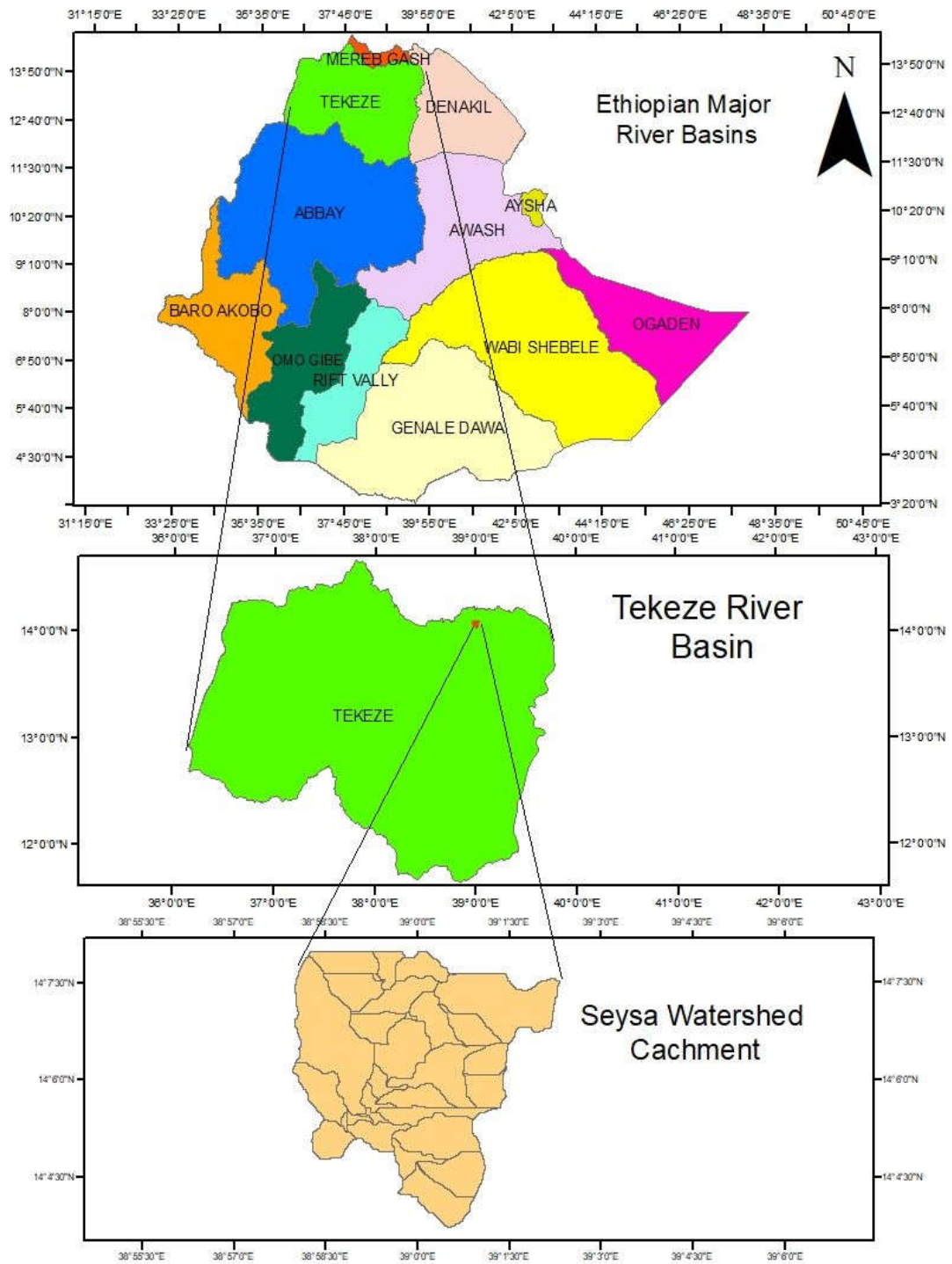
Water storage efficiency ( $E_s$ ) is an index used to measure irrigation adequacy. It is the ratio of quantity of water stored in the root zone during irrigation event to that required to the field (Garg, 1989). The requirement efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of  $E_s$  is important when either the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs and storage efficiency become important when water supplies are limited (FAO, 1989). Water storage efficiency has 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 homogeneous soil condition to be at least 87.5% (Raghuwanshi and Wallender, 1998).

### **3. MATERIALS AND METHODS**

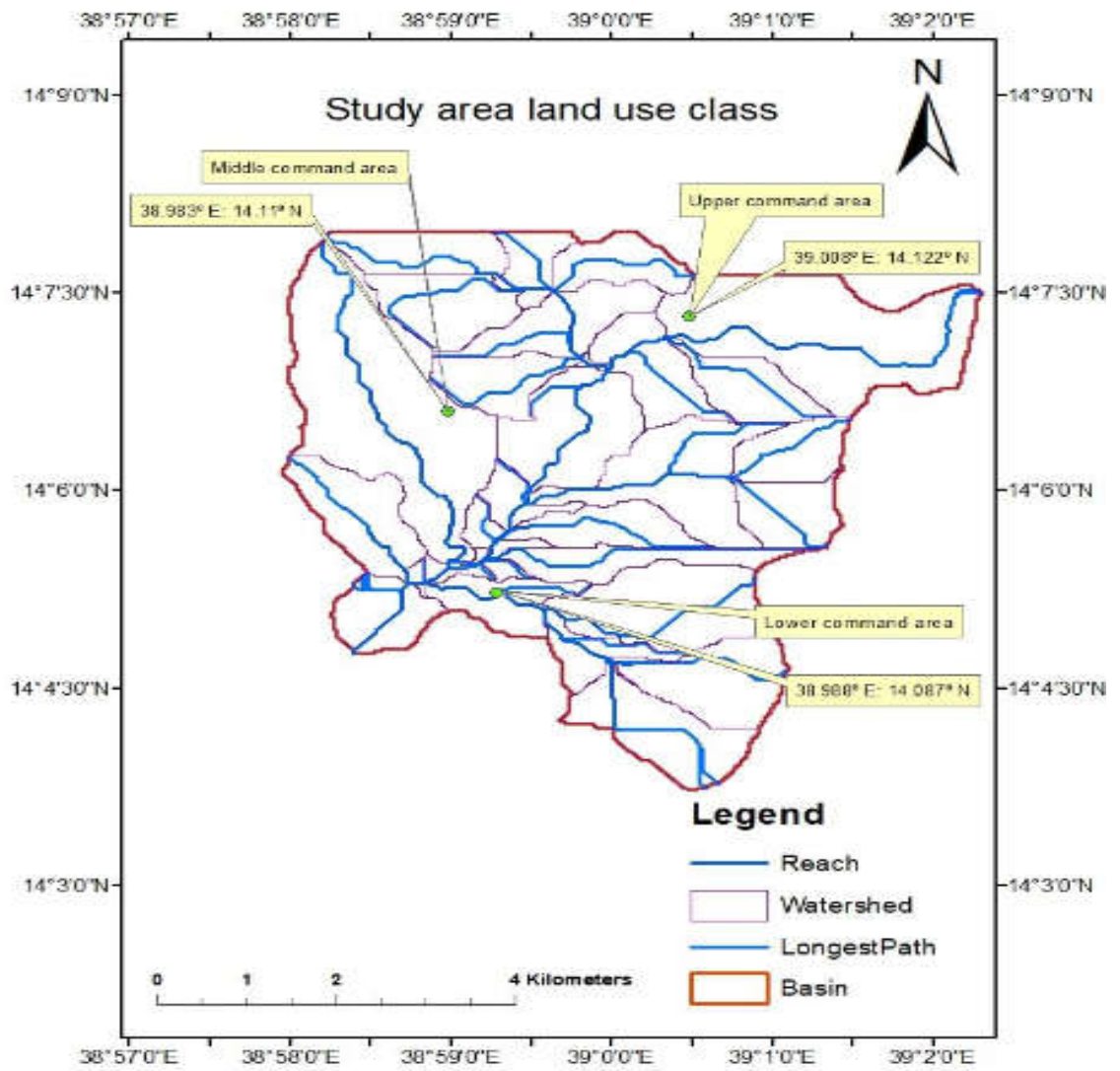
#### **3.1. Location and Climate**

##### **3.1.1. Location**

The study area is found in the central zone of Tigray Region, Adwa Wereda, Laelay logomti Kebele, and Debri Kushet. The study was conducted on Seysa irrigation scheme in order to evaluate irrigation Efficiencies. The Seysa project area lies between 14<sup>0</sup>4'30"N - 14<sup>0</sup>7'30"N latitude and 38<sup>0</sup>58'30"E - 39<sup>0</sup>2'00"E 21 km through the road Adwa to Abiy-adi. In addition, some 5km dry weathered road from Rahya town to river Seysa (Seysa dam design document, 2008). The catchment covers a total area of 66.43km<sup>2</sup>. The command area of irrigation scheme is highly suitable with rational water management and agronomic practices. The irrigation scheme has irrigable 400 ha command area (dam design document, 2008).



**Figure 3.1 location of study area 1**



**Figure 3.2 study area land use 1**

### 3.1.2. Climate

The minimum and maxima temperature ( $^{\circ}\text{C}$ ), relative humidity (%), wind speed (Km/day), sunshine hours (hour), radiation ( $\text{MJ}/\text{m}^2/\text{day}$ ),  $E_t$  (mm/day) rainfall (mm), effective rainfall (mm) are 7.2 , 30.9 , 47 , 131 , 9.2 , 22.1 , 4.43 , 770.7 , 559.5 respectively.

## **3.2. Methods**

### **3.2.1. Data Collection and Material Used**

In this study, primary and secondary data have been gathered and employed for the study. The measurement locations were selected through stratified sampling techniques; the major canal was selected to evaluate the water delivery performance levels at head, middle and tail areas of the main canals of irrigation system, since flow and WSE data were taken along the main canal. The flow measurements were made on the six off taking canals which are located at head; middle and tail reach of the system in the Laelay Logomti kebele. The flow measurement activities were done at crucial points along the selected main canal and taken on the different branch off taking canals. Double ring infiltro-Meter, floated method, tape meter, auger, cutthroat parshal flumes and GPS were used for field data collection and measurement purposes in the study.

#### **3.2.1.1. Primary Data Collection**

Primary data was collected through field measurements related to canal water flows.

#### **3.2.1.2. Secondary Data Collection**

Secondary data was collected from the design documents of regional water resource bureau. The Secondary data included total yields, farm gate prices of irrigated crops, area irrigated per crop per season, crop types, production cost per season and cropping pattern. The 15 years rain fall data, relative humidity, minimum and maximum temperature, wind speed and sunshine hours were collected from Mekelle meteorological station.

### **3.2.2. Data Analysis Methods**

The data collected to evaluate the technical performance of the scheme were analyzed descriptively. Based on the field measurements taken, the internal indicators of the irrigation system were analyzed. The study was carried out in Seysa irrigation scheme and the scheme was weighed by 10 performance indicators recommended by Molden et al (1998), Abernethy (1989), Molden and Gates (1990) Irrigation performance was determined according to the indicators of water application, water storage, uniformity coefficient, and distribution uniformity in some selected farmers irrigation field in the

scheme reaches. The process performance evaluation consists specifically measuring the extent to which the goals and required are being achieved. It is obvious that, the off-farm system should be capable of delivering water to farms with sound adequacy, efficiency, dependability, reliability, and equity (Bos et al, 2004). These parameters are commonly used for evaluating an irrigation system performance.

According to Abernethy (1989) the performance of a system can be defined as the measurement of the degree/level of fulfillment of the established objectives. Such a degree/level is expressed by one or several parameters chosen as evaluation criteria or as indicators of the considered objectives. It is relative to some objectives which should be defined in advance.

The performance of the irrigation system was numerically investigated based on the data collected on December to March, (2018) in one irrigation season in the first way, while the conveyance and utility of water supply indicators were analyzed by the observed data. The measurements of actual discharges in each branch/secondary off taking canal were taken for 9 monitoring days per three months. The study was focused on variability in discharges of water distribution along the main canal delivering to the branch canals and maintenance based parameters.

The parameters on the way of indicating the performance of the scheme were discussed in the following section under three different categories such as; conveyance, utility water supply and maintenance indicator for the aim of measuring the system performances. The performance of the system was classified as good, fair or poor (Molden and Gates, 1990). The important parameters to measure and evaluate the performance of existing irrigation system were desirable to characterize and put a figure on the extent of the established and required objectives of the scheme. The performance of irrigation system was evaluated under the three performance indicator categories presented as in literature review. Therefore, this study was focused on the parameters which includes application efficiency of infrastructures delivery performance ratio, adequacy, dependability, equity, equity ratio for head and tail, deficit, water surface elevation ratio and sustainability of irrigable area.

### 3.3. Determination of Crop Water and Irrigation Water Requirement

CROPWAT 8.0 computer program had used to estimate the total water requirements of major grown crops in the irrigation schemes. The model needs climatic, crop type and soil data for the determination of crop water requirement. In addition, to determine  $ET_o$  values the model required climatic data; average monthly minimum and maximum temperature ( $^{\circ}C$ ), relative humidity (%), wind speed (km/day) and sunshine hours (hr). The program estimates ( $ET_c$ ) based on equation, (FAO, 1989):

$$ET_c = ET_o * K_c \dots \dots \dots (3.1)$$

Where,  $ET_c$  is a crop evapotranspiration (mm/day),  $K_c$  = crop coefficients (dimensionless) and  $ET_o$  is a reference evapotranspiration (mm/day). The value of  $K_c$  for the initial, middle and end growth stages,  $K_{c-init}$ ,  $K_{c-mid}$  and  $K_{c-end}$ , respectively, for many crops taken from (FAO-56, 1998).

Irrigation requirements (IR) refer to the water that supplied through the irrigation system to ensure that the crop receives its full crop water requirements. If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water, (Harare, 2002).

The determination of irrigation requirement has made after estimation of effective rainfall. In order to compute the irrigation water requirement, CROPWAT 8.0 computes a daily water balance of the root zone. Computed as;

$$IWR = ET_c - Reff \dots \dots \dots (3.2)$$

And to estimate the total crop water requirement at scheme level input data of actual irrigated area by crop type was included.

#### Soil Sampling

To explore the moisture content of the soil at permanent wilting point (PWP) , field capacity (FC) and soil texture undisturbed soil samples were collected with auger from

the profiles pit excavated at three locations (upper, middle, and tail of the scheme) up to a depth of 60 cm. These multiple samples were transferred to the sample box and taken to the soil laboratory of Mekelle University for the intended analysis.

### **Texture**

Soil texture is the relative proportion of sand, silt, and clay measured, the soil may have assigned by using hydrometric method. Then the soil textural classes were determined using USDA soil textural triangle, (Bouyoucos, 1951). The procedures for determination of each soil were;

**Determination of Silt:** mix suspension in the hydrometer jar, using a special paddle carefully, withdraw the paddle, and immediately insert the hydrometer.

Disperse any froth, if needed, with one drop of amyl alcohol, and take hydrometer reading 40 seconds after withdrawing the paddle this reading gives silt clay soils.

**Determination of Clay:** mix suspension in the hydrometer jar with paddle; withdraw the paddle, leave the suspension undisturbed and after 4 hour, insert the hydrometer, and take hydrometer reading to determine the content of clay soil.

**Determination of Sand:** after taking readings required for clay and silt, pour suspension quantitatively through a 50- $\mu\text{m}$  sieve and wash sieve until water passing the sieve is clear.

Transfer the sand quantitatively from sieve to a 50 mL beaker of known weight, allow the sand in the beaker to settle, and decant excess water. Dry beaker with sand overnight at 105 °C and Cool in a desiccators then re-weigh beaker with sand.

Generally, the hydrometer method of silt and clay measurement relies in the effect of particle size on the differential settling velocities within a water column. By this method (using Hydrometer with Bouyoucos scale in gram/lit) after 40 second all sand-sized particles (0.05 mm and larger) settle out of the suspension and after 4 h, particles larger than clay (0.002 mm) settle out of the suspension. Theoretically, the particles had assumed spherical having a specific density of 2.65 gram/cm<sup>3</sup>.

**Field capacity, permanent wilting point and moisture content determination**

The most common method to determine the soil moisture content (FC and PWP) in the laboratory is the pressure plate apparatus applied at suction of 1/3 atmosphere for field capacity and 15 atmospheres for permanent wilting point. The soil moisture content measurements before and days of irrigation was made by gravimetric method which involves collecting soil samples with Auger, weighing the wet soil samples, removing the water by drying in an oven at 105 °C and re-weighing the sample to determine the amount of water removed. For the scheme three plots were prepared. Soil samples were taken before irrigation and after of irrigation from zero – 20, 20-40 cm and 40 – 60 cm depths per test pit. Soil moisture content in each sample was determined on weight basis using the equation, (Estefan et al., 2013).

$$E_w = \frac{W_{ws}-W_{ds}}{W_{ds}} * 100 \dots \dots \dots (3.3)$$

Where,  $E_w$  is the soil moisture content on weight basis (%)

$W_{ws}$  is the weight of the wet soil sample (gram),

$W_{ds}$  is the weight of the soil sample after oven drying (gram)

The total available water (TAW) is the difference between field capacity and permanent wilting point moisture content of the soil, (FAO, 1989):

$$TAW(mm) = 1000 * (FC - PWP) * Z_r \dots \dots \dots (3.4)$$

Where, TAW is total available water in the root zone (mm), FC is moisture content at field capacity (%), PWP is the moisture content at permanent wilting capacity (%) and  $Z_r$  is the root depth (m).

**Bulk density**

Soil bulk density (BD) is ratio of the mass (oven-dry weight) of the soil to the bulk volume expressed in grams per cubic cm (gram/cm<sup>3</sup>), which included the volume of both solids and pore space at a specified soil water content (usually the moisture content at sampling). The soil sample from auger dried at 105 °C for 24 hours and the bulk density had calculated using the following equation, (Estefan, et al., 2013).

$$\rho_b = \frac{M_s}{V_c} \dots\dots\dots (3.5)$$

Where,  $\rho_b$  = soil bulk density (g/cm<sup>3</sup>),  $M_s$  = weight of dry soil (g), and  $V_c$  = volume of core sampler (cm<sup>3</sup>)

**Infiltration rate**

The soil intake infiltration rate was measured directly by observing the rate at which the water level declined with respect to time. The soil infiltration rate was measured by using double ring infiltro-meter apparatus. Infiltration was a process of downward movement of water into the soil through soil surface. This phenomenon has a greater practical importance in irrigation. The volume of water passing through a unit cross sectional area per unit time flowing into the soil profile was termed as infiltration rate. Generally, the rate of decrease was rapid initially and the infiltration rate tends to approach a constant value at a certain value of time. The nearly constant infiltration rate that reaches after some lapsed time from start of irrigation is termed as the basic infiltration rate, (FAO, 1989).

**3.3.1. Water Flow Rate Measurement**

Measurement of water flow rate is a relevant data for irrigation scheme performance evaluation activities, computation of conveyance efficiency and losses. There are different methods to measure the flow of water in the rivers/canals. For this study, float method and Cut throat flume water flow rate measurement method was used. For float method, straight and regular reach of intake having a certain lengths based on the slope of canal was selected and then dropped the float material and recording the time from float starting to move down stream until it reach the marked length of canal. The flow rate measurement through float method from the main canal, 10 had taken to computed the lost and amount of diverted flow. The main canal and secondary canal of the irrigation scheme had constructed in lined.

The discharge amount would be equal to the product of the mean velocity ( $V_{mean}$ ) and the area of the cross-section (A). The wetted width of the main canal was equal from the intake to the beginning of secondary canal and the flow depth had measured at each division. The mean flow velocity was calculated by  $0.85 \times (\text{average velocity})$ . A coefficient

of 0.85 had commonly used to convert surface velocity to mean velocity in the vertical, (Shvanda, 2011). The discharge (Q), in each section of the canal could be determined by applying the area of the section by the mean flow velocity in that section. The total discharge would be the summation of individual discharges in the specified cross section.

$$Q = A * V_{\text{mean}} \dots \dots \dots (3.6)$$

Where, Q= flow rate (m<sup>3</sup>/sec), A= cross section area (m<sup>2</sup>), V<sub>mean</sub> = mean flow velocity (m/sec), to capture the amount of losses and to compute the conveyance efficiencies. The computation had carried out in similar procedure like secondary canal. Seysa irrigation, scheme flow rate had measured at two Secondary canals.

To determine the flow rate at farm inlets measurements had taken by Cutthroat Flumes from sampled farmers. Totally three farmer plots were selected purposively from farmers that has been selected for survey at each canal reaches (head, middle and tail) at Seysa irrigation scheme. The depth of flow in the flume was measured in meter/cm from its graduated wall and the discharge was calculated based on the equation suggested by du, Quebee (2007).

$$Q_f = CH^n \dots \dots \dots (3.7)$$

Where, Q<sub>f</sub> is discharge for free flow condition (m<sup>3</sup>/sec); C is free flow coefficient; n is exponents for free condition and H is water depth measured in the parshal flume (m). The value of C =0.1765 and n = 1.547 are depends on the width of parshal flume in this case three inch partial flume was used.

### 3.4. Farmers Field Efficiency Evaluation

Performance evaluation analysis was also conducted using efficiencies indicators. The evaluations were made for the following indicators; irrigation water use efficiency, agricultural productivity, financial and physical indicators were used in this study to assess and compare the performance of Seysa irrigation schemes.

**3.4.1. Estimation of Application Efficiency (Ea)**

Application efficiency is a comparison between the amount of water applied and the amount of water retained in the root zone. Losses from the field occur as deep percolation and runoff and reduce the application efficiency. To calculate the water stored in the root zone measurements were taken from three selected farmers’ field. Water applied to the field was measured by installing partial flumes at entrance of selected farmer’s field during irrigation time. The partial flume was putting at a straight section of flow, before proceeding to the measurement. To determine the amount of water applied to the field, water depth passing through the flume to the field and its respective time intervals was recorded with the size of the field irrigated. Since, it is free flow, only upstream measurement point was used. The discharge in field had calculated using equations (3.7). In addition, the depth of water applied to the field was computed from discharge, elapsed time and area irrigated. The time of cut-off was the time farmer’s decision that enough water was applied to their fields.

The depth of water stored in the root zone of selected field was determined from the soil moisture content before and after irrigation by gravimetric method. The depth of water applied to the field was estimated as (FAO, 1989):

$$Z_r = \sum_{i=0}^n \frac{\theta_{AI} - \theta_{BI}}{100} i * D_i \dots \dots \dots (3.8)$$

Where,  $Z_r$  = depth of water retained into root zone of the soil (mm),

$\theta_{AI}$  and  $\theta_{BI}$  are moisture content of the  $i$ th soil layers after and before irrigation on oven dry volume basis (%), respectively,  $D_i$  is thickness of  $i$ th soil layers of the root zone (mm).

$n$  = number of layers in the root zone

The application efficiency of each field had calculated as:

$$\text{Application Efficiency (Ea)} = \frac{\text{depth of water retained into root zone}}{\text{depth of water applied to the field}} \dots \dots \dots (3.9)$$

### 3.4.2. Estimation of Water Storage Efficiency

The depth of water stored in the root zone was estimated based on the soil water content before and three day after irrigated by taking the soil sample from the selected field (farmers). It was computed by using equation (3.10), and the water needed in the root zone prior to irrigation is estimated by the equation (3.12) given by (Abebe et al, 2013).

$$W_n = \sum_{i=0}^n \frac{\theta_{FC} - \theta_{BI}}{100} i * D_i \dots \dots \dots (3.10)$$

where,  $W_n$  = the depth of water needed in the root zone prior to irrigation (mm),  $\theta_{FC}$  and  $\theta_{BI}$  = soil moisture content at field capacity and moisture content of the soil before irrigation in volume percent, respectively in the  $i$ th soil layers and  $D_i$  = the depth of soil profile in root zone (mm). Storage efficiency was measured using equation (3.8) and (3.10).

$$E_r = \frac{Z_r}{W_n} \dots \dots \dots (3.11)$$

Where,  $E_r$  = Storage efficiency,  $Z_r$  = depth of water retained in to root zone and  $W_n$  = depth of water needed in the root zone prior to irrigation

### 3.4.3. Estimation of Distribution Uniformity (DU)

Distribution efficiency refers to the on-farm system used to store and distribute water to the fields. A common ratio used to calculate distribution efficiency was the volume of water applied to selected fields and the factor that considered evaporative and seepage losses from storage need to be qualified to measure distribution efficiency.

Distribution uniformity is the ratio of the average of the lowest one depth of measurements of irrigation water infiltrated to the average depth of irrigation water infiltrated. In addition, the soil moisture contents of the soils at the selected points were analyzed to determine the depth of water penetration. To determined the distribution uniformity of irrigation water in the field, soil moisture samples were taken from the selected farmer's field at three locations of the scheme, starting from the head to the end of the fields. At each selected points of the fields, soil samples have collected at depths of 0-20 cm, 20-40

and 40-60 cm and the moisture contents of the soil were computed to determine the depth of water penetration.

$$DU = \frac{\text{Minimum depth}}{\text{Average depth}} \dots \dots \dots (3.12)$$

### 3.5. Utility of Water Supply Indicators

**Delivery Performance Ratio (DPR):** it is an important performance indicator which is used to assess the reliability and equity of water distribution in the irrigation system regarded to the operational performance of the water distribution in the irrigation scheme. The parameter is related to the ratio of actual discharge based on water level measurement (QD) to the required discharge based on duty of irrigation water (QR) (Clemmens and Bos, 1990; Molden and Gates, 1990 and Bos et al., 1994) was computed as:

$$DPR = \frac{1}{T} \sum \frac{QD}{QR} \dots \dots \dots (3.13)$$

Where QD: Actual delivered discharges based on actual water level measurement, and QR; required discharges based on duty of irrigation water

**Dependability (PD):** It is defined as the temporal uniformity of the ratio of the delivered amount of water to the required or scheduled amount. An indicator of the degree of dependability of water delivery is the degree of temporal variability in the ratio of amount delivered to the amount required over a region. This performance measurement indicates the uniformity of QD/QR over time, a system which achieves almost steady state is considered to be dependable. The dependability parameter is defined as:

$$PD = \frac{1}{R} \sum_R CvT \frac{QD}{QR} \dots \dots \dots 3.14)$$

Where, CvT is temporal coefficient of variation (ratio of standard deviation to mean) of the ratio  $\frac{QD}{QR}$  over discrete location in a region R and in a time span T ( Bos et al., 1994).

**Adequacy (PA):** Adequacy is defined as the ability of irrigation to meet the required amount of water. It relates to the actual to delivery desired amounts of water needed for crop irrigation to delivery points in the system (Molden and Gates, 1990) which is described as:

$$PA = \frac{1}{T} \sum_T \left( \frac{1}{S} \sum_S \frac{QD}{QR} \right) \dots \dots \dots (3.15)$$

Where,  $PA = \frac{QD}{QR}$ , If  $QD \leq QR$ , otherwise  $PA=1$ , PA is the adequacy performance indicators, T is time and S is site where canals are located. QD is actual amount of water delivered by the system and QR is the amount of water required for crop consumptive use consumed.

**Equity (PE):** Equity, as related to water delivery system can be defined as the delivery of the fair shares of water to the users throughout the system.

$$PE = \frac{1}{T} \sum_T CvR \frac{QD}{QR} \dots \dots \dots (3.16)$$

Where  $CvR$  = special coefficient of variation of the ratio of delivery water to required water ( $\frac{QD}{QR}$ ) over the region R.

**Equity Ratio for Head and Tail:** This parameter focus on the equity for head and tail at different levels of a system, it can either conveyance or utility water supply indicators.

$$ERHT = \frac{\frac{1}{n} \sum_{t=1}^{t=n} MDR(\text{head})}{\frac{1}{n} \sum_{t=1}^{t=n} MDR(\text{tail})} \dots \dots \dots (3.17)$$

Where t is the time period, n is the number of periods monitored while, MDR are:

**Management Delivery Ratio (MDR):** is also conveys similar information to Delivery Performance Ratio, according to Baily and lento (1984) and Ros (1993), the ratio is described as:

$$MDR = \frac{QD}{QR} \dots \dots \dots (3.18)$$

### 3.6. Conveyance Indicators

**Deficiency:** The degree of deficiency (PDF) is another parameter that the farmer is more concerned, so that he/she can take safety measures to meet it. Knowledge of the amount of deficiency is quantitative measure of the dissatisfactions of the users. Estimation of deficiency is given as the ratio of water deficiency to the required amount .A measure of





## 4. RESULT AND DISCUSION

### 4.1. Performance Indicator Evaluation

The actual irrigated area covers 350 ha and only 50 ha were out of production. Soil samples were taken at depth of 0-20, 20-40 and 40-60 cm to examine the physical properties of soil in the site such as moisture content at field capacity (FC) and permanent wilting point (PWP), moisture content before and after irrigation and texture.

**Table 4.1. Average required and delivered discharge (m<sup>3</sup>/sec) in the branch canals (Head, Middle and Tail reach)**

| Mo<br>nth | Head  |       |       |       | Middle |       |       |       | Tail  |       |       |       |
|-----------|-------|-------|-------|-------|--------|-------|-------|-------|-------|-------|-------|-------|
|           | BRC1  |       | BRC2  |       | BRC3   |       | BRC4  |       | BRC5  |       | BRC6  |       |
|           | QD    | QR    | QD    | QR    | QD     | QR    | QD    | QR    | QD    | QR    | QD    | QR    |
| Jan       | 0.034 | 0.034 | 0.084 | 0.083 | 0.055  | 0.060 | 0.062 | 0.072 | 0.046 | 0.053 | 0.049 | 0.058 |
| Feb       | 0.031 | 0.032 | 0.081 | 0.084 | 0.050  | 0.058 | 0.058 | 0.069 | 0.041 | 0.052 | 0.047 | 0.056 |
| Mar       | 0.033 | 0.034 | 0.081 | 0.086 | 0.062  | 0.062 | 0.073 | 0.675 | 0.037 | 0.053 | 0.04  | 0.056 |

#### 4.1.1. Particle size distribution (texture)

Based on laboratory analysis of particle size distribution, the textural classes of Seysa irrigation schemes was determined. As indicated in table 4.2 the soil texture distribution was Sandy Loam at head, Silt Loam at middle, Silty Clay Loam at tail reach of the scheme;

**Table 4.2. Soil physical characteristics of Seysa irrigation scheme**

|        | S/code | Soil depth(cm) | % sand | % silt | %clay | Textural classclass |
|--------|--------|----------------|--------|--------|-------|---------------------|
| Head   | U 20   | 0-20           | 65.00  | 22.00  | 13.00 | Sandy loam          |
|        | U 40   | 20-40          | 65.00  | 25.00  | 10.00 | Sandy loam          |
|        | U 60   | 40-60          | 64.00  | 25.00  | 11.00 | Sandy loam          |
| Middle | M 20   | 0-20           | 21.00  | 65.00  | 14.00 | Silt Loam           |
|        | M 40   | 20-40          | 22.00  | 65.00  | 13.00 | Silt Loam           |
|        | M 60   | 40-60          | 22.00  | 63.00  | 15.00 | Silt Loam           |
| Tail   | L 20   | 0-20           | 17.00  | 43.00  | 36.00 | Silt clay loam'     |
|        | L 40   | 20-40          | 17.00  | 45.00  | 38.00 | Silt clay loam'     |
|        | L 60   | 40-60          | 18.00  | 43.00  | 39.00 | Silt clay loam'     |

#### 4.1.2. Soil field capacity and permanent wilting point

The values of field capacity (FC), permanent wilting point (PWP) and total available water content (TAW) are indicated in table 4.3.

**Table 4.3. Soil FC, PWP, TAW of Seysa irrigation scheme**

|        | S/code | Soil depth(cm) | T/class         | FC (%) | PWP (%) | TAW (%) |
|--------|--------|----------------|-----------------|--------|---------|---------|
| Head   | U 20   | 0-20           | Sandy loam      | 21.5   | 9.8     | 11.7    |
|        | U 40   | 20-40          | Sandy loam      | 23.5   | 8.1     | 15.4    |
|        | U 60   | 40-60          | Sandy loam      | 19.6   | 8.7     | 10.9    |
| Middle | M 20   | 0-20           | Silt Loam       | 22     | 10.5    | 11.5    |
|        | M 40   | 20-40          | Silt Loam       | 19.4   | 9.9     | 9.5     |
|        | M 60   | 40-60          | Silt Loam       | 25.3   | 11      | 14.3    |
| Tail   | L 20   | 0-20           | Silt clay loam' | 22.7   | 22.1    | 0.6     |
|        | L 40   | 20-40          | Silt clay loam' | 23.2   | 20.3    | 2.9     |
|        | L 60   | 40-60          | Silt clay loam' | 24.5   | 23.8    | 0.7     |

#### 4.1.3. Soil infiltration rate

The infiltration rate was measured based on the textural distribution of the soil using double ring infiltrometer. The texture class of Seysa irrigation scheme is sandy loam at the head; Silt loam at the middle field and silt clay loam at the tail reach and the constant infiltration rates of 1.8 cm/hr, 0.7 cm/hr and 0.8 cm/hr. Based on the infiltration rate value in Appendix table 7.11 the infiltration rate was within recommended ranges.

#### 4.1.4. Application Efficiency

Irrigation frequency depends on the farmer's traditional knowledge. They observe the soil and crop leaves status to decide when to irrigate. As shown in Table 4.2 water depth applied to the field was highest at the head and lowest at the tail end of the scheme during all the growth stages. The measured amount of water applied to each field is shown in

Table 4.4. The result shows a decreasing trend from head to tail end users. Tail end farmer seems to have applied the smallest amount of water to his field. This may be the reason why the farmer around the tail end has scarcity of water due to different loses as compared with the head and middle reach of the scheme. As shown in Table 4.4 water depth applied to the Seysa field was highest at the head and lowest at the tail end of the scheme during the study period.

**Table 4.4. Average depth of water applied to farmer’s field**

| Field location | Time (sec) | Flume height (m) | Respective discharge (m <sup>3</sup> /sec) | Area (m <sup>2</sup> ) | Total Volume (M <sup>3</sup> ) | Applied depth (mm) |
|----------------|------------|------------------|--|------------------------|--------------------------------|--------------------|
| Head           | 4200       | 0.13             | 0.008                                      | 400                    | 31.57                          | 78.92              |
| Middle         | 6800       | 0.18             | 0.012                                      | 1250                   | 84.56                          | 67.65              |
| Tail           | 3550       | 0.14             | 0.008                                      | 520                    | 29.92                          | 57.55              |
| Average        |            |                  |  |                        |                                | 68.04              |

The result of application efficiency (Table 4.5) was 72.29%, 62.15 % and 61.87 % for head, middle and tail end farmer’s respectively. FAO (1989), reported that the attainable application efficiency ranges from 55% - 70%, value below this limit would normally be considered unacceptable and Similar research results conducted by Lesley (2002) showed that the application efficiency could be in the range of 50% - 80%, however Roger, et al. (1997) stated that application efficiency varies widely but it is possible to have high application efficiency. As shown in (Table 4.5) at Seysa Irrigation Scheme, the water application efficiency of the farmers varied from 72.29 % at the head, 62.15 % at middle stream to 61.87 % at the tail reach. The average application efficiency was within acceptable range. The result showed that the upstream farmers were more efficient in applying water than middle stream and downstream ends. The probable reason for the low application efficiency values may be attributed due to low level of water management at field level.

**Table 4.5. Application efficiency**

| Farm    | Total depth moisture Stored(mm) | Applied depth (mm) | Ea (%) |
|---------|---------------------------------|--------------------|--------|
| Head    | 57.05                           | 78.92              | 72.29  |
| Middle  | 42.04                           | 67.65              | 62.15  |
| Tail    | 35.61                           | 57.55              | 61.87  |
| Average |                                 |                    | 65.44  |

**4.1.5. Distribution Uniformity**

As shown in Table 4.6 below, the water spreading uniformity of the head, middle and tail end user fields are 67.97%, 61.44 % and 48.9 % respectively with an average value of 59.42 %. It is not sufficient based on FAO (1992) recommendation. The distribution uniformities of middle and tail farms are by far lesser than the value categorized as sufficient (i.e. 65%) by FAO (1992). From this it can be concluded that much portion of the irrigation fields received and stored not equal amount of water in their root zone depth. This was due to improper arrangement of furrow length, layout and illegal water users. This indicates that the higher the value of DU, the better the uniformity of application and the higher the distribution efficiency. Eisenhauer, D.E. (1997) studied distribution efficiency;  $\eta_d (\leq 60\%)$  indicates that the irrigation water is unevenly distributed, while  $\eta_d (\geq 60\%)$  indicates that the application is relatively uniform over the entire field. Therefore, according to this study the results of distribution efficiency obtained in Seysa irrigation scheme indicates the application is non uniform in the entire field.

**Table 4.6. Distribution Uniformity**

| Farm position | XLq    | Xav    | DU (%) |
|---------------|--------|--------|--------|
| Head          | 175.32 | 258.10 | 67.97  |
| Middle        | 119.58 | 194.63 | 61.44  |
| Tail          | 96.85  | 198.03 | 48.90  |
| Average       |        |        | 59.42  |

#### 4.1.6. Storage Efficiency

The storage efficiency ( $E_s$ ) was obtained using equation 3.11. As shown in (Table 4.7) storage efficiency of the Seysa irrigation scheme of selected fields varies between 89.43 % and 58.20 % with mean value of 73.87 %. According to Raghuwanshi and Wallender (1998), the recommended storage efficiency is 87.5%. Thus, the storage efficiency of the system is below the recommended value. It can be concluded that the irrigation system was not adequate in fulfilling the soil moisture. This was due to low frequency of water applied to the field.

**Table 4.7. Irrigation storage efficiency**

|         | Total depth moisture<br>Stored $D_s$ , (mm) | water needed $W$<br>$d$ (mm) | Storage efficiency ( $E_r$ )% |
|---------|---|------------------------------|-------------------------------|
| Head    | 58.2  | 63.80                        | 89.43                         |
| Middle  | 42  | 56.83                        | 73.98                         |
| Tail    | 35.61                                       | 61.17                        | 58.20                         |
| Average |   |                              | 73.87                         |

The storage efficiencies of the scheme can be regarded as low, less than recommended value in all evaluation periods decreasing from head to tail end irrigation user's field. They apply much lower depth than the water requirement. FAO (1992) recommends storage efficiency to be as high as 90%.

#### 4.1.7. Utility of Water Supply Indicators

##### **Delivery Performance Ratio (DPR)**

Molden et al. (2007) discussed the characteristics of DPR, classifying it as the most important hydraulic and operational performance indicator. It enables a manager to determine the extent of the water actually delivered against the required discharge. The primary utility of DPR in the operation of an irrigation system is that it allows for instantaneous checking of whether discharges are more or less than required discharges.

According to Belebaye et al., (2008) delivery performance ratio (PR) is defined as the ratio of the total water delivered (QD) to irrigation water requirement (QR). Average DPR for the head, middle and tail reach of the distribution system is shown in table 4.8 and the value has been calculated using equation (3.14). The monthly plot of DPR would provide an insight into the proportional water delivery to the different components of the system. As a result, the delivery performance ratio of a system temporary varies from 0.70 to 0.91 with an average value of 0.83 in head; middle and tail reach off takes. As per Molden and Gates (1990) performance range classification in Appendix table 7.9, the performance of irrigation system is fair with regard to the temporal DPR indicators. The minimum and maximum average DPR was observed in March and January respectively. The DPR of Seysa irrigation system is fair.

**Table 4.8. Average spatial and temporal DPR of seysa irrigation scheme**

|              | Head |      | Middle |      | Tail |      |             |
|--------------|------|------|--------|------|------|------|-------------|
| Month        | BR1  | BR2  | BR3    | BR4  | BR5  | BR6  | Spatial.DPR |
| Jan          | 1.00 | 1.00 | 0.92   | 0.86 | 0.86 | 0.84 | 0.91        |
| Feb          | 0.97 | 0.96 | 0.86   | 0.84 | 0.79 | 0.84 | 0.88        |
| Mar          | 0.97 | 0.94 | 0.76   | 0.08 | 0.69 | 0.76 | 0.70        |
| Temp.DPR     | 0.98 | 0.97 | 0.85   | 0.59 | 0.78 | 0.81 |             |
| Average (PA) | 0.97 |      | 0.72   |      | 0.80 |      | 0.83        |

### **Adequacy**

To access adequate supply of water meeting the requirements of water for different crops in a season is a basic requirement of the farming system, by monitoring the adequacy of the water supplies in the system (Clemmens and Bos, 1990, Molden and Gates, 1990, Bos et al., 2004), the statutes and management of the delivery system can be oversee. Adequacy is important parameters, which displays the extent to which total water deliveries are sufficient to fulfill the needs of the crops in a specific growing season and command area. Since the adequacy value can be calculated with equation (3.15), the spatial and temporal mean values of PA in head, middle and tail reaches of the system are shown in Table 4.9. Average spatial and temporal values of the indicator are exhibited in

with an average value of 0.91, 0.88 and 0.70 in January, February and March and 0.97, 0.72 and 0.80 at head middle and tail reaches of the system respectively. However, the overall adequacy value of the system is 0.83. Due to the fact that, the PA performance criteria suggested by Molden and Gates (1990) value below 0.8 poor, between 0.8 to 0.9 fair and more than 0.9 is assumed to be good, since the spatial and temporal average adequacy of the scheme is fair except the head reach of the distribution system, which is stated in the good range. Similar result has been found by (Efriem et al, 2017).

**Table 4.9. Average adequacy of water distribution system**

| Month       | Head |      | Middle |      | Tail |      | Spatial.Average |
|-------------|------|------|--------|------|------|------|-----------------|
|             | BR1  | BR2  | BR3    | BR4  | BR5  | BR6  |                 |
| Jan         | 1.00 | 1.00 | 0.92   | 0.86 | 0.86 | 0.84 | 0.91            |
| Feb         | 0.97 | 0.96 | 0.86   | 0.84 | 0.79 | 0.84 | 0.88            |
| Mar         | 0.97 | 0.94 | 0.76   | 0.08 | 0.69 | 0.76 | 0.70            |
| Temp.Aver   | 0.98 | 0.97 | 0.85   | 0.59 | 0.78 | 0.81 | 0.83            |
| Average(PA) | 0.97 |      | 0.72   |      | 0.80 |      | 0.83            |

### **Dependability**

Dependability of water supply is defined as the temporal uniformity of the ratio of the delivered amount of water to the required amount. The measurement indicates the degree of temporal variability in the ratio of amount delivered to the required over a region. The indicator enables us to answer the question outlined on: does the timing of the water deliveries match the growth needs of the crops and the expectations of the users? The parameter was computed as the coefficient of variation of the adequacy values for individual locations of the system reaches over different time periods using equation (3.14) (Molden and Gates, 1990). The average dependability values of head, middle and tail reaches of a system are shown in table 4.10 which is ranging from 0.02 to 0.71 with an overall average dependability of 0.18. Molden and Gate (1990) and Mohsen et al. (2012) suggested the performance standards of dependability of water distribution in irrigation service on Appendix table 7.9. The dependability of water distribution at middle reach is

poor ( $>0.2$ ), while good in head and tail reach of the distribution system. Since, the performance of the entire system (Table 4.10) in terms of dependability of water distribution is found to be fair range.

**Table 4.10. Dependability of water supplied and equity of water distribution on the system**

| Month   | Head |      | Middle |      | Tail |      | aver | Std  | CV,PE |
|---------|------|------|--------|------|------|------|------|------|-------|
|         | BR1  | BR2  | BR3    | BR4  | BR5  | BR6  |      |      |       |
| Jan     | 1.00 | 1.00 | 0.92   | 0.86 | 0.86 | 0.84 | 0.91 | 0.07 | 0.08  |
| Feb     | 0.97 | 0.96 | 0.86   | 0.84 | 0.79 | 0.84 | 0.88 | 0.07 | 0.08  |
| Mar     | 0.97 | 0.94 | 1.00   | 0.11 | 0.69 | 0.76 | 0.75 | 0.34 | 0.45  |
| Average | 0.98 | 0.97 | 0.93   | 0.60 | 0.78 | 0.81 |      |      | 0.21  |
| Std     | 0.02 | 0.03 | 0.07   | 0.43 | 0.09 | 0.04 |      |      |       |
| CV,(PD) | 0.02 | 0.03 | 0.07   | 0.71 | 0.11 | 0.05 | 0.18 |      |       |

### Equity

The delivery of the fair shares of water to the users throughout the system is said to be equity. Equitable water distribution is attained when the ratio of water delivery to outlets equal to one over the system (Molden and Gates, 1990). In community managed irrigation scheme, the openings of the distribution outlets are dependent on the system managers and users perception of their crop needs with reference to the irrigation scheduling, however the beneficiary receives water at varied time outside the time prescribed in the intended agreement of the scheme. The equity of water distribution was calculated as the coefficient of variation of the adequacy values between different locations using equation (3.16). The values are given in Table 4.10. The equity of water distribution in January, February is fair and in March is perceived below the standard (Table 4.10), which is side to be poor. The average overall equity value of the delivery system is found to be 0.21 (Table 4.10). The result shows that equity of water distribution during the monitoring period is fair over the entire system. Some of the factors which cause for uneven distribution of water along the main canal were sedimentation, inadequate unlawful water abstraction. Also the beneficiaries reflected that, the right time of equitable water delivery were not applied due

to a number of reasons including limited water availability because of other schemes provided in the upstream of the scheme, poor management of the scheme governors.

### **Equity Ratio for Head and Tail (ERHT)**

Equity ratio for head and tail describes an equity concept in terms of the spatial variations of MDR; it provides the equity of water delivery among the distributaries with special focused on head and tail reaches. It needs to estimate how well water was managed and delivered fairly in head and tail reach of the main canal. The ERHT was calculated via equation (3.17). Table 4.11 displayed equity ratio for head and tail and the value of MDR. The value of ERHT ranging in 1.18 to 1.31, yet the overall average value of ERHT is found to be 1.23. As the range of performance indicator of irrigation system described in Appendix table 7.9 suggested by Molden and Gates (1990), the value ranging in between 1.21-1.3 can be fair. Thus, the analytical results of ERHT in temporal scale are fair (Table 4.11). Likewise, all the value of the ratio in the table are greater than one, it indicates that the MDR of the head reach of the system is higher than the tail reach. Generally the performance of the branch canal is not in a reasonable level with respect to ERHT (MDR), the head delivery systems receive more water than the tail in all months.

**Table 4.11. Equity ratio for Head and Tail (ERHT(MDR)) reach of the system**

|         | Head  |       | Tail  |       |           |
|---------|-------|-------|-------|-------|-----------|
|         | BR1   | BR2   | BR5   | BR6   |           |
| Month   | MDR   | MDR   |       | MDR   | ERHT(MDR) |
| Dec     | 1.010 | 1.012 | 0.862 | 0.839 | 1.18      |
| Jan     | 0.969 | 0.960 | 0.788 | 0.839 | 1.19      |
| Feb     | 0.971 | 0.942 | 0.692 | 0.765 | 1.31      |
| Average |       |       |       |       | 1.23      |

#### 4.1.8. Conveyance Indicators

##### Deficiency of Water

If water does not arrive at the farm delivery system timely and adequate amount, crop yields may suffer and farm net returns. Delivery of less water than adequate supply of water to the delivery points within the system results in shortage. The parameter will help to the system managers and users to take safety measurements for system improvements in the deficit area. The measure of spatial and temporal average value of deficit is stated in Table 4.12. The average temporal deficit in head reach are relatively less, yet shortage of water is not emerged in the first branch canal, BR1 (Table 4.12), while the deficit of the middle reach of the delivery system had been highest. The average spatial deficit in the conveyance system has been faced in all months, the spatial deficit is advanced in March, largely in branch canal four (BR4). As a result high spatial deficit is happened in March. However, the average overall deficiency of the entire system is found to be 0.17 (17 percent). The conveyance system supplied less water than the required in generally, hence the performance of the system is fair with respect to deficit indicators.

**Table 4.12. Average Spatial and Temporal Deficiency**

| Month     | Head |      | Middle |      | Tail |      | Spatial.Average |
|-----------|------|------|--------|------|------|------|-----------------|
|           | BR1  | BR2  | BR3    | BR4  | BR5  | BR6  |                 |
| Jan       | 0.00 | 0.00 | 0.08   | 0.14 | 0.14 | 0.16 | 0.09            |
| Feb       | 0.03 | 0.04 | 0.14   | 0.16 | 0.21 | 0.16 | 0.12            |
| Mar       | 0.03 | 0.06 | 0.24   | 0.89 | 0.31 | 0.24 | 0.30            |
| Temp.Aver | 0.02 | 0.03 | 0.15   | 0.40 | 0.22 | 0.19 | 0.17            |
|           | 0.03 |      | 0.23   |      | 0.20 |      | 0.17            |

##### Efficiency (PF)

Efficient irrigation practice is a very relevant topic at present, and there is much effort going on improving the performance of irrigation system, which is an important agronomic indicator for areas with limited water resources (Howell, 2001). Improved management of irrigation water can provide multiple benefits conserving scarce water

supplies, reducing the impacts of irrigation on water quality, detaining conflict due to water scarcity, and enhancing producer returns. The parameter shows how the water resource would be conserved (Mohsen et al., 2012) and knowing how the system was conveyed a required amount. The Spatial and temporal average values of PF are given in Table 4.13, which was calculated by using equation (3.20). The special average efficiency is higher in both February and January the delivery system spatially perceived in a good range in all months. The delivery of water in the middle and tail reaches of the system have observed higher efficiency over the observation period, while the efficiency of water supplied in the head reach is poor, this problem is transpired due to uncontrolled delivery of water in the first branch canal (Table 4.13 ). The overall efficiency (PF) of a system is estimated to be 0.78, as Molden and Gates (1990) suggested the range of performance evaluation criteria of efficiency in Appendix table 7.9, the performance of the system is fair with respect to efficiency.

**Table 4.13. Average spatial and temporal efficiency**

|           | Head |      | Middle |      | Tail |      |                 |
|-----------|------|------|--------|------|------|------|-----------------|
| Month     | BR1  | BR2  | BR3    | BR4  | BR5  | BR6  | Spatial.Average |
| Jan       | 0.63 | 0.84 | 0.90   | 0.86 | 0.73 | 0.82 | 0.79            |
| Feb       | 0.69 | 0.80 | 0.85   | 0.81 | 0.77 | 0.86 | 0.80            |
| Mar       | 0.81 | 0.76 | 0.75   | 0.76 | 0.64 | 0.82 | 0.76            |
| Temp.Aver | 0.71 | 0.80 | 0.83   | 0.81 | 0.71 | 0.83 | 0.78            |
|           | 0.75 |      | 0.82   |      | 0.77 |      | 0.78            |

#### 4.1.9. Maintenance Performance of the System

Maintenance performance inspection of irrigation scheme would provide to insight the feature of maintenance situations. Inspecting the maintenance statuses of the Seysa irrigation system requires identifying the rooting problems of a system; correspondingly the study helps to reflect the management performance of the scheme user associations covering maintenance services and contribution of beneficiaries in project administration. Bos et al. (1993) have pinpointed that the maintenance innovation of a system have a duty undertaking for the purposes of safety improvement, keeping water control, distribution and other infrastructures in good working condition designed for sustainable base .Hence,

to convey such activities for system improvement, maintenance requirement in this study was observed according to the maintenance indicators of water surface elevation ratio, effectiveness of infrastructure, delivery duration ratio and sustainability of irrigable area. The canal section and other structures in its working condition were categorized as operative, nearly operative, nearly inoperative and inoperative, if at least one of the following conditions are present: change of canal cross-section, scouring of canal section, broken of structure, missing of flow control and distribution work, damaging of the structure sedimentation and weed growth (Samad and Vermillion, 1998 and Vermillion et al., 1999). Based on information obtained from the scheme operation and maintenance manual, the whole responsibility of scheme maintenance (like clearing and repairing of canals and drains, repairing structures, silt and grass removal, and canal reshaping, clearing and lubricating gates etc) is given to the beneficiaries. Irrigation office helps by coordinating farmers and identifying problems.

**Water surface elevation ratio (WSER):** The parameter of WSER was concerned on the main canal sections; the result would help to predict the impact of sedimentation, wild plant and erosion problem on the physical irrigation system. The inspection would also prove to recommend the management capacity of beneficiaries in the prevailing situation. It was computed by taking the actual water depth from the canal bottom on different measurement points in each individual inspection locations and comparing it with the design water depth at the same position in the main canal (equation 3.22). The result of WSER was derived from the average value of the ratio in the prescribed monitoring locations on head; middle and tail reach of the main canal, and represents the average value of the water surface elevation below the FSD of the canal. Therefore, the parameter was estimated based on the result taken from 9 inspection stations along the main canal.

As per the design document the intended water depth of the main canal from the canal bottom 0.67m and at FSD discharge capacity 1.08 m<sup>3</sup>/s whereas the average actual water surface elevation at FSD is found to be 0.53 m. The parameter of average WSER at head, middle and tail reaches of the main canal during the monitoring period is generally less than one, thus the main canal is infested by weed and sedimentation problem (Table 4.14).

**Table 4.14. Average Water Surface Elevation (WSE) status of the main canal**

| Location<br>Cnge<br>(m) | Head     |          |          | Middle       |      |          |          | Tail        |          |          |          |
|-------------------------|----------|----------|----------|--------------|------|----------|----------|-------------|----------|----------|----------|
|                         | WS<br>EI | WS<br>Ea | WS<br>ER | Cnge<br>e(m) | WSEI | WS<br>Ea | WS<br>ER | Cnge(<br>m) | WS<br>EI | WS<br>Ea | WS<br>ER |
| 23                      | 0.67     | 0.52     | 0.78     | 50           | 0.67 | 0.49     | 0.73     | 45.00       | 0.51     | 0.46     | 0.90     |
| 30                      | 0.67     | 0.53     | 0.79     | 70           | 0.67 | 0.48     | 0.72     | 60.00       | 0.51     | 0.43     | 0.84     |
| 54                      | 0.67     | 0.54     | 0.81     | 100          | 0.67 | 0.51     | 0.76     | 80.00       | 0.51     | 0.42     | 0.82     |
| average                 |          | 0.53     | 0.79     |              |      | 0.49     | 0.74     | 61.67       |          | 0.44     | 0.86     |
|                         | 0.79     |          |          |              | 0.74 |          |          |             |          |          |          |

Note: the result is based on mean level measurement of water depth at FSD in various main canal sections and all measurements are in meter unit.

**Delivery Duration Ratio (DDR):** The flow rate and duration of irrigation hour are obviously changed from one irrigation event to another through the networking system. Accordingly to distribute water efficiently and equitably in predefined amount at a requested time, water delivery, distribution and control structures would be well managed and functional, however those structures were not performed its basic design function due to inadequate management of the scheme, as a result the delivery hour may extend. Such problems mostly perceived close to old community managed irrigation schemes. The value of DDR was calculated using equation (3.23). As per the design document the intended duration of water delivery was 16 hours per day. However, due to the availability of water, mainly for tail end beneficiaries water delivery is neither timely nor reliable, since actual duration of water delivery is elongated to 24 hours per day. Therefore, the DDR is 150 percent, showing the system is dependable, which is insufficient and needs further work in management.

**Sustainability of irrigated area (SI):** This indicator enabled to study the variation in area actually irrigated against the planned area in terms of ratio (Raghava, 2011) and provide valid reasons for such variation. As per the design document the intended command area that a scheme could potentially irrigate was 400 ha, while the actual irrigated area in a cropping season was 350 ha. Hence, SI is found to be 87.5 %. The command areas of the irrigation scheme are reduced compared with the previous/planned/; however, the

reductions of command area were not due to the inability of the scheme water supplied to the farm with insufficient maintenance activity. As the farmers reaction, the command areas were dropped because of different reasons such as; the command area is found in two kebele the users of laelay logemty kebele and tahtay logemty kebele doesn't use according to the schedule due to poor management. Therefore, the management system of the irrigation system is the limiting factors in the reduction of irrigated area; it implies that; this parameter will not be intensifying the management requirements of the system. Seysa dam irrigation scheme did not provide the planned service to the farmer, because of different reasons which are elaborated previously.

As Mekonen and Belete (2006) pointed out, an irrigation scheme design did not consider the farmers will, when the canal networking system outlined. It has been realized that the involvement of users in each phases of the project development promotes the sustainability of the scheme (planning, design, construction and management phase). It is observed that, the communities were not satisfactorily aware in the project planning and didn't participate in certain phase of the scheme development.

## **5. CONCLUSION AND RECOMMEDATION**

### **5.1. Conclusion**

To be able to measure any improvements in irrigation system performance either through better management or through the application of technology, it is important to take baseline measurement, this baseline refers to the performance of the system. The performance of irrigation system was measured by 10 performance indicators under water conveyance, utility and maintenance categories. Performance of Seysa irrigation scheme irrigated farms in relation to water balance ratios: application efficiency (65.44%), storage efficiency, distribution uniformity (59.42%) (73.87%) was evaluated. From the study of the farmers' fields the application efficiencies were good while distribution and storage efficiencies were poor. In the main canal system, the performance of water utility was evaluated as fair in delivery performance ratio (0.83), adequacy (0.83), and dependability (0.18) and equity (0.21), fair in equity ratio for head to tail (1.23). The conveyance system supplied less water than the required, which is considered as poor with respect to deficit. With regard to maintenance performance of the system, as per the analytical result observed in the parameter of water surface elevation ratio, effectiveness of infrastructure, canal operating condition and delivery duration ratio the maintenance activity of a system was very poor. The command areas of the irrigation scheme was reduced compared with the planned; yet, the reduction of command area was due to lack of management and water related conflicts in the Seysa irrigation scheme. It was concluded that the scheme is satisfactory to farmers benefit with respect to dependability, adequacy, equity, timelines of water delivery and operation and maintenance requirements, since the estimated parameters have significant effect to user's satisfaction. However, the contribution of beneficiaries in operation and maintenance activity for system management has not significant role. According to the result perceived, the performance of the system is fair.

### **5.2. Recommendation**

To improve the performance of the scheme with regard to water delivery, conveyance and maintenance performance of the system, the following possible measures are recommended.

- The irrigation Department applies fixed rotational irrigation scheduling, since for reducing water related disputes and water savings for farmers when irrigating and applying flexible supply and demand based scheduling could be useful in large parts of the beneficiary. Because cropping pattern, soil and climatic conditions may spatial and temporarily vary extensively in a scheme, since ridged rotation scheduling is not often acceptable. The WUAs would plan a canal water delivery schedule in discussion with the local agronomist (Development agents) allowing to the crop water requirements of the command area.
- It is recommended that frequent canal cleaning is necessary to minimize the accumulation of silt and sediments that minimizes the volume of water through the canal. The canal requires continuous action to keep them free from weeds and reducing the deposition of sediment by taking curative actions.
- Awareness creation and capacity building should be given to development agent, local administrations, irrigation water users and farmers on management of irrigation water and irrigation structures.
- There should be integration between Laelay logemty and Tahtay logemty kebel to form disciplined water users association is obvious needed to improve peaceful irrigation water use, resolving conflicts and sustainable system management, but in the study area the water user association is not well-organized, which has management target gaps. Later, reforming or giving training to them is important for guarantee better management practice of the scheme.

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## 7. LIST OF APPENDIXES

Table 7.1 1monthly climatic and rain fall data from mekelle metreological station from 2003 to 2017

| Month     | Min Temp | Max Temp | Humidity | Wind   | Sunshine | Radiation              | ETo    | Rain  | Eff. rain |
|-----------|----------|----------|----------|--------|----------|------------------------|--------|-------|-----------|
|           | °C       | °C       | %        | km/day | hours    | MJ/m <sup>2</sup> /day | mm/day | mm    | mm        |
| January   | 7.5      | 28.2     | 41       | 112    | 10       | 20.8                   | 3.73   | 3.6   | 3.6       |
| February  | 9.3      | 29.1     | 30       | 121    | 10       | 22.5                   | 4.34   | 5.5   | 5.5       |
| March     | 12.3     | 31.4     | 35       | 130    | 10       | 24.2                   | 5.05   | 15    | 14.6      |
| April     | 14.6     | 31.1     | 33       | 138    | 10.1     | 25.1                   | 5.53   | 26.6  | 25.5      |
| May       | 14.9     | 30.9     | 40       | 156    | 10.7     | 25.8                   | 5.75   | 44.1  | 41        |
| June      | 14.3     | 29.1     | 47       | 147    | 9.8      | 24.1                   | 5.26   | 76.9  | 67.4      |
| July      | 13.8     | 24.7     | 73       | 138    | 6.5      | 19.2                   | 3.83   | 222.2 | 143.2     |
| August    | 13.2     | 24       | 80       | 138    | 5        | 17.1                   | 3.29   | 252.8 | 150.3     |
| September | 11.6     | 26.3     | 56       | 130    | 9.1      | 22.9                   | 4.42   | 96.4  | 81.5      |
| October   | 10.3     | 28.1     | 43       | 164    | 10.1     | 23                     | 4.69   | 17.3  | 16.8      |
| November  | 9.2      | 27.8     | 44       | 104    | 10.2     | 21.4                   | 3.87   | 9.8   | 9.6       |
| December  | 7.2      | 27.4     | 40       | 95     | 9.2      | 19.1                   | 3.39   | 0.5   | 0.5       |
| Average   | 11.5     | 28.2     | 47       | 131    | 9.2      | 22.1                   | 4.43   | 770.7 | 559.5     |

Table 7.2 crop water and irrigation requirement for cabbage

| Month | Decade | Stage | Kc    | ETc    | ETc    | Eff rain | Irr. Req. |  |
|-------|--------|-------|-------|--------|--------|----------|-----------|--|
|       |        |       | coeff | mm/day | mm/dec | mm/dec   | mm/dec    |  |
| Nov   | 1      | Init  | 0.7   | 2.9    | 20.3   | 2.8      | 18.2      |  |
| Nov   | 2      | Init  | 0.7   | 2.7    | 27     | 3.3      | 23.8      |  |
| Nov   | 3      | Init  | 0.7   | 2.59   | 25.9   | 2.2      | 23.7      |  |
| Dec   | 1      | Init  | 0.7   | 2.48   | 24.8   | 0.5      | 24.4      |  |
| Dec   | 2      | Deve  | 0.72  | 2.43   | 24.3   | 0        | 24.3      |  |
| Dec   | 3      | Deve  | 0.78  | 2.73   | 30     | 0.2      | 29.8      |  |
| Jan   | 1      | Deve  | 0.84  | 3.05   | 30.5   | 0.9      | 29.6      |  |
| Jan   | 2      | Deve  | 0.91  | 3.37   | 33.7   | 1.2      | 32.5      |  |
| Jan   | 3      | Deve  | 0.97  | 3.81   | 41.9   | 1.4      | 40.5      |  |
| Feb   | 1      | Deve  | 1.04  | 4.28   | 42.8   | 1.4      | 41.4      |  |
| Feb   | 2      | Mid   | 1.07  | 4.64   | 46.4   | 1.5      | 44.9      |  |
| Feb   | 3      | Mid   | 1.07  | 4.89   | 39.1   | 2.6      | 36.5      |  |
| Mar   | 1      | Mid   | 1.07  | 5.14   | 51.4   | 3.8      | 47.6      |  |
| Mar   | 2      | Mid   | 1.07  | 5.39   | 53.9   | 4.8      | 49.1      |  |
| Mar   | 3      | Mid   | 1.07  | 5.57   | 61.3   | 6        | 55.2      |  |
| Apr   | 1      | Late  | 1.04  | 5.6    | 56     | 7.2      | 48.9      |  |
| Apr   | 2      | Late  | 0.98  | 5.43   | 38     | 5.8      | 29.7      |  |
|       |        |       |       |        | 647.5  | 45.6     | 600.2     |  |

Table 7.3 crop water and irrigation requirement for maize

| Month | Decade | Stage | Kc    | Etc    | ETc    | Eff rain | Irr. Req. |  |
|-------|--------|-------|-------|--------|--------|----------|-----------|--|
|       |        |       | coeff | mm/day | mm/dec | mm/dec   | mm/dec    |  |
| Nov   | 1      | Init  | 0.3   | 1.24   | 8.7    | 2.8      | 6.7       |  |
| Nov   | 2      | Init  | 0.3   | 1.16   | 11.6   | 3.3      | 8.3       |  |
| Nov   | 3      | Deve  | 0.37  | 1.39   | 13.9   | 2.2      | 11.7      |  |
| Dec   | 1      | Deve  | 0.63  | 2.25   | 22.5   | 0.5      | 22        |  |
| Dec   | 2      | Deve  | 0.9   | 3.06   | 30.6   | 0        | 30.6      |  |
| Dec   | 3      | Mid   | 1.17  | 4.09   | 45     | 0.2      | 44.8      |  |
| Jan   | 1      | Mid   | 1.24  | 4.46   | 44.6   | 0.9      | 43.8      |  |
| Jan   | 2      | Mid   | 1.24  | 4.6    | 46     | 1.2      | 44.8      |  |
| Jan   | 3      | Mid   | 1.24  | 4.86   | 53.4   | 1.4      | 52        |  |
| Feb   | 1      | Late  | 1.21  | 4.99   | 49.9   | 1.4      | 48.5      |  |
| Feb   | 2      | Late  | 0.96  | 4.15   | 41.5   | 1.5      | 39.9      |  |
| Feb   | 3      | Late  | 0.69  | 3.15   | 25.2   | 2.6      | 22.6      |  |
| Mar   | 1      | Late  | 0.45  | 2.18   | 17.4   | 3.1      | 13.6      |  |
|       |        |       |       |        | 410.3  | 21       | 389.3     |  |

Table 7.4 crop water and irrigation requirement for onion

| Month | Decade | Stage | Kc    | ETc    | ETc    | Eff rain | Irr. Req. |  |
|-------|--------|-------|-------|--------|--------|----------|-----------|--|
|       |        |       | coeff | mm/day | mm/dec | mm/dec   | mm/dec    |  |
| Nov   | 1      | Init  | 1.05  | 4.34   | 30.4   | 2.8      | 28        |  |
| Nov   | 2      | Deve  | 1.05  | 4.05   | 40.5   | 3.3      | 37        |  |
| Nov   | 3      | Deve  | 1.03  | 3.8    | 38     | 2.2      | 36        |  |
| Dec   | 1      | Deve  | 0.99  | 3.53   | 35.3   | 0.5      | 35        |  |
| Dec   | 2      | Mid   | 0.97  | 3.29   | 32.9   | 0        | 33        |  |
| Dec   | 3      | Mid   | 0.97  | 3.4    | 37.4   | 0.2      | 37        |  |
| Jan   | 1      | Mid   | 0.97  | 3.51   | 35.1   | 0.9      | 34        |  |
| Jan   | 2      | Mid   | 0.97  | 3.61   | 36.1   | 1.2      | 35        |  |
| Jan   | 3      | Mid   | 0.97  | 3.81   | 42     | 1.4      | 41        |  |
| Feb   | 1      | Mid   | 0.97  | 4.01   | 40.1   | 1.4      | 39        |  |
| Feb   | 2      | Mid   | 0.97  | 4.21   | 42.1   | 1.5      | 41        |  |
| Feb   | 3      | Late  | 0.91  | 4.17   | 33.4   | 2.6      | 31        |  |
| Mar   | 1      | Late  | 0.76  | 3.66   | 36.6   | 3.8      | 33        |  |
| Mar   | 2      | Late  | 0.59  | 2.99   | 29.9   | 4.8      | 25        |  |
| Mar   | 3      | Late  | 0.42  | 2.17   | 23.9   | 6        | 18        |  |
| Apr   | 1      | Late  | 0.31  | 1.66   | 3.3    | 1.4      | 3.3       |  |
|       |        |       |       |        | 537.1  | 34.1     | 505       |  |

Table 7.5 crop water and irrigation requirement for potato

| Month | Decade | Stage | Kc    | ETc    | ETc    | Eff rain | Irr. Req. |  |
|-------|--------|-------|-------|--------|--------|----------|-----------|--|
|       |        |       | coeff | mm/day | mm/dec | mm/dec   | mm/dec    |  |
| Nov   | 1      | Init  | 0.5   | 2.07   | 14.5   | 2.8      | 12.5      |  |
| Nov   | 2      | Init  | 0.5   | 1.93   | 19.3   | 3.3      | 16        |  |
| Nov   | 3      | Deve  | 0.51  | 1.88   | 18.8   | 2.2      | 16.5      |  |
| Dec   | 1      | Deve  | 0.67  | 2.37   | 23.7   | 0.5      | 23.3      |  |
| Dec   | 2      | Deve  | 0.89  | 3.03   | 30.3   | 0        | 30.3      |  |
| Dec   | 3      | Mid   | 1.12  | 3.91   | 43     | 0.2      | 42.9      |  |
| Jan   | 1      | Mid   | 1.18  | 4.24   | 42.4   | 0.9      | 41.6      |  |
| Jan   | 2      | Mid   | 1.18  | 4.37   | 43.7   | 1.2      | 42.5      |  |
| Jan   | 3      | Mid   | 1.18  | 4.62   | 50.8   | 1.4      | 49.4      |  |
| Feb   | 1      | Mid   | 1.18  | 4.86   | 48.6   | 1.4      | 47.2      |  |
| Feb   | 2      | Late  | 1.12  | 4.84   | 48.4   | 1.5      | 46.9      |  |
| Feb   | 3      | Late  | 0.99  | 4.55   | 36.4   | 2.6      | 33.7      |  |
| Mar   | 1      | Late  | 0.87  | 4.2    | 42     | 3.8      | 38.2      |  |
| Mar   | 2      | Late  | 0.79  | 3.97   | 11.9   | 1.4      | 9.5       |  |
|       |        |       |       |        | 473.8  | 23.3     | 450.3     |  |

Table 7.6 crop water and irrigation requirement for tomato

| Month | Decade | Stage | Kc    | ETc    | ETc    | Eff rain | Irr. Req. |  |
|-------|--------|-------|-------|--------|--------|----------|-----------|--|
|       |        |       | Coeff | mm/day | mm/dec | mm/dec   | mm/dec    |  |
| Nov   | 1      | Init  | 0.6   | 2.48   | 17.4   | 2.8      | 15.4      |  |
| Nov   | 2      | Init  | 0.6   | 2.32   | 23.2   | 3.3      | 19.9      |  |
| Nov   | 3      | Init  | 0.6   | 2.22   | 22.2   | 2.2      | 20        |  |
| Dec   | 1      | Deve  | 0.64  | 2.27   | 22.7   | 0.5      | 22.2      |  |
| Dec   | 2      | Deve  | 0.78  | 2.64   | 26.4   | 0        | 26.4      |  |
| Dec   | 3      | Deve  | 0.93  | 3.26   | 35.8   | 0.2      | 35.6      |  |
| Jan   | 1      | Deve  | 1.08  | 3.9    | 39     | 0.9      | 38.2      |  |
| Jan   | 2      | Mid   | 1.17  | 4.37   | 43.7   | 1.2      | 42.5      |  |
| Jan   | 3      | Mid   | 1.18  | 4.61   | 50.8   | 1.4      | 49.4      |  |
| Feb   | 1      | Mid   | 1.18  | 4.86   | 48.6   | 1.4      | 47.1      |  |
| Feb   | 2      | Mid   | 1.18  | 5.1    | 51     | 1.5      | 49.5      |  |
| Feb   | 3      | Late  | 1.17  | 5.35   | 42.8   | 2.6      | 40.2      |  |
| Mar   | 1      | Late  | 1.09  | 5.23   | 52.3   | 3.8      | 48.4      |  |
| Mar   | 2      | Late  | 0.97  | 4.89   | 48.9   | 4.8      | 44        |  |
| Mar   | 3      | Late  | 0.86  | 4.49   | 36     | 4.4      | 29.9      |  |
|       |        |       |       |        | 560.6  | 31       | 528.7     |  |

Table 7.7 Actual observed data on the main canal

| location | ACTUAL MONITORED (QD) ON THE BRANCH OFFTAKING CANAL IN M <sup>3</sup> /S |       |       |         |          |       |       |         |       |       |       |         |
|----------|--|-------|-------|---------|----------|-------|-------|---------|-------|-------|-------|---------|
|          | January  |       |       | average | February |       |       | average | March |       |       | average |
|          | 1  | 2     | 3     |         | 1        | 2     | 3     |         | 1     | 2     | 3     |         |
| BR1      | 0.036  | 0.033 | 0.034 | 0.034   | 0.032    | 0.031 | 0.030 | 0.031   | 0.032 | 0.036 | 0.031 | 0.033   |
| BR2      | 0.086  | 0.084 | 0.082 | 0.084   | 0.079    | 0.084 | 0.079 | 0.081   | 0.078 | 0.083 | 0.082 | 0.081   |
| BR3      | 0.059  | 0.057 | 0.050 | 0.055   | 0.053    | 0.049 | 0.048 | 0.050   | 0.045 | 0.051 | 0.046 | 0.047   |
| BR4      | 0.062  | 0.064 | 0.059 | 0.062   | 0.054    | 0.061 | 0.058 | 0.058   | 0.051 | 0.053 | 0.049 | 0.051   |
| BR5      | 0.046  | 0.043 | 0.048 | 0.046   | 0.042    | 0.043 | 0.038 | 0.041   | 0.039 | 0.036 | 0.035 | 0.037   |
| BR6      | 0.051  | 0.049 | 0.046 | 0.049   | 0.048    | 0.046 | 0.047 | 0.047   | 0.044 | 0.043 | 0.041 | 0.043   |

Table 7.8 average moisture content before irrigation and three days after irrigation

|        |                   | Soil depth,mm |       |       |
|--------|-------------------|---------------|-------|-------|
|        |                   | 0-20          | 20-40 | 40-60 |
| Head   | Before irrigation | 22.78         | 22    | 23.8  |
|        | After irrigation  | 33.88         | 47.48 | 41.1  |
| Middle | Before irrigation | 18.86         | 30.72 | 23.76 |
|        | After irrigation  | 40.51         | 39.02 | 39.08 |
| Tail   | Before irrigation | 24.02         | 24.32 | 21.48 |
|        | after irrigation  | 30.19         | 36    | 43.25 |

Table 7.9 range of performance indicators

| Performance indicator | Range           |                       |           |           |
|-----------------------|-----------------|-----------------------|-----------|-----------|
|                       | Poor            | Fair                  | Good      | excellent |
| DPR                   | <0.7 or<br>>1.3 | 0.7-0.9 or<br>1.1&1.3 | 0.9-1.1   |           |
| DDR                   | 0 or >1         | 1.0                   |           |           |
| ERHT(MDR)             | <0.7 or<br>>1.3 | 0.7-0.9 and 1.21-1.3  | 0.8-0.9   | 0.9-1.1   |
| PD                    | >0.2            | 0.11-0.2              | 0.00-0.10 |           |
| PA                    | <0.8            | 0.8-0.89              | 0.9-1.0   |           |
| PE                    | >0.25           | 0.11-0.25             | 0.00-0.10 |           |
| PF                    | <0.7            | 0.7-0.84              | 0.85-1.0  |           |

Source: Molden and Gates (1990) and Mohsen et al. (2012)

Table 4.10. Basic infiltration rates for various soil types

| Soil type  | Basic infiltration rate (cm/hour) |
|------------|-----------------------------------|
| Sand       | less than 3                       |
| sandy loam | 2 – 3                             |
| Loam       | 1 – 2                             |
| clay loam  | 0.5 – 1                           |
| Clay       | 0.1 – 0.5                         |

Source: FAO, (1990)

Table 4.1 I constant infiltration rate of Seysa irrigation scheme

| Time elapsed (min) | Cumulative time(min) |           |                 | Depth difference |           |                 | Cumulative depth(cm) |           |                 | Infiltration rate (cm/hr) |           |                 |
|--------------------|----------------------|-----------|-----------------|------------------|-----------|-----------------|----------------------|-----------|-----------------|---------------------------|-----------|-----------------|
|                    | Sandy loam           | Silt loam | Silty clay loam | Sandy loam       | Silt loam | Silty clay loam | Sandy loam           | Silt loam | Silty clay loam | Sandy loam                | Silt loam | Silty clay loam |
| 0                  | 0                    | 0         | 0               | 0                | 0         | 0               | 0                    | 0         | 0               | 0                         | 0         | 0               |
| 2                  | 2                    | 2         | 2               | 2.4              | 1.2       | 0.9             | 2.4                  | 1.2       | 0.9             | 72                        | 36        | 27              |
| 2                  | 4                    | 4         | 4               | 1.8              | 1.1       | 0.7             | 4.2                  | 2.3       | 1.6             | 54                        | 33        | 21              |
| 2                  | 6                    | 6         | 6               | 1.6              | 1         | 1               | 5.8                  | 3.3       | 2.6             | 48                        | 30        | 30              |
| 2                  | 8                    | 8         | 8               | 1.7              | 1.1       | 0.7             | 7.5                  | 4.4       | 3.3             | 51                        | 33        | 21              |
| 4                  | 12                   | 12        | 12              | 2.1              | 0.9       | 0.8             | 9.6                  | 5.3       | 4.1             | 31.5                      | 13.5      | 12              |
| 4                  | 16                   | 16        | 16              | 1.8              | 0.7       | 0.6             | 11.4                 | 6         | 4.7             | 27                        | 10.5      | 9               |
| 4                  | 20                   | 20        | 20              | 1.7              | 0.8       | 0.9             | 13.1                 | 6.8       | 5.6             | 25.5                      | 12        | 13.5            |
| 10                 | 30                   | 30        | 30              | 1.8              | 0.7       | 0.7             | 14.9                 | 7.5       | 6.3             | 10.8                      | 4.2       | 4.2             |
| 10                 | 40                   | 40        | 40              | 1.6              | 0.9       | 0.6             | 16.5                 | 8.4       | 6.9             | 9.6                       | 5.4       | 3.6             |
| 20                 | 60                   | 60        | 60              | 2                | 1.1       | 0.8             | 18.5                 | 9.5       | 7.7             | 6                         | 3.3       | 2.4             |
| 20                 | 80                   | 80        | 80              | 1.7              | 0.9       | 0.6             | 20.2                 | 10.4      | 8.3             | 5.1                       | 2.7       | 1.8             |
| 20                 | 100                  | 100       | 100             | 2.2              | 0.8       | 0.7             | 22.4                 | 11.2      | 9               | 6.6                       | 2.4       | 2.1             |
| 30                 | 130                  | 140       | 140             | 1.9              | 0.8       | 0.7             | 24.3                 | 12        | 9.7             | 3.8                       | 1.6       | 1.4             |
| 30                 | 160                  | 180       | 180             | 1.7              | 0.8       | 0.7             | 26                   | 12.8      | 10.4            | 3.4                       | 1.6       | 1.4             |
| 30                 | 190                  | 220       | 220             | 1.8              | 0.8       | 0.7             | 27.8                 | 13.6      | 11.1            | 3.6                       | 1.6       | 1.4             |
| 50                 | 240                  |           |                 | 1.8              |           |                 | 29.6                 |           |                 | 2.16                      |           |                 |
| 50                 | 290                  |           |                 | 1.8              |           |                 | 31.4                 |           |                 | 2.16                      |           |                 |
| 50                 | 340                  |           |                 | 1.8              |           |                 | 33.2                 |           |                 | 2.16                      |           |                 |

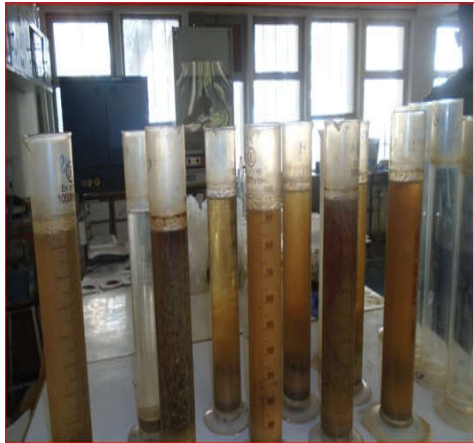


Fig 7.1 Soil lab picture



Fig 7.2 Crop grown in the command area and water loss from the irrigation scheme