



**PERFORMANCE EVALUATION OF LAMO SMALL-SCALE
IRRIGATION SCHEME IN TEMBARO WOREDA, KEMBATA
TEMBARO ZONE, SNNPR**

MSc. THESIS

**BY
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**June, 2017
HAWASSA, ETHIOPIA**



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TEMBARO ZONE, SNNPR**

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**A Thesis Submitted to the Institute of Technology,
School of Biosystems and Environmental Engineering
HAWASSA UNIVERSITY**

**In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Water Resources Engineering and Management**

June, 2017

HAWASSA, ETHIOPIA

APPROVAL SHEET-I

As member of the *Board of Examiners* of the *MSc. Thesis open defense examination*, we certify that we have read and evaluated the thesis prepared by **Tigabu Tamirat**, entitled “**Performance Evaluation of Lamo Small-scale Irrigation Scheme in Tembaro Woreda, Kembata Tembaro Zone, SNNPR**” and examined the candidate. We recommended that the thesis be accepted as fulfilling the *Thesis* requirement for the Degree of *Master of Science in Water Resources Engineering and Management*.

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DEDICATION

I dedicate this thesis manuscript to my families for nursing me with affection, love and for their dedicated partnership in the success of my life.

STATEMENT OF AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for an advanced MSc. degree at the Hawassa University and is deposited at the University library to be made available to borrowers under the rules of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

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ACKNOWLEDGMENTS

First of all, I would like to thank the “Almighty God” for giving me the life, patience, wisdom and who made it possible, to begin and finish this work successfully.

My heartfelt appreciation goes to my Major advisor Brook Abate (PhD) for his academic assistance, follow up and review of this thesis manuscript. With deep respect, I am equally expressing my sincere gratitude to my Co-advisor Abraham W/Michael (PhD) for his professional guidance, continuous follow up, unbounded constructive comments and all possible assistance during the research work.

I would like to thank Hawassa University for giving me the training, for providing references and other materials with good working environment that facilitated my research work. I express my heartfelt thanks to the administrative and all division staff of the University for helping me to conduct this work. My special thanks go to Biosystems and Environmental Engineering Department, School of Graduate Studies.

The financial support from Tembaro Woreda Agriculture and Natural Resource Development Office is gratefully acknowledged. Without the financial support of Norwegian Agency for International Development (NORAD Project), this study would not have been possible.

I would like to thank laboratory assistants at soil laboratory for their valuable technical assistance throughout the experiment in laboratory investigations. I am pleased to acknowledge meteorological stations for providing me with climatic data of the study area.

Lastly, I would like to express my gratitude to all individuals and organizations that contributed towards the successful completion of this study.

LIST OF ABBREVIATIONS AND ACRONYMS

CWR	Crop Water Requirement
DPR	Deep Percolation Ratio
DU	Distribution Uniformity
Ea	Application efficiency
Es	Storage efficiency
ETc	Crop evapo-transpiration
ETo	Reference evapo-transpiration
FAO	Food and Agricultural Organization
FC	Field Capacity
kc	Crop coefficient
MoWR	Ministry of Water Resource
NGO	Non Governmental Organization
NIR	Net Irrigation Requirement
NORAD	Norwegian Agency for International Development
P	Depletion level
Pe	Effective rainfall
PWP	Permanent Wilting Point
RAW	Readily Available Water
SMD	Soil Moisture Deficit
SNNPR	South Nation Nationalities and People's Region
TAW	Total Available Water
TWADO	Tembaro Woreda Agricultural Development Office
TWR	Tail Water Ratio
USSCS	United States Soil Conservation Service
WMEO	Water, Mines and Energy Office

TABLE OF CONTENTS

STATEMENT OF AUTHOR.....	IV
BIOGRAPHICAL SKETCH.....	V
ACKNOWLEDGMENTS.....	VI
LIST OF ABBREVIATIONS AND ACRONYMS.....	VII
TABLE OF CONTENTS.....	VIII
LIST OF TABLES.....	XI
LIST OF FIGURES.....	XII
LIST OF TABLES IN THE APPENDIX.....	XIII
ABSTRACT.....	XIV
1. INTRODUCTION.....	1
1.1. Background and Justification.....	1
1.2. Statement of the Problem.....	3
1.3. Objectives of the Study.....	4
1.3.1. General Objective.....	4
1.3.2. Specific Objectives.....	4
2. LITERATURE REVIEW.....	5
2.1. Irrigation Development in Ethiopia.....	5
2.2. Evaluating Performance of Irrigation System.....	6
2.2.1. Irrigation Performance Indicators.....	7
2.2.1.1. Application Efficiency.....	9
2.2.1.2. Storage Efficiency.....	9
2.2.1.3. Distribution Uniformity.....	10
2.2.1.4. Deep Percolation Ratio.....	10
2.2.1.5. Tail Water Ratio.....	11
2.3. Irrigation Scheduling.....	12

2.4. Soil Water Balance.....	13
2.5. Water Supply.....	15
2.6. Estimation of Crop Water Requirement and CROPWAT Model.....	15
2.6.1. Net Irrigation Requirement.....	16
2.7. Operation and Maintenance of Irrigation Scheme.....	16
3. MATERIALS AND METHODS.....	18
3.1. Description of the Study Area.....	18
3.1.1. Location of the Study Area.....	18
3.1.2. Climate and Rainfall Distribution.....	19
3.1.3. Geology and Soil.....	19
3.1.4. Population.....	19
3.1.5. Economic Activities.....	19
3.2. Field Layout and Selection of Crops.....	20
3.3. Data Collection Methods.....	20
3.3.1. Primary Data Collection Methods.....	20
3.3.2. Secondary Data Collection Methods.....	21
3.4. Crop Water Requirement and Net Irrigation Requirement.....	22
3.5. Soil Water Balance.....	23
3.6. Water Supply.....	24
3.7. Irrigation Scheduling.....	24
3.8. Field Measurements for Irrigation Evaluation.....	25
3.9. Performance Evaluation of Irrigation Scheme.....	26
3.10. Assessment of Problems on Current Irrigation Practices.....	28
3.11. Data Analysis.....	28

4. RESULTS AND DISCUSSIONS.....	29
4.1. Characterization of Soil in the Study Area	29
4.2. Irrigation Water Quality.....	31
4.3. Crop Water Requirement.....	32
4.4. Soil Water Balance.....	35
4.5. Water Supply.....	35
4.6. Irrigation Scheduling.....	35
4.7. Field Measurements for Irrigation Evaluation.....	37
4.8. Performance Evaluation of Irrigation Scheme.....	38
4.9. Water Losses in Conveyance and Delivery System	41
4.10. Water Delivery and Distribution System.....	43
4.11. Scheme Management and Operation.....	44
4.12. Assessment of Problems on Current Irrigation Practices.....	44
4.12.1. Problems on Physical Structure of the Scheme.....	44
4.12.2. Operational and Management Problems of the Scheme.....	45
5. SUMMARY AND CONCLUSION.....	46
5.1. Summary.....	46
5.2. Conclusion.....	48
5.3. Recommendations.....	49
6. REFERENCES.....	50
7. APPENDICES.....	55

LIST OF TABLES

Table	Page
Table 1 Properties of soil in the study area (texture, PH).....	29
Table 2 Bulk density, field capacity, permanent wilting point, total available water.....	30
Table 3 Chemical analysis of irrigation water	31
Table 4 Crop water requirement report of onion	33
Table 5 Crop water requirement report of tomato	34
Table 6 Crop calendar of the study area.....	36
Table 7 Required irrigation depth to be applied for fully grain annual irrigated crop.....	36
Table 8 Irrigation variables / parameters	37
Table 9 Summary results of different irrigation efficiency of irrigation events	38
Table 10 Significance effect of inflow rate on performance indicators	39
Table 11 Main canal efficiency and loss rate using velocity-area method	42
Table 12 Secondary canal efficiency and loss rate using velocity-area method.....	42

LIST OF FIGURES

Figure	Page
Figure 3.1. Location map of study area (Lamo irrigation scheme).....	18

LIST OF TABLES IN THE APPENDIX

Appendix Table	Page
Appendix Table 1 Total and effective rainfall data.....	56
Appendix Table 2 Crop parameters for major irrigated annual crops at Lamo.....	57
Appendix Table 3 Mean monthly climatic data of study area (Meteorological station).....	58
Appendix Table 4 Irrigation scheduling report of onion.....	59
Appendix Table 5 Irrigation scheduling report of tomato.....	60
Appendix Table 6 Average soil moisture contents before and a day after irrigation.....	61
Appendix Table 7 Measured soil water needed and stored used for determination of application, storage efficiency and deep percolation ratio.....	62
Appendix Table 8 Measured soil water contents and calculated distribution uniformity of onion field.....	63
Appendix Table 9 Measured soil water contents and calculated distribution uniformity of tomato field.....	64
Appendix Table 10 Inventory data for physical structure of the scheme.....	65
Appendix Table 11 Generalized data on Rooting Depth of Full Grown Crops, Fraction of available soil water (p) and Readily Available Soil Water (p*Sa) for different soil types in (mm/m soil depth) when ET _{crop} is 5 – 6 mm/day.....	70
Appendix Questionnaires: Survey questionnaires for baseline data.....	71

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ABSTRACT

The level of performance of irrigated farms is one of the most important issues that need to be addressed in Ethiopia where development of irrigation, in particular small-scale irrigation, is adopted as one of strategies to achieve food security. Lamo small-scale irrigation scheme operates under low level of performance due to poor water management and lack of timely maintenance of structures. The performance evaluation of Lamo small-scale irrigation scheme was made by using internal performance indicators as a tool such as application efficiency, storage efficiency, distribution uniformity and deep percolation ratio. Six farmer's plots located at head, middle and tail of the command area were selected and grown with two commonly grown vegetable crops in the command area viz, onion, and tomato. The average application efficiency, storage efficiency, distribution uniformity and deep percolation of the selected farmer's fields were found to be 48.12%, 81.90%, 79.80% and 51.88%, respectively. Based on the analysis of variance (ANOVA), the result indicated that inflow rate had significant effect ($p < 0.05$) on different performance indicators (application efficiency, storage efficiency, distribution uniformity, and deep percolation ratio) at field level. Since farmers were using end-dyke furrow irrigation system, therefore no runoff was observed. The result of the study also showed that the irrigation water applied to farmers' fields (136mm) was much higher than the required depth to be applied per irrigation event. As a result, large amount of water was lost as deep percolation. Conveyance efficiencies of the main and secondary canals were found as 82.5% and 80.8%, respectively. Seepage losses of the main and secondary canals were found out as 16.70lit/sec/km and 14.70lit/sec/km, respectively. Operational and management, and status of physical structure of the scheme were analyzed using field observations and inventories. Moreover, poor irrigation management and operation of the scheme were identified as major problems at the study site.

Key words: *Performance evaluation, small scale irrigation, performance indicator, efficiency*

1. INTRODUCTION

1.1. Background and Justification

One of the world's great challenges is to increase food production in a sustainable manner that a rapidly growing global population can be fed. The world's growing population combined with unsustainable consumption patterns is putting increasing stress on land, water and other essential resources. Efficient use of limited land and water resources can only be achieved by development, monitoring and evaluation of those resources. Irrigated agriculture is playing a major role in reaching the broader development objectives of achieving food security and improvements in the quality of life in developing world (FAO, 2013).

The sustainability of irrigation agriculture continues to be a priority issue in both developed and developing countries. Sustained development of irrigation agriculture is limited by shortages of suitable water supply and irrigable land. It is recognized, however, that opportunities may be available for substantial increase in agricultural outputs using existing water supply and project infrastructure through improvements in project management (including operation), modernization of project infrastructure, better maintenance and improved on-farm agriculture practices (World Bank/UNDP, 2012).

Irrigation can and should play an important role in raising and stabilizing food production, especially in the less-developed parts of Africa-south of the Sahara. Although the Ethiopian surface and groundwater resources amount to 123 and 2.6 billion cubic meters per annum, respectively, their distribution in terms of area and season does not give adequate opportunity for sustainable growth to the economy. The intensity of recurrent droughts affects the livelihoods of the agricultural communities and the whole economy. Even in a year of good rain, the occurrence of floods affects the livelihoods of riparian residents with little capacity to neither protect from the seasonal flood nor mitigate the impact (McCornick *et al.*, 2003).

In recent years, governments of many developing countries, international developing agencies and non- governmental organizations (NGOs) have realized that the most effective method to tackle the problem of food shortage is by the help of small-scale irrigation projects and rehabilitating the traditional ones. Traditional irrigation systems based on surface water are centuries old practices in Ethiopia.

Taking into account the potentials of land and water resources and the problems of food insecurity, population increase, and insufficient rainfall, agricultural development is a priority for Ethiopia. Rain fed and traditionally irrigated agriculture is not sufficient to meet the food demand of the increasing population. The introduction of modern irrigation practices in the form of small-scale irrigation system will be set as a solution (MoWR, 2008).

Renault (2008) stated that effective irrigation management required reliable performance assessment. Good farm irrigation management assures correct frequency of irrigations, correct application depth, uniform irrigation, minimum runoff and minimum deep percolation.

As many farmers manage irrigation systems but do not perform as they should and there is a need to identify the areas in which they fall short of their potential. It is, therefore, important to measure and evaluate their success or failure objectively and identify specific areas in need of improvement (Jorge, 1993). Field evaluation of surface irrigation system plays a fundamental role in improving surface irrigation management (Pereira, 1996).

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. The performance of farm irrigation system is determined by the efficiencies with which water is diverted, conveyed, and applied and also by adequacy and uniformity of application in each field on the farm (Ali, 2000).

Lamo irrigation scheme was designed in 1991 E.C. by the Regional Agriculture Bureau and technically assisted by Irrigation Department to introduce irrigation practice in the woreda. The irrigation scheme is located in Tembaro woreda, particularly in Osheto kebele and it is approximately 15km away from Mudulla town. The main component of the irrigation system consists of diversion weir, 4.25 km main lined canal, secondary unlined canals with varying lengths and capacities. The source of the irrigation water is “Lamo” river and the total irrigable command area of the scheme is about 120 hectare but about 100 hectare is fully irrigated, which was planned to benefit about 168 households. The type of irrigation method practiced in the area is furrow irrigation.

The establishment of this irrigation project has a great positive impact on the farmers of the area both socially as well as economically. The presence of the scheme benefits the people to have good nutritional value foods, to overcome starvation which happened in the past due to erratic climatic conditions as well as the less productivity of the land and thereby to increase their daily income (TWADO, 2008).

The performance evaluation of the scheme would help to improve the performance of the irrigation system in terms of field water management and efficiencies, to identify causes for poor irrigation management system, to increase additional command area and also to dig out the problems of physical structure of the irrigation scheme.

1.2. Statement of the Problem

In Ethiopia, irrigation technology has advanced significantly during the past two decades, but many existing projects and on-farm irrigation systems have not been improved significantly and practiced at low level of performance which finally decreases the yield per unit of irrigated area.

The irrigation network is perhaps the most costly element of an irrigation scheme and is designed to last a long time. However, quite often one finds that irrigation schemes not long constructed bear little resemblance to the original construction and design.

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

In recognition to both the promise and hazards associated with irrigation, evaluating irrigation performance has now become of paramount importance not only to point out where the problem exists but also helps to identify alternatives that may be both effective and feasible in improving system performance.

1.3. Objectives of the Study

1.3.1. General objective

The overall objective of this study was to evaluate the performance of Lamo small-scale irrigation scheme in Tembaro woreda, Kembata Tembaro zone, SNNPR.

1.3.2. Specific objectives

- To determine crop water requirement, establish water balance and analyze current water supply;
- To check the performance of irrigation system in terms of technical efficiencies, and also operation and management;
- To identify the key problems in current irrigation practices

2. LITERATURE REVIEW

2.1. Irrigation Development in Ethiopia

Ethiopian farmers have practiced agriculture since earliest times using the technology sufficient to sustain food supplies of the then low population level. Though agriculture is the major economic sector, its production is largely subsistent and predominantly rain-fed and as a result it has suffered from recurrent drought and unreliable rainfall.

Concerning the country's irrigation potential, there are various estimates by different organizations. FAO estimate put it at about 1.8 million hectares, while IFAD estimates 2.8 million hectares (as cited in Gedion, 1990). According to the MoA report of 1993, the total coverage of irrigation in the country then was only 168,000 hectares which is less than 6 percent of the country's average estimated potential of 2.7 million hectares (as cited in Fuad, 2001).

Moreover, it has also been indicated by Dessalegn (1999) that in Ethiopia irrigation covers less than two percent of the countries cropped land and if all the irrigated land is utilized to produce food crops the contribution of irrigation to the production of food can't exceed two percent. This shows that in respect of the country's endowment with potentially huge irrigable land, irrigation has made little contribution toward agricultural development and national food self-sufficiency in Ethiopia.

Apparently, irrigated agriculture is not an entirely new phenomenon in Ethiopia. As indicated on some literatures, informal traditional irrigation culture has a history of more than one century in some parts of Ethiopia. Small-scale traditional irrigation has been practiced for decades throughout the highlands where small farmers could be diverted seasonally for limited dry season cropping (FAO, 1994).

At the early time of the Derg, like of the past regime, emphasis was given to large-scale irrigation development as part of the modernization and socialization of the country's agricultural economy (Dessalegn, 1999).

However, the drought of 1984/85 produced a strong impetus towards irrigation with the government initiating programs for the development of small and medium scale irrigation projects with the expectation that such schemes will provide a standard against the variability of rainfall. During the early period, minor river diversion projects were undertaken in different parts of the country to assist drought victims and to reduce the adverse effect of recurrent drought. However, it has been reported that the projects were not sustainable due to lack of continual support in management and maintenance of infrastructure.

At present, small-scale irrigation schemes in Ethiopia take two forms. The first form is the traditional scheme, which are organized and managed by the community members themselves. The other form is recently upgraded (with permanent diversion weir and lined canals) which government and some NGOs have constructed since the 1980s. According to the inventory, there are 1309 traditional small-scale irrigation schemes covering about 60,000 hectares that scattered throughout the country. Such traditional schemes in most cases serve mainly to supplement and provide a greater degree of security to peasant farmers' rain fed agriculture (MoWR, 2008).

When we look at the performance level of irrigation in Ethiopia, small-scale schemes (especially those operated privately and traditional irrigation systems) have had a better record of success than large-scale schemes. This was attributed to the distinct characteristics and advantages of small-scale irrigation that the management of village or community in the development process, there is a possibility to make use of local materials, local skills and labor which contribute to low cost of investment and operation. Due to such comparative advantages, irrigation development strategy in Ethiopia has mainly focused on the development of smallholders' schemes. In this regard, the statement of concern is clearly stated in the Ethiopian Food Security Strategy (FDRE, 2002).

2.2. Evaluating Performance of Irrigation System

The ever-growing demand for water among competing societal activities has put undue pressure on the resource base to the point that the need for sagacious use of water has become a global concern. Progress has been made towards minimizing non-beneficial consumption of irrigation water, yet a lot remains to be done (Zerihun and Feyen, 1996).

FAO (1995) pointed out that only 40 to 60% of the water is effectively used by the crops, the remains of the water is lost in the system either through evaporation, run-off or by percolation into the ground water. On the other hand, application of irrigation water beyond the crop needs has contributed to the rise of ground water table to the effective plant root zone.

The principal objective of evaluating surface irrigation system is to determine the efficiency of the system as it is being used and to identify management practices and system configurations that can be easily and efficiently implemented to improve the overall irrigation efficiency of the system (Merriam, 1983 and Walker, 1989). The field evaluation should identify at least problems such as poor management of water (applying too much or too little water), poor distribution of infiltrated water over the field, excess tail water runoff or significant deep percolation losses. Although various authors have suggested many performance measures, type of measures or indicators chosen, depends on the purpose of the performance assessment.

2.2.1. Irrigation performance indicators

To carry out performance evaluation of irrigation schemes, a set of recognized and accepted parameters are required. Abrenethy (1989) defined performance as measured levels of achievement in terms of one or several parameters which are chosen as the indicators of the system's goals.

Rust and Snellen (1993) stated that the performance indicators measured the value of a particular item such as yield or canal discharge and had to include a measure of quality as well as quantity, and be accompanied by appropriate standards.

In connection with main system performance, the authors concluded that the services provided by the system and appropriate performance standards were greatly influenced by the design of that system. The improvement of irrigation practice requires knowledge of crop water requirement and yield responses to water, constraints that are specific to each irrigation method, limitation to water supply system, and financial and economic implication of irrigation practice.

Improvement of irrigation method requires considerations of the factors influencing hydraulic process, water infiltration and uniformity of water application to the entire field (Hlavec, 1992).

Different indices have been developed that are used for evaluating the performances of irrigation systems and for comparing the performances of different irrigation systems as well as farms. The type and number of indices used for a particular situation depend on the level of details required for quantification, and on the number of disciplines selected for assessment. These may include, water balance, economics, environment, management, etc. (Bos, 1997).

The common efficiency terms used for on-farm irrigation system evaluation include application efficiency, uniformity, storage efficiency, and recently complementary terms such as runoff ratio, deep percolation ratio, etc. are being applied (Jurriens *et al.* 2001). When water is applied to a crop, various fractions of the total applications arrive at various destinations at different stages in their interval.

At the heart of any consideration, irrigation performance is irrigation water balance and determination of the rate of various fractions of the total irrigation water applied: how much gets to the crop and how it is distributed among the plants, how much of the remainder is recoverable, how much enters the ground water, surface drainage, and so forth. An important related issue is how adequately crop needs are met. The type of performance measure chosen depends on the purpose of performance assessment activity. However, the irrigation performance measures are based solely on the irrigation water balance (Burt *et al.*, 1997).

Irrigation performance indicators includes internal indicators or water supply indicators, which focus on the hydraulic process of irrigation systems, and external indicators when the emphasis is more on the out puts i.e. agricultural production and economic and environmental impacts (Molden *et al.*, 1998).

Michael (1997) and Jurriens *et al.*, (2001) put as a remark that the primary performance indicators are: application efficiency, storage efficiency and distribution uniformity.

2.2.1.1. Application efficiency, E_a

Depending on the type of the source, water is diverted, or pumped to a canal or pipe for conveyance to the farm for distribution and finally for application to the crops in the field. When water is diverted into any water application system such as furrows, part of the water infiltrates into the soil for consumptive use by the crop, while the rest is lost as deep percolation and as runoff. The efficiency terms determine these components and compare them with the volume of water actually applied to the field.

The term is an indication of the effectiveness of the system in reducing losses during an irrigation event. After the water reaches the field supply channel, it is important to apply the water as efficiently as possible. A measure of how efficiently this is done is the application efficiency.

According to Jurriens *et al.* (2001), application efficiency is a common yardstick of relative irrigation losses and this definition is valid for all situations and all irrigation methods. Losses from the field occur as deep percolation and as field tail water or runoff and reduce the application efficiency. To compute E_a it is necessary to identify at least one of these losses as well as the amount of water stored in the root zone. This implies that the difference between the total amount of root zone storage capacity available at the time of irrigation and the actual water stored due to irrigation be separated, i.e. the amount of under-irrigation in the soil profile must be determined as well as the losses (FAO, 1989).

2.2.1.2. Storage efficiency, E_s

Storage efficiency is an index used to measure irrigation adequacy. It is the ratio of the quantity of water stored in the root zone during irrigation event to the potential storage of water in the root zone.

Jurriens *et al.* (2001) expressed adequacy of irrigation turn in terms of storage efficiency and the purpose of an irrigation turn was to meet at least the required water depth over the entire length of the field.

Conceptually, the adequacy of irrigation depends on how much water is stored within the crop root zone, losses percolating below the root zone, losses occurring as the surface run off or tail water, the uniformity of the applied water and the remaining deficit or under-irrigation within the soil profile following irrigation. To get a complete picture of an irrigation event performance we need to know more than just the indicators above, because these are averages taken over the entire length of the fields.

2.2.1.3. Distribution uniformity, DU

To fully express the efficiency of an irrigation system, the uniformity of the water applied need to be evaluated. Distribution Uniformity (DU) is a term that describes how uniformly water is applied in a field. It is the ratio of the minimum infiltrated amount to the average infiltrated depth over the field.

Furrow irrigation is adaptable where soils and topography are reasonably uniform (Jensen, 1983) and furrows are sloping channels cut into the soil surface and into which a relatively large initial non-erosive stream of water is turned.

The logic behind the evaluation of water distribution uniformity along the furrow is that when irrigation water is applied into a longer furrow with a given discharge, the upper and the lower ends cannot get equal amount of water (Michael, 1997). The length of furrow which can be efficiently irrigated may be as short as 45m on soils which take up water rapidly, or as much as 300m or longer on soils with low infiltration rates. For such long furrows the maximum allowable slope is 1% and the furrow stream varies from 0.5 to 2.5 liter per second.

2.2.1.4. Deep percolation ratio, DPR

Deep percolation ratio (DPR) expresses the ratio between the percolated water beyond the root zone to the volume of water applied to the field (Zerihun *et al.*, 1997, Feyen and Zerihun, 1999).

2.2.1.5. Tail water ratio, TWR

It is defined as the ratio between the volume of water lost as runoff to the volume of water applied to the field. High ratio indicates water application rate exceeding the infiltration capacity of the soil, thus calling for reduction in inflow rate (Jurriens, *et al.*, 2001).

Water Losses in Conveyance and Delivery System

Conveyance efficiency, E_c

Conveyance efficiency is defined as the ratio of the amount of water delivered at the main irrigation conveyance network to the total amount of water diverted into the irrigation system. The concept can also be viewed as the evaluation of the water balance of the main, lateral and sub-lateral canals relate structures of the irrigation system (Rust and Snellen, 1993).

Significant volume of water is lost by the net works of the conveyance canals due to seepage and evaporation depending on the nature of the soil and agro-climatic zone in which the canals are located. It is one of several closely related and commonly used output measures of performance that focus on the physical efficiency of water conveyance by the irrigation system (Bos, 1997).

Water is conveyed from the water source to cropped area of the farm in networks of open channels and/or pipelines. Open channels may be lined or unlined and pipelines partially open to the atmosphere or pressurized (James, 1988).

Conveyance and distribution of water are integral part of an irrigation project. The efficiency of the conveyance and distribution system, that is, the transport of water at minimum cost and with minimum water loss, therefore, essentially affects the total economy of an irrigation project (Kraatz, 1977).

Losses of irrigation water in the conveyance system can be a major component of the overall water losses particularly for farms located at significant distances from water sources where the main canals are long and unlined. These are important in particular in the highlands of Ethiopia where the canals are long because of the steep topography.

The amount lost depends on quality of operation and maintenance, and the nature of the soil that affects the seepage rate. In Ethiopia, typical conveyance efficiency values generally reported are 70.0% and 50.0% for unlined poorly managed and operated main and field canals, respectively, while for the well managed canals the figures were 85.0% and 80.0%, respectively (Ministry of Agriculture and Food Security, 2007).

2.3. Irrigation Scheduling

Irrigation scheduling is the process of determining when to irrigate and how much water to apply per irrigation. When to irrigate also provide data for estimating the amount of water to apply per irrigation. How much water to apply is depending on the irrigator's strategy a critical element is accurate measurement of the volume of water applied or the depth of application.

The purpose of irrigation scheduling is to determine the application of exact amount of water to the field and the exact timing for application. Proper scheduling is essential for the efficient use of water, and other production inputs, such as fertilizer. It allows irrigations to be coordinated with other farming activities including cultivation and chemical applications. The benefit of proper irrigation scheduling includes improved crop yield and/or quality, water and energy conservation, and lower production costs (James, 1988).

FAO (1989) explains that when surface irrigation methods are used, however, it is not very practical to vary the irrigation depth and frequency too much. In surface irrigation, variations in irrigation depth are only possible within limits. It is also very confusing for the farmers to change the schedule all the time. Therefore, it is often sufficient to estimate or roughly calculate the irrigation schedule and to fix the most suitable depth and interval: to keep the irrigation depth and the interval constant over the growing season.

Normally farmers will use their own experience and indicators (wilting characteristics, soil dryness) to determine when to irrigate (Smith and Munoz, 2002). According to them this has proved not very accurate and a scientific advice to farmers on when to irrigate can lead to considerable water savings and a more rational planning of water distribution.

Readily available water (depth of irrigation application) is the depth of water that can be stored within the root zone between field capacity and allowable level of the soil water can be depleted for a given crop, soil and climate (James, 1988).

The total available water in the root zone is the difference between the water content at field capacity and wilting point (Allen *et al*, 1998).

If there are plants growing on the soil, the moisture level continues to drop until it reaches the "permanent wilting point" (PWP). Soil moisture content near the wilting point is not readily available to the plant. Hence the term "readily available moisture" has been used to refer to that portion of the available moisture that is most easily extracted by the plants, approximately 75% of the available moisture. After that, the plants cannot absorb water from the soil quickly enough to replace water lost by transpiration (ICE, 1983).

2.4. Soil Water Balance

The water balance is a useful concept for characterizing, evaluating or monitoring surface irrigation system. Crop water requirement and soil moisture content are important components in the field water balance which impact design and evaluation (Doorenbos and Pruitt, 1977).

To develop an indicative irrigation schedule that comply with the existing irrigation method and operation criteria and at the same time minimizes irrigation water loss and/or yield reduction a number of run with timing option of fixed interval during a given stage and application option set at fixed depth will be carried out for major irrigated annual crops in the study area. Water budget method is more commonly applied these days.

The large amount of studies and research on crop water requirements has led to more accurate crop water estimation from weather data and has made the reference evapotranspiration based on water balance method the most convenient and reliable way to predict when to irrigate (Smith and Munoz, 2002).

Soil based irrigation scheduling involves determining the current water contents of the soil, comparing it to a predetermined minimum water content and irrigation to maintain soil water contents above the minimum level. A farmer cannot manage water to maximum efficiency without knowing how much water to be applied. Also, uniform water distribution across the field is important to derive the maximum benefits from irrigation scheduling and management. Accurate water application prevents over-or under- irrigation.

According to FAO (1989), the total available water (TAW), for plant use in the root zone is commonly defined as the range of soil moisture held at a negative apparent pressure of 0.1 to 0.33 bar (a soil moisture level called 'field capacity') and 15 bars (called 'permanent wilting point'). The TAW will vary from 25 cm/m for silt loams to as low as 6 cm/m for sandy soils.

The net quantity of water to be applied depends on magnitude of moisture deficit in the soil, leaching requirement and expectancy of rainfall. When no rainfall is likely to be received and soil is not saline, net quantity of water to be applied is equal to the moisture deficit in the soil, i.e. the quantity required to fill the root zone to field capacity.

According to Jurriens et al (2001), the required depth is not usually the same as the applied depth which is equal to the applied volume divided by the area. If the applied depth infiltrates the field area entirely, the applied depth equals the average infiltrated depth. Jurriens et al (2001) further discussed on that, the average depth of water that is actually stored in the target root zone is the storage depth. When the target zone is entirely filled, storage depth will equal required depth. If storage depth is less than required depth, then there is under-irrigation and if storage depth is greater than required depth, then there is deep-percolation.

2.5. Water Supply

The quantity of the source of water can have a significant impact on the irrigation practices. Crop water demands are continuous during the growing season. The soil moisture reservoir transforms this continuous demand into a periodic one which the irrigation system can service. A water supply with a relatively small discharge is best utilized in an irrigation system which incorporates frequent applications. The depths applied per irrigation would tend to be smaller under these systems than under systems having a large discharge which is available less frequently (IWMI, 2007).

2.6. Estimation of Crop Water Requirement and CROPWAT Model

As a first step in the proper design of an irrigation scheme, it is necessary to know the crop water requirements. The crop water requirement is defined here in as the rate of evaporation of a disease-free crop growing in a field of not less than one hectare under optimal soil conditions. The optimal soil conditions assume adequate fertility and water to achieve the full production potential of the crop under the prevailing environment. The crop water requirement is designed as ET_c and is expressed in millimeters per day (mm/day) (FAO, 1998). Direct measurement of ET_{crop} in the field is laborious and time-consuming. Consequently a large number of estimation methods have been developed.

The four most widely known and used are the Blaney-criddle, Radiation, Penman and Pan Evaporation methods. Among them the Penman method recently further refined as modified FAO Penman Monteith method is best for mean estimates over short periods of about 10 days (FAO, 1998).

CROPWAT model is a computer program for irrigation planning and management, and its development is based on FAO Penman-Monteith method (Smith, 1992). Its basic function includes the calculation of reference evapo-transpiration (ET_o), and crop water requirement. Calculation of crop water requirements utilizes input of climatic and crop data. The climatic input data required are reference evapo-transpiration (monthly/decade) and rainfall (monthly, decade/daily).

The crop parameters used for estimation of the crop evapo-transpiration, water balance calculations, and yield reduction due to stress include: crop coefficient (K_c), length of growing season, depletion level (p), and yield response factor (K_y).

The reference crop evapo-transpiration value is defined as the rate of evapo-transpiration from an extended surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water (FAO, 1980). The calculation of E_{To} requires only meteorological data. Usually, the determination of K_c involves the knowledge of crop type and date of sowing, length of total growing season and durations of initial, development, mid-season and late season stages of the crop along with climatic data such as wind speed and humidity.

2.6.1. Net Irrigation Requirement

The net irrigation requirement (NIR) is the depth of water, exclusive of precipitation, carry-over soil moisture or ground contribution or other gains in soil moisture that is required consumptively for crop production.

It is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. Thus it is the difference between field capacity and soil moisture content in the root zone before starting irrigation (Michael, 1997).

2.7. Operation and Maintenance of Irrigation Scheme

Water distribution is clearly of central importance in any irrigation project, but many other aspects of project organization and management also have profound influence on performance. These include the project's organizational structures, its overall direction and coordination, and the provision of other services such as operation, maintenance and rehabilitation of the irrigation scheme, irrigation assistance to farmers, finance and administration (Sagardoy *et al.*, 1986).

The irrigation network is perhaps the most costly element of an irrigation scheme and is designed to last a long time. However, quite often one finds that irrigation schemes not long constructed bear little resemblance to the original construction and design.

Silt deposition, weed infestation, malfunction of structures and other undesirable situations make it practically impossible to control the flow in these canals. As result, the system is unable to deliver the necessary water and distribute it equitably.

On the other hand, according to Sagardoy *et al.*, (1986), there are many examples illustrating that with proper maintenance and cooperation among farmers in this task, irrigation systems may last much longer than their original ever envisaged. Irrigation schemes that have been in operation for centuries can be found in Spain, Egypt, Italy, Pakistan and other countries, and are a living testimony that properly maintained irrigation schemes can be of permanent benefit to many generations.

Joint responsibility for maintenance by farmers and irrigation authorities is essential to bring about sustainability (IFAD, 2005). It is good to recognize the importance of farmers and irrigation authorities in irrigation scheme maintenance activities. The distinctions between minor maintenance which can be carried out by farmers, major maintenance which is beyond the capacity of farmers but within the mandate of woreda, zone and regional authorities, and rehabilitation of physical and social infrastructure which requires significant external funding, need to be defined.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location of the study area

The study was conducted in Tembaro woreda, Kembata Tembaro Zone, South Nation Nationalities and People's Region (SNNPR). Tembaro woreda is located at about 400km and 180km south of Addis Ababa and south west of Hawassa, respectively. Tembaro woreda is composed of 19 administrative Kebeles and 2 municipality towns and bordered by Omo River in the south, Hadero-Tunto zuria woreda in the east, Soro woreda in the west and Duna woreda in the north.

Geographically, it is located between 37°21'E to 37°36'E and 07°11'N to 07°21'N. The total area of the woreda is about 27,917 hectares. The altitude of the woreda ranges from 800 to 2600 m.a.s.l and the slope ranges from intermediate (3%) to very steep slope (above 30%). The irrigation scheme is located in Osheto kebele at about 15km south-west of Mudulla town. The geographical location of the irrigation scheme is 07°18'66"-07°19'16"N latitude and 37°26'92"-37°27'69"E longitude. The total irrigable area of the scheme is about 120 hectare (TWADO, 2008).

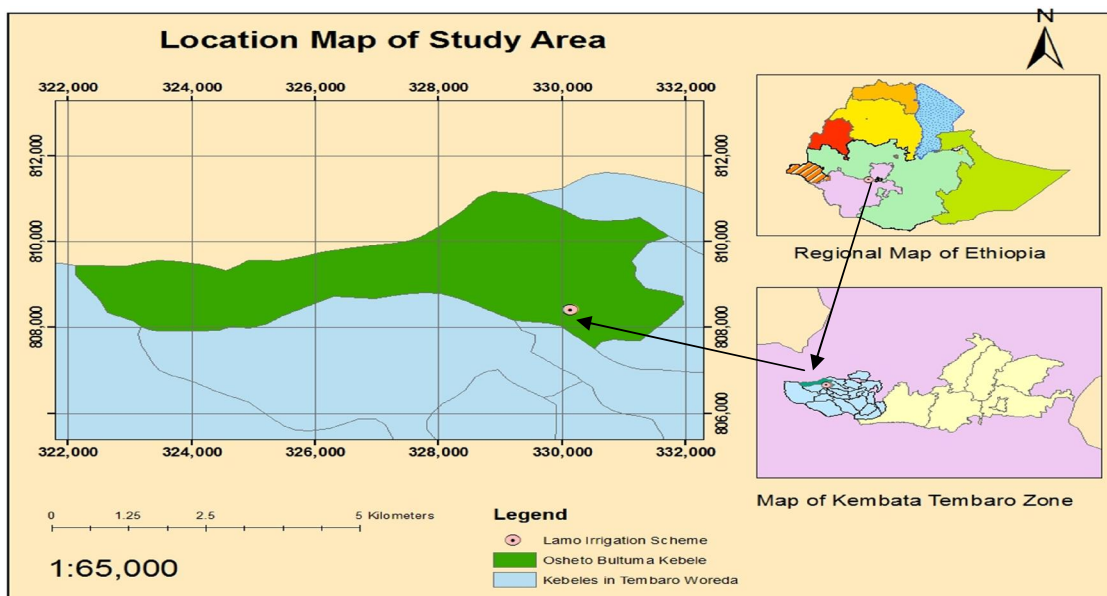


Figure 3.1. Location map of study area (Lamo irrigation scheme)

3.1.2. Climate and Rainfall Distribution

Tembaro woreda encompasses three agro-ecological zones (i.e. Kolla, Woyena-Dega and Dega). Kolla lies between altitudinal range of 800m.a.s.l to 1650m.a.s.l, annual rainfall of about 800mm to 900mm and its annual temperature is 22⁰C to 25⁰C. The Weyna Dega lies between the altitude ranges of 1650m.a.s.l. to 2300m.a.s.l, annual rainfall of about 900mm to 1000mm and its annual temperature is 15⁰C to 22⁰C. Dega coverage is smaller, which is the third agro-climatic zone with altitudinal range of 2300m.a.s.l. to 2600m.a.s.l, annual rainfall of 1000mm to 1200mm and annual temperature of 12⁰C to 15⁰C.

The study area lies in kolla agro-ecological zone (dry season) with average annual rainfall of 875.36mm and temperature of 23.25⁰C (TWADO, 2008).

3.1.3. Geology and Soils

The dominant soil of the woreda is Alfisols. According to many evidences, Alfisols are among the best agricultural soils with clay-to-clay loam texture and the pH value ranges from 6.5 to 7.8. The soil in the study area is characterized with clay loam texture and average pH value of 7.25 (TWADO, 2008).

3.1.4. Population

The total population of the woreda is estimated to be 129,849. Out of this, the total population of Osheto kebele is 4,170 (CSA, 2008). The area is characterized by high population densities with average family size per household are 5. Apparently, the continuous rise of population puts huge pressure on the essential resources like: water, land and forest (TWADO, 2008).

3.1.5. Economic Activities

The livelihood of people in the woreda depends mainly on mixed agriculture (crop-livestock production) characterized by subsistence production. The most commonly cultivated crops in the study site using rain-fed agriculture include Maize and Teff while using irrigated agriculture onion and tomato crops are dominant which are used for both household consumption and income generation (TWADO, 2008).

3.2. Field Layout and Selection of Crops

In order to evaluate the performance of Lamo small-scale irrigation scheme at field level and to compare each other in the project, six farmers' fields were selected. These fields were selected from head, middle and tail end water users of the irrigation project with respect to water source. A total of 6 farmer's plots grown with two major crops (onion and tomato) due to the crops are dominant, resistant to crop disease, have good market access, water availability and ease of management.

3.3. Data Collection Methods

To acquire the required information needed to meet the objectives of the study, both primary and secondary data collection techniques were employed.

3.3.1. Primary data collection methods

Primary data were obtained through questionnaires, interviews, field observations/measurements and laboratory analyses (soil and water sample). By using questionnaires and interviews, water committee members and fifteen randomly selected irrigators give information on irrigation scheme (water management and operation currently used by irrigators, and problems on physical structure of the scheme).

Soil characterization

To investigate the bulk density and moisture content of the soil at field capacity (FC) and permanent wilting point (PWP), undisturbed soil samples were collected with core sampler from six locations based on effective root depth of the crops at 30cm depth intervals.

To know the PH and particle size distribution, disturbed soil samples were taken from different points at depths of 30cm intervals in a zigzag fashion. After taking the samples, they were mixed thoroughly. The composite samples transferred to plastic bag and taken to soil laboratory for different analysis.

Moisture contents at field capacity, wilting point, and bulk density

Moisture contents at field capacity, wilting point and bulk density of the soil profile were determined using twenty four undisturbed soil samples, with two replications per sample, collected by using core cylinder of 100cm³ volume from six soil pits at 30cm depth interval.

The soil samples were placed in containers of known weights and weighed to find the total weights. The container with the sample was placed in an oven and kept at 105⁰C for 24hrs and then weighed.

Soil samples were saturated for one day (24hrs) and a pressure of 1/3 bar (for field capacity) and 15 bars (for permanent wilting point) were exerted until no further change in soil moisture content was observed. The difference between the weights before and after drying gave the moisture content of the soil sample on dry weight basis.

Irrigation water quality

The chemical analyses of the water samples of the Lamo River conveyed to the canals of the scheme were conducted at Hawassa water resource and irrigation development bureau (water quality laboratory) to study the salinity hazard from the water.

3.3.2. Secondary data collection methods

Secondary data was obtained from Mudulla meteorological station (climatic data: rainfall, temperature, humidity, and sun shine), agricultural development offices (crop data: major irrigated crops, cropping pattern and crop calendar) and water, mines and energy offices (WMEO): operation and management of irrigation scheme, and problems on physical structure of the scheme.

3.4. Crop Water Requirement and Net Irrigation Requirement

To estimate the crop water requirements (CWR) and irrigation scheduling of the irrigated crops at field levels and the irrigation project as a whole the CropWat 4 windows (Version 4.2) was used. This program uses the FAO (1992) Penman-Monteith equation for calculating reference crop evapo-transpiration. The determination of CWR by this model depends on the determination of reference evapo-transpiration values using the available climatic data.

i. Crop data

Through field observations, interview with agricultural development agents and beneficiaries, and water, mines and energy offices (irrigation experts), assessments were made to obtain information on the type of crops grown, planting and harvesting dates of the crops, cropping pattern and, current irrigation practices.

ii. Reference crop evapo-transpiration

Monthly reference crop evapo-transpiration (ET_o) for each year of climatic record were calculated based on the modified FAO Penman-Monteith equation (Allen *et al.*, 1998) using FAO CROPWAT software. The input data include, location i.e. altitude, latitude and longitude of Mudulla meteorological station, monthly average daily values of maximum and minimum air temperatures (⁰C), air humidity (%), sunshine duration (hours) and wind speed at 2-meter height.

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \dots\dots\dots(3.1)$$

Where: ET_o-reference evapo-transpiration (mm/day), R_n-net radiation at the crop surface (MJ/m² day), T-air temperature (⁰C), u₂-wind speed at 2 m height (m/s), e_s-saturation vapour pressure (KPa), e_a-air vapour pressure (KPa), (e_s-e_a)-saturation vapour pressure deficit (KPa), Δ-slope vapour pressure curve (KPa/⁰C), G-soil heat flux density (MJ/m² day) and γ-psychometric constant (KPa/⁰C).

iii. Crop water requirement

The crop water requirement (CWR) is the water which must be supplied to the crop plant to ensure that it received its full water requirement or a predetermined portion of it. Crop water requirement (ET_c) was determined for major crops of the study area based on the well established procedure given by Allen *et al.*, (1998) using Penman-Monteith equation.

$$ET_c = ET_o * K_c \dots\dots\dots(3.2)$$

Where: ET_c = crop water requirement (mm/day), ET_o = reference evapo-transpiration (mm/day) and K_c = crop coefficient (%)

iv. Net irrigation requirement

Net irrigation requirement (NIR) is the amount of irrigation water required to be delivered at the field to meet the evapo-transpiration needs of a crop during its full growth. Net irrigation requirement was calculated using the following equation:

$$NIR = ET_c - P_e \dots\dots\dots(3.3)$$

Where: NIR = net irrigation requirement (mm), ET_c = crop water requirement (mm/day), and P_e = effective rainfall (mm)

3.5. Soil Water Balance

The calculation of soil water balance is based on the relationship of crop water requirement and soil moisture content, where the soil moisture status will be determined based on a daily accounting of all incoming and outgoing water in the root zone as discussed in FAO guide lines (Smith, 1992; Allen *et al.*; 1998).

$$SMD_i = SMD_{i-1} + ET_c - P_e - I_d + R_o + D_p \dots\dots\dots(3.4)$$

Where: SMD_i = soil moisture depletion at day i (mm); SMD_{i-1} = soil moisture depletion at previous day (mm); ET_c = crop water requirement (mm/day); P_e = effective rainfall (mm); I_d = irrigation depth applied (mm); R_o = runoff (%); and D_p = deep percolation (%)

3.6. Water Supply

The total amount of water required by crops at all stages of growth at field level depends on depth of irrigation.

Total available water (TAW) is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and rooting depth.

$$TAW = 10(\Theta_{FC} - \Theta_{WP}) * Z_r \dots\dots\dots(3.5)$$

Where: TAW = total available soil water in the root zone (mm), Θ_{FC} = water content at field capacity (cm^3/cm^3), Θ_{WP} = water content at wilting point (cm^3/cm^3), and Z_r = rooting depth (cm)

Readily available soil water (RAW) is the amount of water that a crop uses readily available in the root zone.

$$RAW = 10(\Theta_{FC} - \Theta_{cwc}) * Z_r \dots\dots\dots(3.6)$$

Where: RAW = readily available soil water in the root zone (mm), Θ_{cwc} = critical water content (cm^3/cm^3)

3.7. Irrigation Scheduling

The irrigation scheduling was calculated by taking the farmers practices into consideration. This helps to create similar conditions with the farmers' irrigation practices and facilitates to examine and compare efficiencies of the selected fields against the optimum.

Scheduling at farmers fields should consider fixed interval and fixed depth application techniques throughout the growing season because farmers are not in a position to measure and monitor the soil moisture contents of the soil prior to irrigation to use appropriate scheduling.

3.8. Field Measurements for Irrigation Evaluation

Field topography and configuration

Topographic survey on the selected farmers' fields was made by placing a simple reference grid on the field at 5m interval and taking the elevation of grid points.

The survey had established the distance of each grid point from field inlet as well as field dimensions (length of the field in the primary direction of water movement as well as field width). From this survey, slope and area of the field were determined.

Flow measurement

Discharge rate available for irrigation from different locations was measured using Velocity-Area method. During an irrigation event the surface velocity ($v_s = L/t$) was obtained by using floating materials at specified length of interval in specific duration of time and average velocity of stream flow was calculated as: $V = 0.85 * v_s$.

The cross sectional area of the stream flow was determined by measuring the width of furrow and average depth of water applied (i.e. $A = w * d_{av}$). Finally the discharge rate (Q) of the stream at different sections was determined by multiplying average velocity by cross sectional area and computed as follows:

$$Q = \frac{(0.85 * L) * (w * d_{av})}{t_{app}} \dots \dots \dots (3.7)$$

Where: Q =discharge rate (lit/sec), d_{av} =average depth of water applied (mm), L =furrow length (m), w =furrow width (m), t_{app} =application time (sec).

3.9. Performance Evaluation of Irrigation Scheme

The following internal performance indicators were employed to characterize the performance of on-farm irrigation systems during an irrigation event.

a. Application efficiency

It is defined as the ratio of amount of water stored in the subject region to amount diverted into the subject region. The application efficiencies of irrigation at field level were calculated as follows (Mishra and Ahmed, 1990):

$$E_a = \frac{W_r}{W_f} \times 100 \dots\dots\dots(3.8)$$

Where: E_a = application efficiency (%), W_r = average depth of water added to the root zone (mm), and W_f = average depth of water applied to the field (mm)

b. Storage efficiency

The water storage efficiency should show how completely the water needed prior to irrigation has been stored in the root zone during irrigation. Storage efficiency is expressed using the following relation (Ramulu, 1998):

$$E_s = \frac{W_s}{W_p} \times 100 \dots\dots\dots(3.9)$$

Where: E_s = storage efficiency (%), W_s = average depth of water stored (mm), and W_p = average depth of potential storage (mm)

c. Distribution uniformity

To determine the distribution uniformity of irrigation water in the furrows, auguring were done at inlet, middle and end of each furrow before and after irrigation. At each selected points of the furrow, soil samples were collected at different depths with an interval of 30cm.

Moisture contents of the soils at the selected points were analyzed by gravimetric method. For calculating the distribution uniformity, the root depth of the crop was taken as the zone of distribution.

Burt, *et al.*, (1977) modified the model and expressed it as a ratio between the mean of low quarter depth and average irrigation depth as follows:

$$DU = \frac{Z_{lq}}{Z_{av}} \times 100 \dots \dots \dots (3.10)$$

Where: DU = distribution uniformity (%),

Z_{lq} = mean of the lower quarter depth (cm), and

Z_{av} = mean of depth infiltrated over the furrow length (cm)

d. Deep percolation ratio

Deep percolation ratio (DPR) that expresses the ratio between percolated water beyond the root zone to the volume of water applied to the field and calculated using the following equation:

$$DPR = \frac{D_p}{D_{av}} \times 100 \dots \dots \dots (3.11)$$

Where: DPR = deep percolation ratio (%), D_p = depth of water percolated below the root zone (mm), and D_{av} = average depth of water applied to the field (mm)

e. Tail water ratio

Losses from the irrigation system via runoff from the end of the field are indicated in the tail water ratio (TWR) and calculated as follows:

$$TWR = \frac{V_r}{V_f} \times 100 \dots \dots \dots (3.12)$$

Where: TWR = tail water ratio (%), V_r = volume of runoff (mm),

V_f = volume of water applied to field (mm)

Water Losses in Conveyance and Delivery System

For the determination of the losses in the main and secondary canals, flow measurements were made using velocity-area method.

To evaluate the existing delivery channel performance, inflow-outflow rate of the main conveyance irrigation channel at specified location were collected from the delivery channels using velocity-area method at 1.0km intervals in the channels. Besides, velocities of flow cross sectional areas of irrigation channels at different sections and locations were measured to analyze canal flow rate at different locations.

Variables used to describe delivery channel performance were channel delivery efficiency and channel loss rate.

Conveyance (Channel delivery) efficiency, E_d , for a length of channel is defined as follows:

$$Ed = \frac{Q_{out}}{Q_{in}} \times 100 \dots \dots \dots (3.13)$$

Channel loss rate (L_r) is measured as $m^3/sec/km$ of channel and is defined for a length of channel as follows:

$$Lr = \frac{Q_{in} - Q_{out}}{L} \dots \dots \dots (3.14)$$

Where: Q_{in} = inflow rate (m^3/s), Q_{out} = out flow rate (m^3/s), and
 L = length of channel (km)

3.10. Assessment of Problems on Current Irrigation Practices

To identify the key problems found on current irrigation practices, assessments were done through field observations, and inventories as well as discussions with beneficiaries, water committee, and development agents.

3.11. Data Analysis

Tabular data for different performance indices were analyzed using EXCEL, to compare the significance of performance indicators using inferential statistics (ANOVA) and to determine the crop water requirement by using CropWat software.

4. RESULTS AND DISCUSSIONS

4.1. Characterization of Soil in the Study Area

To investigate some of the properties of soil in the study area (texture, bulk density, PH, moisture content at field capacity (FC) and permanent wilting point (PWP), moisture content before and after irrigation), for the purpose of understanding the general feature of the irrigated soil type, different field observations were taken and analyzed.

Based on laboratory analysis, the textural class of soil in the study area was found to be clay loam at all depths and the average PH value of the soil was 7.25 which is suitable for crop production.

Table 1 Properties of soil in the study area (texture, PH)

Sampling depth (cm)	Particle size distribution (%)			Textural class	PH
	Sand	Silt	Clay		
0-30	35.00	30.00	35.00	Clay loam	6.85
30-60	34.78	29.66	35.56	Clay loam	7.26
60-90	33.31	29.00	37.69	Clay loam	7.42
90-120	32.88	28.90	38.22	Clay loam	7.47

Bulk density, Moisture contents at field capacity and permanent wilting point

The bulk density of soil of the area showed a variation with depth. The top surface soil had an average bulk density of 1.28 g/cm³ whereas; the subsurface had an average bulk density of 1.35 g/cm³, respectively. Generally, the top surface soil had lower bulk density than the subsurface (Table 2). According to the result, variation in bulk density of soil was due to variation in soil compaction i.e top surface soil had low compaction than subsurface and vice versa.

The moisture content at the field capacity varied with depth between 28.43% and 39.97% with average value of 33.62% on volume basis. The top surface soil has average FC value of 37.27%. Similarly, the sub surface soils have FC with average value of 32.25%. The moisture content at permanent wilting point also showed variation with depth ranging between 17.99% and 25.94% with average value of 21.77% on volume basis. The top layer has an average PWP value of 24.37% where as the subsurface soil has an average PWP value of 20.96%.

The total available water (TAW) is directly related to variation in FC and PWP. As a result, high values of TAW were found in topsoil, where as lower values were found in the subsurface soils. Average value of TAW was found to be 41.20mm at the top and 34.53mm in the sub-surface soil (Table 2). The result indicated that the moisture content is decreased from top to subsurface due to surface soil holds high moisture content than subsurface soil.

Table 2 Bulk density, field capacity, permanent wilting point, total available water

Sampling Point	Sampling depth (cm)	Bulk density (g/cm ³)	FC (%)		PWP (%)		TAW (mm/m)
			w/w	v/v	w/w	v/v	
SP1	0-30	1.22	26.69	32.56	15.87	19.36	39.60
	30-60	1.34	23.35	31.29	13.77	18.45	38.52
	60-90	1.29	23.32	30.08	14.24	18.37	35.14
	90-120	1.38	21.33	29.44	13.04	17.99	34.35
SP2	0-30	1.21	31.64	38.28	21.44	25.94	37.02
	30-60	1.23	29.01	35.68	19.13	23.53	36.47
	60-90	1.35	22.25	30.03	14.10	19.04	33.00
	90-120	1.51	19.54	29.50	13.87	20.94	25.70
SP3	0-30	1.41	28.35	39.97	17.47	24.63	46.02
	30-60	1.26	28.07	35.37	18.48	23.28	36.27
	60-90	1.34	24.47	32.79	15.63	20.94	35.55
	90-120	1.58	19.76	31.22	13.29	20.99	30.70
SP4	0-30	1.20	29.59	35.51	19.64	23.57	35.82
	30-60	1.26	28.76	36.24	18.66	23.51	38.20
	60-90	1.22	26.67	32.54	17.20	20.98	34.68
	90-120	1.28	23.15	29.63	15.05	19.26	31.12
SP5	0-30	1.20	31.15	37.38	18.51	22.21	45.51
	30-60	1.24	28.17	34.93	17.31	21.46	40.41
	60-90	1.29	25.70	33.15	15.72	20.28	38.62
	90-120	1.26	22.58	28.45	14.59	18.38	30.21
SP6	0-30	1.42	28.10	39.90	17.96	25.50	43.21
	30-60	1.40	26.12	36.57	16.21	22.69	41.64
	60-90	1.48	22.96	33.98	15.15	22.42	34.68
	90-120	1.35	21.06	28.43	14.55	19.64	26.37

SP = sampling point

4.2. Irrigation Water Quality

Results of water quality analysis are presented and discussed as follows. The electrical conductivity of irrigation water was found to be 96 micro mhos/cm which is below the recommended value for low salinity water (250 micro mhos/cm), and suitable for irrigation. The average pH value of the water is 6.85, which is in the range of normal value. This indicates that there would not be problem of acidity or basicity from this source.

The sodium percentage of the water sample was found to be 3mg/l which is in the lower range. Therefore the water might be considered as suitable for irrigation of all types of crops. The chlorine concentration of the water was found to be 1.25mg/l, and is free of toxicity since the recommended value is in the range of 0.99 to 1.5mg/l.

The quality of water might be considered as high for irrigation purpose (Class C1-S1) with low sodicity and low salinity hazards (SAR of 1.11 and EC_w of 96 micro mhos/cm) causing no hazard to the soil if applied for long time (Brady, 1988).

Table 3 Chemical analysis of irrigation water

Item	Result
Electrical Conductivity (micro mhos/cm at 25°C)	96
PH	6.85
Sodium (mg/l Na^+)	3
Calcium (mg/l Ca^+)	8.8
Magnesium (mg /l Mg^{+2})	5.84
Potassium (mg/ l K^+)	1.75
Chloride (mg/ l Cl)	1.25
Nitrate (mg/l NO_3)	1.7
Bicarbonate (mg/l HCO_3)	51.24
SAR (%)	1.11

4.3. Crop Water Requirement

The water requirement of the major crops grown in the irrigation scheme were determined using CROPWAT computer model based on the irrigation intervals of each crops as practiced by the farmers at each plots presented on seven (7) days basis.

The computation result using the software indicated that a total crop water requirement of onion was 459.67mm and effective rainfall was 11.70mm. As a result shown in Table 4, the total net irrigation water required over the growing period of onion was 447.98mm. The daily peak irrigation demand of the onion crop was found to be 40.10mm.

From Table 5, the total crop water requirement for the growing period of tomato was 585.44mm and the amount of peak irrigation demands was 38.11mm. The amount of effective rainfall was 71.31mm and 514.10mm water for the consumptive use of the crop was required from irrigation; it was needed throughout the growing season of the crop.

Similar research results conducted by Dessalew et al. (2016) at Hallaba special woreda in Bedene Alemtena irrigation scheme showed that the crop water requirement for onion and tomato crops were 460.25mm and 536.42mm, respectively. The values indicate similar results obtained using Cropwat in Lamo irrigation scheme.

According to the result obtained, the total crop water requirement for the crops practiced by the farmers is far more than the required crop water demand. This indicates that the farmers applied excess amount of water to the field without considering the stages of crop growth and crop water demand.

Table 4 Crop water requirement report of Onion

- Crop # 1: Onion

- Planting date: 19/2/08

- Calculation time step = 7 Day(s) - Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (ha)	Crop Kc	CWR (ETc)	Total Rain ----- (mm/period)	Effect. Rain -----	Irr Req.
19/2/08	32.37	100.00	0.70	22.66	0.00	0.00	22.66
26/2/08	33.64	100.00	0.70	23.55	0.00	0.00	23.55
2/3/08	36.62	100.00	0.70	25.69	0.00	0.00	25.69
9/3/08	37.14	100.00	0.76	28.17	0.00	0.00	28.17
16/3/08	37.57	100.00	0.84	31.57	0.00	0.00	31.57
23/3/08	37.90	100.00	0.92	34.93	0.00	0.00	34.93
30/3/08	38.11	100.00	1.00	38.24	0.00	0.00	38.24
6/4/08	38.19	100.00	1.05	40.10	0.00	0.00	40.10
13/4/08	38.15	100.00	1.05	40.06	0.00	0.00	40.06
20/4/08	37.98	100.00	1.05	39.88	0.76	0.74	39.14
27/4/08	37.68	100.00	1.05	39.57	1.97	1.61	37.96
3/5/08	37.26	100.00	1.04	38.77	3.03	2.51	36.26
10/5/08	36.73	100.00	1.00	36.61	4.38	3.88	32.73
17/5/08	20.71	100.00	0.96	19.88	3.20	2.96	16.92
Total	500.06			459.67	13.35	11.69	447.98

Table 5 Crop water requirement report of Tomato

- Crop # 1: Tomato - Calculation time step = 7 Day(s)
 - Planting date: 7/2/08 - Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (ha)	Crop Kc	CWR (ETc)	Total Rain ----- (mm/period) -----	Effect. Rain	Irr Req.
7/2/08	30.74	100.00	0.50	15.37	0.00	0.00	15.37
14/2/08	31.71	100.00	0.50	15.85	0.00	0.00	15.85
21/2/08	32.63	100.00	0.50	16.32	0.00	0.00	16.32
28/2/08	34.63	100.00	0.50	17.31	0.00	0.00	17.31
4/3/08	36.78	100.00	0.53	19.38	0.00	0.00	19.38
11/3/08	37.28	100.00	0.61	22.84	0.00	0.00	22.84
18/3/08	37.68	100.00	0.70	26.38	0.00	0.00	26.38
25/3/08	37.97	100.00	0.79	29.90	0.00	0.00	29.90
1/4/08	38.15	100.00	0.88	33.38	0.00	0.00	33.38
8/4/08	38.19	100.00	0.96	36.76	0.00	0.00	36.76
15/4/08	38.11	100.00	1.00	38.11	0.00	0.00	38.11
22/4/08	37.91	100.00	1.00	37.91	1.23	1.14	36.77
1/5/08	37.57	100.00	1.00	37.57	2.24	1.81	35.77
8/5/08	37.12	100.00	1.00	37.12	3.39	2.86	34.26
15/5/08	36.56	100.00	1.00	36.56	4.81	4.34	32.22
22/5/08	35.89	100.00	1.00	35.89	6.48	6.09	29.80
29/5/08	35.13	100.00	0.98	34.46	8.36	8.01	26.46
5/6/08	34.28	100.00	0.89	30.63	10.44	10.00	20.63
12/6/08	33.36	100.00	0.80	26.70	12.69	11.99	14.70
19/6/08	32.39	100.00	0.71	22.90	15.09	13.95	8.94
26/6/08	22.52	100.00	0.63	14.11	12.31	11.13	2.98
Total	736.58			585.44	77.05	71.31	514.14

4.4. Soil Water Balance

In order to establish water balance during irrigation event over the growing season of the crops, the knowledge of crop water requirement and soil moisture content are important. Based on incoming and outgoing water in the root zone of crops the average soil moisture deficit was found to be 30.9mm/m and 24.35mm/m for onion and tomato crops, respectively.

There is a room to improve performance of furrow irrigation system in the scheme through soil water balance by applying a depth equivalent to the management allowable soil moisture deficit on the least watered point-zero deficit irrigation (Ley and Clyma, 1981). There was variation in soil moisture deficit from place to place due to poor water management, variation in irrigation depth of crops and also soil moisture content.

4.5. Water Supply

To analyze current water supply at field level, total available water and readily available water are critical factors. Based on the result obtained from field evaluation, the average actual water applied by the farmers with 7 days interval was 136mm that was more than three times of the required value.

According to IWMI (2007), the amount of water applied to the root zone of crops was based on irrigation scheduling. The depth applied per irrigation should be small under frequent applications than large discharge which is available less frequently. This happens due to very poor water application problem seen at field level and concluded that there was no shortage of water supply observed as problem according to their location.

4.6. Irrigation Scheduling

Mean application depth per irrigation turn, measured during field evaluation was much higher than the required depth to be applied, irrespective of the type and stages of crop grown in the area since the irrigators could not control the irrigation depth. The maximum crop water requirement (ET_c) and net irrigation requirement (NIR) for major irrigated crops with 7 days interval of the study area were calculated with CropWat and presented in Table (4-5). But by the farmers practice, the actual net irrigation supplied for all crops during their growing period was far more than NIR calculated.

Table 6 Crop calendar of the study area

Crop type	Growing length (month)	Planting period		Harvesting period	Remark
		Range	Common		
Onion	3-4	Oct.-Dec.	Nov.-Jan.	Jan.-March	Irrigated
Tomato	3-4	Oct.-Jan.	Oct.-Dec.	Dec.-Jan.	Irrigated

The required depth of irrigation water to be applied (Z_r) during irrigation event was computed for each of fully grown major irrigated crops to sustain normal crop growth and obtain satisfactory yield.

The required irrigation depth to be applied by tomato fields (50.8mm) during an irrigation event was highest. Onion fields require relatively small depth of irrigation water, about 25.1mm. The average depth of irrigation water applied by irrigators was 136mm and was far more than the required depth of all crops in the area.

In surface irrigation, it is very confusing for the farmers to change the schedule all the time. Therefore, it is often sufficient to estimate or roughly calculate the irrigation schedule and to fix the most suitable depth and interval: to keep the irrigation depth and interval constant over the growing season (FAO, 1989). This happened due to large amount of water applied to the field by the farmers practice resulted into wastage of large amount of irrigation water.

Table 7 Required irrigation depth to be applied for fully grain annual irrigated crop

Crop	Rooting depth (m)	Depletion fraction (P)	TAW (mm/m)	Z_r (mm)
Onion	0.45	0.30	83.8	25.1
Tomato	1.00	0.40	127.0	50.8

4.7. Field Measurements for Irrigation Evaluation

The results of irrigation variables or parameters measured in the study area were presented and discussed as follows:

Table 8 Irrigation variables / parameters

Irrigation variables	Minimum	Maximum	Mean
Furrow length (m)	10.00	30.00	20.00
Furrow space (m)	0.45	0.75	0.60
Area (m ²)	4.50	22.50	13.50
Slope (%)	0.20	1.30	0.75
Inflow rate (lit. /sec.)	5.73	6.61	6.17
Inflow time (min)	2.13	7.55	4.84

4.7.1. Furrow inflow time

The starting and cutoff times experienced by the farmers to irrigate each furrow were monitored at the time of water application during growing season. The result showed that the mean furrow inflow time during irrigation event was 4.84 minutes and used for determining water delivered to the furrow. The result indicated that maximum amount of water was applied to the field with in very short period of time.

4.7.2. Furrow slope

Farmers in the study area used the same types and size of irrigation event irrespective of the type of crop grown. All farmers smooth their land as part of their field preparation before each cropping season with the help of hand equipment. Thus this results rough surface and variable slopes which lead to poor application of water at field level.

4.7.3. Furrow length

Furrow lengths determined on the basis of the current sizes of farms. For small scale irrigation schemes the maximum length of furrow was determined by the maximum width of irrigation plot. The measured furrow length varied between 10m to 30m with mean value of 20m. This variation in furrow length affects the distribution uniformity (i.e. short furrow length had higher distribution uniformity than long furrow length and vice versa).

4.7.4. Furrow geometry and spacing

Furrow dimensions on each selected plots were measured at 5-10m intervals depending on furrow lengths. The spacing of furrows varied between 0.45m to 0.75m with mean value of 0.60m.

Furrows can be characterized by U-Shape with depth varying from 15 to 20cm, and the top width varying from 65 to 75cm and bottom width varying from 25 to 45cm. This variation of the furrow spacing was based on the variation of crop type.

4.7.5. Furrow inflow rate

The inflow rate varies from 5.73 to 6.61 lit/sec with mean value of 6.17 lit/sec. This happened due to farmers apply excess amount of water to the field without considering crop water requirement.

4.8. Performance Evaluation of Irrigation Scheme

The parameters required to evaluate the performance of Lamo small-scale irrigation scheme using internal performance indicators were determined and discussed as follows.

Fields (F1 and F4) were located at the head of the main canal, fields (F2 and F5) were located at the middle of the main canal and fields (F3 and F6) were located at end of the main canal. Looking into average depth of water applied, more water was applied by fields that were located at tail end users of 153mm, than head and middle users 130 and 124mm, respectively.

The distance of the field from the water source did not limit the farmers from applying excess water. This phenomenon was more demonstrated by the average depths of water applied by the farmers in relation to their locations.

The average actual water applied by the farmers (136mm) with 7 days interval was more than three times of the required irrigation depth to be applied. This was happened due to poor application of water seen at field level by the farmers.

Table 9 Summary results of different irrigation efficiency of irrigation events

Crop Type	Farmer's Field	Average efficiencies, %			Deep percolation ratio
		Application	Storage	Distribution	
ONION	F1	38.09	86.25	78.00	61.91
	F2	40.07	81.60	81.00	59.93
	F3	43.12	77.56	79.30	56.88
	Average	40.4	81.8	79.4	59.6
TOMATO	F4	57.58	82.40	90.30	42.42
	F5	46.66	85.35	81.90	53.34
	F6	63.20	78.26	68.30	36.80
	Average	55.8	82.0	80.2	44.2

4.8.1.1. Application efficiency

From Table 9, it could be inferred that the plots planted with deep- rooted crops performed much better than those planted with shallow rooted -crops in case of application efficiency. Tomato fields had the highest application efficiency of 57.58%, 46.66% and 63.20% with mean of 55.8% on plots F4, F5, and F6, respectively. Onion fields had the second highest application efficiency that were found as 38.09%, 40.07% and 43.12% with mean value of about 40.4% for plots F1, F2, and F3, respectively.

From the above results, it could be concluded that the major portion of irrigation water admitted into onion fields was lost and the minimum loss was occurred in fields planted with tomato. Application efficiency was significantly affected ($p < 0.05$) by the inflow rate. Large mean value of application efficiency (55.8%) was observed for small inflow rate (5.95 l/s) and least mean application efficiency (40.4%) was recorded for large inflow rate (6.13 l/s).

Research results conducted by Dessalew et al. (2016) showed that the average application efficiency in Bedene Alemtena irrigation scheme at Hallaba special woreda was found as 54.9% which indicates the performance of irrigation scheme was poor. FAO (1989) reported that the attainable application efficiency according to the USSCS ranges from 55-70%, values below this limit would normally be considered as unacceptable.

Furrow irrigation system design followed by the farmer is not acceptable since application efficiency was less than 70% (Ley and Clyma, 1981). The main reason for variation of application efficiency with type of crops grown might be due to poor application of water at field level without considering the required irrigation depth to be applied for the crops.

Table 10 The significance effect of inflow rate on different performance indicators

	efficiencies, %			Deep percolation ratio
	Application	Storage	Distribution	
Mean	48.1	81.9	79.8	51.9
SEm±	0.367	0.642	1.446	0.386
LSD (0.05)	1.64	2.848	4.56	1.475
CV (%)	2.08	2.36	4.42	3.61

SEm- Error mean square, LSD- Least significant difference, CV- Coefficient of variance

4.8.1.2. Storage efficiency

The storage efficiency for onion crops planted on fields F1, F2 and F3 were found as 86.25, 81.60 and 77.56%, respectively while for tomato crops planted on fields F4, F5 and F6 were found as 82.40, 85.35 and 78.26%, respectively. Fields planted with tomato were found to have the highest storage efficiencies of 82.0% followed by onion with mean E_s values of 81.8% (Table 9).

Inflow rate had significant effect ($p < 0.05$) on storage efficiency of the scheme. The least mean storage efficiency (81.8%) was observed for large inflow rate (6.13 l/s) and highest mean storage efficiency (82.0%) was recorded for small inflow rate (5.95 l/s).

According to Dessalew et al. (2016) research results in Bedene Alemtena irrigation scheme indicates that the average storage efficiency was obtained as 62.34%. When compared to this value Lamo irrigation scheme performs better with average storage efficiency of 81.9%. However, Natural Resource Conservation of UK recommends storage efficiency for homogenous soil condition to be 87.5% (Raghuwanshi and Wallender, 1998). Based on the result obtained, variation in storage efficiencies was due to farmers applied excess amount of water without considering potential storage depth of the crops.

4.8.1.3. Distribution uniformity

Distribution uniformity in each plot was estimated as; 78.0, 81.0, and 79.3% for onion crop on plots, F1 (24m), F2 (15m), and F3 (26m), respectively. Plot F2 was more efficient than the other plots since its inflow rate was high and with minimum furrow length.

For tomato crop the distribution uniformity values were observed as 90.3, 81.9, and 68.3% for farms, F4 (10m), F5 (15m), and F6 (30m), respectively. Farm F4 was more efficient than Farm F5 and Farm F6. This may be due to smaller length of farm F4 as compared to farms F5 and F6 (Table 9).

Distribution uniformity was significantly affected ($p < 0.05$) by the inflow rate. Large mean value of distribution uniformity (80.2%) was observed for small inflow rate (5.95 l/s) and least distribution uniformity (79.4%) was recorded for large inflow rate (6.13 l/s). The result indicated that the main reasons for the variation of distribution uniformity was due to farmers were applying the same irrigation depth without considering the furrow length.

Based on the findings done by Dessalew et al. (2016), the average distribution uniformity was found as 90.23% which is more uniform than the value obtained by Lamo irrigation scheme, 79.8%. According to the study conducted by Eisenhauer (1997), distribution uniformity $\geq 60\%$ indicates that the application is relatively uniform over the entire field. Therefore, the value of distribution uniformity obtained in Lamo irrigation scheme indicates the application is uniform over the entire field.

4.8.1.4. Deep percolation ratio

The two principal irrigation water losses in surface irrigation method are runoff and deep percolation. In this particular case, since the furrow ends were dyked there were no runoff losses. The magnitude of deep percolation loss varies with the type of crops grown. Crops with high application efficiencies had lowest deep percolation ratio value and vice versa.

Accordingly, irrigation water loss due to deep percolation was highest in onion fields and those were found as 61.91%, 59.93% and 56.88% with average value of 59.6% for farms F1, F2 and F3, respectively. Deep percolation ratio in tomato fields were found as 42.42%, 53.34% and 36.80% with mean value of 44.20% for farms F4, F5 and F6, respectively (Table 9).

Deep percolation ratio was significantly affected ($p < 0.05$) by the inflow rate. Large mean value of deep percolation ratio (59.6%) was observed for large inflow rate (6.13 l/s) and least deep percolation ratio (44.2%) was recorded for small inflow rate (5.95 l/s).

Furrow irrigation system design followed by the farmer is not acceptable since deep percolation ratio was greater than 10% (Ley and Clyma, 1981). Therefore, the result obtained from Lamo irrigation scheme was far more than the acceptable limit which indicates poor performance of the scheme. This variation happened due to farmers were applying excess amount of water to the field without considering the required irrigation depth of the crops.

4.9. Water Losses in Conveyance and Delivery System

The performance of irrigation channel was analyzed using conveyance efficiency (channel delivery efficiency) and channel loss rate as presented and discussed as follows:

4.9.1. Conveyance efficiency

Using velocity-area method, the average conveyance efficiency for main canal was found to be 82.5% where as for secondary canal; it was found to be 80.8% (Table 11-12).

Ministry of Agriculture and Food Security (2007) study indicated that typical conveyance efficiency values for well managed canals should be above 85%. According to this study the value of conveyance efficiency obtained in Lamo irrigation scheme indicates the canals were poorly managed and at low level of performance. The result indicated the channel delivery capacity was decreased due to seepage losses from canal bank damage, crack and breaching of the canals.

Table 11 Main canal efficiency and loss rate using velocity-area method

Parameters	Distance of station (km) from the head of the canal				
	0	1	2	3	4
Canal cross sectional area (m ²)	0.275	0.229	0.208	0.200	0.198
Flow velocity (m/sec)	0.452	0.437	0.386	0.344	0.290
Canal discharge, Q (m ³ /sec)	0.1243	0.1001	0.0803	0.0688	0.0574
Conveyance efficiency (%)	80.5 80.2 85.7 83.4				
Canal loss rate (m ³ /sec/km)	0.0167				

Table 12 Secondary canal efficiency and loss rate using velocity-area method

Parameters	Distance of station (m) from the head of the canal	
	0	450
Canal cross sectional area (m ²)	0.06	0.056
Flow velocity (m/sec)	0.66	0.58
Canal discharge, Q (m ³ /sec)	0.0396	0.033
Conveyance efficiency (%)	80.8	
Canal loss rate (m ³ /sec/km)	0.0147	

4.9.2. Channel loss rate

The average channel loss rates from main and secondary canal were found to be 0.0167 m³/sec/km (16.7 lit/s/km) and 0.0147 m³/sec/km (14.7 lit/s/km), respectively (Table 11-12). Generally channel loss rate which considers seepage losses were happened to be within 0.0035 to 0.0175 m³/sec/km (3.5-17.5 lit/s/km) values as obtained and reported in Greece (Kraatz, 1977). According to the result, this loss was happened due to damages and cracks were found on the canals which decreases the canal capacity.

4.10. Water Delivery and Distribution System

According to survey and inventory of the scheme, water delivery and distribution system consists of 4.25km lined main canal which has the maximum discharge capacity to deliver 230l/s and it has trapezoidal shape and has 0.578m² cross-sectional area and the land adjacent to the main canal has steep gradient which does not permit direct off take from the main canal.

In order to irrigate a relatively plain area towards the river bank, secondary unlined canals with varying lengths and capacities were 30lit/s each with 0.06m² cross-sectional area. These canals run nearly parallel to the main canal at 1 in 30 recommendable longitudinal slopes each. Tertiary canals were constructed to distribute water from secondary canals to irrigation fields. For the off take of this water, temporary small openings at the side of secondary canals and plastic siphons were directly constructed.

From field's observation and analysis of interview, due to unwise use of water by the head end users, there is water logging on the field and losses problem of the main canal, as a result the tail end users faces water shortage frequently. A representative farmer assigned by the association throughout the year manipulates the gate at diversion weir.

Once it is opened, it stays till the rainy season comes with only for few days' interruption for canal cleanings. The representative water committee makes water allocation for the farmers. The distribution could be allocated day and night rotation or for specific period (days interval) within a week.

4.11. Scheme Management and Operation

According to the analysis of interview and discussions with water committee, farmers and development agents, the scheme was managed by water committee and beneficiaries. The water committee members are locally elected from farmers. The method of operating the supply system is rotational. To use the water efficiently, this committee had a responsibility of controlling the whole system of the project i.e. controlling the health of all structure, and evenly distribution of water for all farmers.

Use of water from the canal was based on rotation systems i.e. some crew used the water for certain days and the other crews used the water keeping their time without any quarrel and vandalize. The water that the farmers used to irrigate their farmland did not have any fee. The canals were maintained by the farmers during the rainy season.

The water committees had three executive persons and one monitorial person. Each plot holder was kept responsible to operate the scheme during his turn and supposed to check the distribution field ditch starting from his plot to the outlet.

According to IFAD (2005) study indicated that joint responsibility of beneficiaries and irrigation authorities for maintenance is essential to bring sustainability of the irrigation scheme.

4.12. Assessment of Problems on Current Irrigation Practices

4.12.1. Problems on Physical Structure of the Scheme

1. Diversion weir and ancillary structures

Based on survey and inventory data of physical structures, there was no as such significant default on the weir crest. But the intake gate had a problem during the operation time i.e. the gate rod gates had a bending effect during the closing and opening of the intake gate and also the same problem faced for the gate of the sluice. Pipe culvert, which was placed between the intake gate and the main canal, had a seepage problem.

2. Cross drainage structures

The structures, which were constructed to drain the erosion, had got a problem of embankment erosion i.e. the soils that support the cross drainage structure was severely eroded at its side as well as bed.

3. Main canal ancillary structures

Main canal is a structure which conveys water from the river to different parts of the scheme. The canal capacity decreased due to seepage loss. At damaged part of the main canal, during the rainy season there was a great problem of erosion due to improper management cross drainage structures.

4. Secondary canals

For the first block of farm land, secondary canal was not constructed and due to this field near to the canal was left out of production.

4.12.2. Operational and Management Problems of the Scheme

Based on the study conducted by Cakmak (2004) improving performance of irrigation scheme is becoming important because the performance of many irrigation schemes is significantly under their potential due to one of the shortcomings such as poor planning, operation and maintenance, and over all poor water management practices.

Based on the analysis of the survey data, 40% of farmers interviewed, responded as the water logging at the field was serious problem for their operation which occurred at the head end farms. Due to this problem, some part of the farm land was out of production, whereas 60% of farmers interviewed responded as the shortage of water occurred in some part of tail end farm during dry season.

According to survey analysis, 92% of farmers interviewed responded that generally field water application system was traditional and water management was poor. Due to poor awareness level of the farmers in water application techniques and poor practice of removing surplus water, resulted into shortage of water and water logging problems and these counts the major and critical problem of the irrigator.

According to survey and inventory analysis, due to absence of cross drainage structures at the head of the main canal resulted siltation due to erosion in rainy season and consequently the capacity of the main canal decreased and reduced flow with disruption of irrigation supply. The result of analysis indicated that poor canal conditions, leakage of structures, unfunctional intake gates and canal bank damages were observed to be sources of seepage loss on the main canal.

5. SUMMARY AND CONCLUSION

5.1. Summary

This study was made to evaluate the performance of Lamo small-scale irrigation system using internal performance indicators as a tool such as application efficiencies, storage efficiencies, distribution uniformity and deep percolation ratio while Operation and management, and status of physical structure of the scheme were analyzed using household questionnaires, interviews, field observations and inventories in the study area.

Primary data collection was carried out through questionnaires, interviews, field observations/measurements, laboratory analyses (soil and water sample) and inventories. Secondary data was obtained from Mudulla meteorological station (climatic data: rainfall, temperature, humidity, and sun shine), agricultural development offices (crop data: major irrigated crops, cropping pattern and crop calendar) and water, mines and energy offices (WMEO): operation and management of irrigation scheme, and problems on physical structure of the scheme.

The crop water requirement of the major crops grown in the study area was calculated using CropWat software. The computation result indicated that a total crop water requirement for onion and tomato crops was found to be 459.67mm and 585.44mm, respectively. According to the result obtained, the total crop water requirement for the crops practiced by the farmers was far more than the required crop water demand. This was due to the farmers applied excess amount of water to the field without considering the stages of crop growth and crop water demand.

In order to evaluate the performance of furrow irrigation system at field level and to compare each other in the project, six (6) farmers' fields were selected in relation to their location (head, middle and tail end water users) and considering the major irrigated crops (onion and tomato) of the command area. The parameters used to compare the performance of irrigation scheme at field level were application efficiency, storage efficiency and distribution uniformity.

Fields (F1 and F4) were located at the head of the main canal, fields (F2 and F5) were located at the middle of the main canal and fields (F3 and F6) were located at end of the main canal.

Looking into average depth of water applied, more water was applied by fields that were located at tail end users of 153mm, than head and middle users 130 and 124mm respectively. The distance of the field from the water source did not limit the farmers from applying excess water. The result indicated that farmers were applying excess amount of water to their fields without considering the crop water requirement.

The result obtained from field evaluation, average application efficiencies of tomato crops were found as 55.81%, where as the onion field had the least application efficiency with average value of 40.40%. Application efficiency was significantly affected ($p < 0.05$) by the inflow rate. Large value of application efficiency was observed for small inflow rate and vice versa. The main reason for variation of application efficiency with type of crops grown might be due to poor application of water at field level without considering the required irrigation depth to be applied for the crops.

Average storage efficiencies in onion and tomato fields were observed as 81.80% and 82.00%, respectively. Inflow rate had significant effect ($p < 0.05$) on storage efficiency of the scheme. The least storage efficiency was observed for large inflow rate and vice versa. According to the result obtained, variation in storage efficiencies was due to farmers applied excess amount of water without considering potential storage depth of the crops.

Average distribution uniformity in onion and tomato fields was observed as 79.40% and 80.20%, respectively. Distribution uniformity was significantly affected ($p < 0.05$) by the inflow rate. Large value of distribution uniformity was observed for small inflow rate and vice versa. The result indicated that the main reasons for the variation of distribution uniformity was due to farmers were applying the same irrigation depth without considering the furrow length.

The magnitude of deep percolation loss varied with types of crop grown. Deep percolation ratio was varied from 44.20% to 59.60%. Deep percolation ratio was significantly affected ($p < 0.05$) by the inflow rate. Deep percolation ratio varied with inflow rate. This variation happened due to farmers were applying excess amount of water to the field without considering the required irrigation depth of the crops. Since farmers were using end-dyke furrow irrigation system there was no problem of runoff loss.

The conveyance efficiencies and seepage losses in the main canal and secondary canals were found as 82.5 and 80.8% and 0.0167 and 0.0147 m³/sec/km (16.70 and 14.70 lit/sec/km), respectively. This result indicated the channel delivery capacity was decreased due to seepage losses from canal bank damage, crack and breaching of the canals.

There was some canal structures which were found damaged. Especially the improper management of cross drainage structures resulted in a great erosion effect on the main canal and also the presence of seepage loss on the main canal was found responsible for the shortage of water and water logging problem at field level. Dykes that were constructed to protect the erosion from the main canal were unable to direct the water to the cross drainage structures and breaching of canals by the cattle was found in the nearby kebele.

5.2. Conclusion

From investigations made during the study, the conclusions outlined below can be drawn.

- The evaluation of the irrigation scheme indicated that higher amount of water was diverted to the field which indicates irrigation water was not a constraint at field level.
- Farmers were applying excess amount of water to their fields without considering the crop water requirement. Low efficiencies were achieved due to the fact that poor water management by the farmers at field level.
- The awareness level of the farmers in water application system especially on appropriate water application depth, appropriate cut-off time, and use of water economically, and practice of removing surplus water was very poor.

- Since there is a great loss of water at damaged part of the main canal, it was felt better to compact by providing pit soil or stony materials.
- The dykes constructed to protect the main canal from erosion were unable to protect it. The pipe culvert which allowed the water from the diversion weir to the main canal resulted into seepage problem and there was also observed cracks on the aqueduct.
- At first block the main canal, the secondary canal was not been constructed and due to this, the land near to the canal was not properly cultivated by the farmers.
- There is about ten hectare area which is suitable for the future expansion at the downstream side of the river which needs more money for its expansion.

5.3. Recommendations

Based on the study results, the following recommendation should be drawn for better performance of the irrigation scheme.

1. In order to overcome the poor water management at field level;

- it is better to give intensive practical training to the farmers about removing surplus water and economical application of water with appropriate inflow rate.

2. Water user associations and committees that undertake the operation and management of irrigation scheme should be empowered for better health of the system.

3. All activities in the irrigation network should be continuously monitored and checked, and also technical requirements should be met.

4. Immediate solution should have to be solicited for seepage loss in the main canal;

- it is better to compact damaged part of the main canal by packing materials.

5. Since there is breaching of main canal by erosion;

- it is better to provide cross drainage structures to protect the severe effect of the erosion up on the canal and
- it is better to upgrade the height of the dykes which are built up to prevent the main canal from overtopping of the flow.

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7. APPENDICES

7.1. Appendix Table

Appendix Table 1 Total and effective rainfall data

Month	ETo (mm/d)	Total Rainfall (mm/month)	Effective Rain (mm/month)
January	5.14	0.4	0.4
February	5.50	4.0	4.0
March	5.28	21.2	20.5
April	5.21	50.0	46.0
May	3.98	108.7	89.8
June	3.14	147.9	112.9
July	2.89	191.5	132.8
August	2.95	200.0	136.0
September	3.27	155.3	116.7
October	3.54	105.3	87.6
November	3.04	18.4	17.9
December	4.75	1.0	1.0
Total (mm/Year)	1460.7	1003.7	765.6

Source: Mudulla meteorological station

N.B: Effective rainfall calculated using the USSCS formula:

Effective RF = $(125 - 0.2 * \text{Total RF}) * \text{Total RF}/125$ (Total RF < 250 mm/month),

Effective RF = $0.1 * \text{Total RF} - 125$ (Total RF > 250 mm/month)

Appendix Table 2 Crop parameters for major irrigated annual crops at Lamo irrigation scheme

Crop		Growth stages				Total
		Initial	Development	Mid	Late	
Onion	Stage lengths (Days)	20	30	30	15	95
	Crop coefficients (kc)	0.70	-	1.05	0.95	
	Rooting depths (m)	0.25	-	0.45	0.45	
	Depletion levels (P)	0.30	-	0.45	0.50	
	Yield response factors(ky)	0.80	0.40	1.20	1.00	1.00
Tomato	Stage lengths (Days)	30	40	45	30	145
	Crop coefficients (kc)	0.50	-	1.00	0.6	
	Rooting depths (m)	0.25	-	1.00	1.00	
	Depletion levels (P)	0.30	-	0.40	0.50	
	Yield response factors(ky)	0.50	0.60	1.10	0.80	1.05

Source: Crop data obtained from CROPWAT software

Appendix Table 3 Mean monthly climatic data of study area (Mudulla meteorological station)

Month	Rainfall (mm)	Max Temp (°C)	Min Temp (°C)	Humidity (%)	Wind Speed (Km/d)	Sunshine (Hours)	Solar rad. (MJ/M ² /d)	ETo (mm/d)
January	0.4	30.4	13.9	51.2	147.0	8.6	22.0	5.14
February	4.0	31.8	14.9	47.7	147.0	8.6	22.8	5.50
March	21.2	32.5	15.8	50.0	121.0	8.2	22.4	5.28
April	50.0	32.1	15.9	54.6	147.0	7.8	21.2	5.21
May	108.7	28.7	15.8	67.8	147.0	5.6	16.8	3.98
June	147.9	25.6	15.2	78.6	121.0	4.9	15.2	3.14
July	191.5	24.9	14.6	82.3	121.0	3.9	14.0	2.89
August	200.0	24.5	14.4	86.4	121.0	4.0	14.9	2.95
September	155.3	25.5	14.1	86.4	121.0	4.5	16.3	3.27
October	105.3	26.5	14.0	86.0	121.0	5.3	17.6	3.54
November	18.4	14.0	5.3	73.8	147.0	8.3	21.6	3.04
December	1.0	29.5	13.7	58.3	132.0	8.6	21.7	4.75
Average	83.6	27.2	14.0	68.6	132.8	6.5	18.9	4.06

Source: Mudulla meteorological station

Appendix Table 4 Irrigation scheduling report of onion

* Crop Data:

- Crop 1 : Onion
- Planting date: 19/2/08

* Soil Data:

- Soil description : Medium
- Initial soil moisture depletion: 100%

* Irrigation Scheduling Criteria:

- Application Timing: Irrigate each 7days.
- Applications Depths: Fixed depths of 136mm each.
- Start of Scheduling: 19/2
- Estimated total yield reduction = 1.1%

Date	TAW (mm)	RAW (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	Crop Kc	Interv. (Days)	SMD (mm)
19/2/08	35.0	10.5	0.0	0.0	22.66	0.70	0	35.0
26/2/08	41.9	13.4	0.0	0.0	23.55	0.70	7	21.7
2/3/08	48.7	16.7	0.0	0.0	25.69	0.70	7	23.4
9/3/08	55.6	20.2	0.0	0.0	28.17	0.76	7	25.7
16/3/08	62.4	24.0	0.0	0.0	31.57	0.84	7	28.6
23/3/08	69.3	28.1	0.0	0.0	34.93	0.92	7	32.0
30/3/08	76.2	32.4	0.0	0.0	38.24	1.00	7	35.4
6/4/08	83.0	37.1	0.0	0.0	40.10	1.05	7	38.7
13/4/08	84.0	37.8	0.0	0.0	40.06	1.05	7	40.1
20/4/08	84.0	37.8	0.76	0.74	39.88	1.05	7	40.0
27/4/08	84.0	37.8	1.97	1.61	39.57	1.05	7	38.8
3/5/08	84.0	37.8	3.03	2.51	38.77	1.04	7	37.6
10/5/08	84.0	39.2	4.38	3.88	36.61	1.00	7	36.0
17/5/08	84.0	41.2	3.20	2.96	19.88	0.96	7	28.9
Total			13.35	11.69	459.67			

Appendix Table 5 Irrigation scheduling report of tomato

Crop Data:

- Crop 1 : Tomato

- Planting date: 7/2/08

* Soil Data: - Soil description : Medium

- Initial soil moisture depletion: 100%

* Irrigation Scheduling Criteria: - Application Timing: Irrigate each 7days.

- Applications Depths: Fixed depths of 136mm each.

- Start of Scheduling: 7/2

- Estimated total yield reduction = 0.4%

Date	TAW (mm)	RAW (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	Crop Kc	Interv. (Days)	SMD (mm)
7/2/08	35.0	10.5	0.0	0.0	15.37	0.50	0	35.0
14/2/08	45.5	14.1	0.0	0.0	15.85	0.50	7	15.4
21/2/08	56.0	17.9	0.0	0.0	16.32	0.50	7	15.9
28/2/08	66.5	21.9	0.0	0.0	17.31	0.50	7	16.4
4/3/08	77.0	26.2	0.0	0.0	19.38	0.53	7	17.6
11/3/08	87.5	30.6	0.0	0.0	22.84	0.61	7	19.8
18/3/08	98.0	35.3	0.0	0.0	26.38	0.70	7	23.3
25/3/08	108.5	40.1	0.0	0.0	29.90	0.79	7	26.9
1/4/08	119.0	45.2	0.0	0.0	33.38	0.88	7	30.4
8/4/08	126.0	49.1	0.0	0.0	36.76	0.96	7	33.9
15/4/08	126.0	50.4	0.0	0.0	38.11	1.00	7	37.2
22/4/08	126.0	50.4	1.23	1.14	37.91	1.00	7	38.1
1/5/08	126.0	50.4	2.24	1.81	37.57	1.00	7	36.5
8/5/08	126.0	50.4	3.39	2.86	37.12	1.00	7	35.6
15/5/08	126.0	50.4	4.81	4.34	36.56	1.00	7	31.2
22/5/08	126.0	50.4	6.48	6.09	35.89	1.00	7	32.4
29/5/08	126.0	50.4	8.36	8.01	34.46	0.98	7	30.8
5/6/08	126.0	52.5	10.44	10.00	30.63	0.89	7	27.0
12/6/08	126.0	55.4	12.69	11.99	26.70	0.80	7	21.9
19/6/08	126.0	58.4	15.09	13.95	22.90	0.71	7	11.7
26/6/08	126.0	61.3	12.31	11.13	14.11	0.63	7	10.6
Total			77.05	71.31	585.44			

Appendix Table 6 Average soil moisture contents before and after irrigation

Crop Type	Sampling Code	Time of soil Sampling	Soil moisture contents,% volume		
			Soil depth, cm		
			0-30	30-60	60-90
Onion	F1	Before irrigation	27.54	25.38	24.64
		After irrigation	35.96	34.10	33.56
	F2	Before irrigation	22.13	22.66	27.96
		After irrigation	32.30	33.20	37.27
	F3	Before irrigation	24.95	20.45	21.68
		After irrigation	36.98	33.96	34.81
Tomato	F4	Before irrigation	22.55	22.57	24.99
		After irrigation	32.10	31.37	30.63
	F5	Before irrigation	29.32	26.86	22.53
		After irrigation	34.25	32.94	32.52
	F6	Before irrigation	22.85	21.50	20.66
		After irrigation	34.34	33.73	32.50

F= Farm

Appendix Table 7 Measured soil water needed and stored used for determination of application, storage efficiency and deep percolation ratio

Crop Type	Sampled irrigation farms	Water stored in the root zone of the plant, W_s cm	Water needed in the root zone prior to irrigation, W_n cm	Furrow length, m	Furrow spacing, m	Average furrow inflow rate Q, lit/sec.	Water delivered to the furrow, W_{fin} cm	Application efficiencies %	Storage Efficiency %	DP %	Tappl. sec	Furrow slope %	Dapp. (cm)
Onion	F 1	5.14	5.14	24	0.55	6.61	13.50	38.09	86.25	61.91	269	0.2	13.5
	F 2	6.21	6.21	15	0.45	6.06	15.50	40.07	81.60	59.93	128	0.5	11.5
	F 3	7.66	8.07	26	0.55	5.73	17.77	43.12	77.56	56.88	424	1.3	17.7
Tomato	F 4	7.20	7.20	10	0.65	5.74	12.50	57.58	82.40	42.42	141	0.8	12.5
	F 5	6.30	6.30	15	0.60	5.73	13.50	46.66	85.35	53.34	209	0.5	13.3
	F 6	10.67	13.63	30	0.75	6.39	16.88	63.20	78.26	36.80	453	0.3	12.9
	Min	5.14	5.14	10	0.45	5.73	12.50	38.09	77.56	36.80	128	0.2	11.5
Max	10.67	13.63	30	0.75	6.61	17.77	63.20	86.25	61.91	453	1.3	17.7	
Mean	7.90	9.38	20.00	0.60	6.17	15.13	50.64	81.90	49.35	290.5	0.75	13.60	

Appendix Table 8 Measured soil water contents and calculated distribution uniformity of onion field

Crop type	Total soil water content applied by irrigation within 30-60 cm crop root depth, cm			Total low-quarter soil water content applied by irrigation within 30-60 cm crop root depth ,cm		
	Sampled irrigation farms with their length			Sampled irrigation farm with length,		
	Farm 1 (24m)	Farm 2 (15 m)	Farm 3 (26 m)	Farm 1 (24 m)	Farm 2 (15 m)	Farm 3 (26 m)
Onion	6.22	7.50	10.00			
	5.91	6.90	8.90			
	5.78	6.70	8.77			
	5.76	6.65	7.80			
	5.67	6.54	7.77			
	4.90	6.51	7.60			
	4.60	5.98	7.00	4.60	5.98	7.00
	4.21	5.90	5.67	4.21	5.90	5.67
	3.21	3.21	5.43	3.21	3.21	5.43
Average value (cm)	5.14	6.21	7.66	4.01	5.03	6.03
Distribution uniformity, %	78.0	81.0	79.3			

Appendix Table 9 Measured soil water contents and calculated distribution uniformity of tomato field

Crop type	Total soil water content applied by irrigation within 60-90 cm crop root depth (cm)			Total low-quarter soil water content applied by irrigation within 60-90 cm crop root depth (cm)		
	Sampled irrigation farms, with length			Sampled irrigation farms with length,		
	F4 (10 m)	F5 (15 m)	F6 (30 m)	F4 (10 m)	F5 (15 m)	F6 (30 m)
Tomato	12.80	9.70	8.90			
	11.91	8.08	8.00			
	11.28	7.65	7.00			
	11.13	7.44	6.90			
	10.00	7.37	6.63			
	10.00	6.87	6.36			
	9.80	6.57	4.76			
	9.78	6.23	4.25	9.80	6.57	4.76
	9.33	4.89	3.90	9.78	6.23	4.25
	10.98	7.47	8.90	9.33	4.89	3.90
Average value (cm)	10.67	7.20	6.30	9.64	5.90	4.30
Distribution Uniformity, %	90.3	81.9	68.3			

Appendix Table 10 Inventory data for physical structure of the scheme

S.N	Type of Structure	Observed expected problem	Cause of the problem	Possible measures
1	Diversion weir	<ul style="list-style-type: none"> - Hair line cracks on face of the wing wall - Deformation (bend) of sluice gate rode during operation Deformation (bending. of intake gate rode during operation) - Dry & rusted sluice & intake gate sliding groove - Gate groove & body of Intake & sluice gate is rusted - Stone pitching is susceptible for Scouring/washing/ during the allowance of max. flood 	<ul style="list-style-type: none"> - Improper construction - Improper gate operation - Poor specification of material - Improper gate operation - Poor specification of material - cease of grease application for the last one year - Not applying antirust - The Gabion, Laid and stone pitching is stolen by the nearby villages 	<ul style="list-style-type: none"> - Effective maintenance - On job training about gate operation - Procure & fix the appropriate gate - On job training about gate operation - Procure & fix the appropriate gate Proper & timeless application of grease - Timely & proper painting of anti rust - Schedule the farmer to gate guard all structures by turn.
2	Pipe culvert (b/n) Intake gate & start of main canal)	<ul style="list-style-type: none"> - Leakage is observed on the pipe culverts just after intake gate -clogging of pipe culvert and other conveyance structures is expected 	<ul style="list-style-type: none"> - Improper construction - Absence of trash rack at the end of pipe culvert 	<ul style="list-style-type: none"> - Curative maintenance Procure & install trash rack
3	Lined main canal (Just at the end of pipe culvert)	<ul style="list-style-type: none"> - High siltation on the bed of the canal 	<ul style="list-style-type: none"> - Infrequent the shining of the accumulated silt 	<ul style="list-style-type: none"> - Timely flushing of silt accumulation via sluice gate
4	Lined main canal (up to siphon No 1)	<ul style="list-style-type: none"> - Progressive scale ring (Irregularly shaped canal is observed) creating in effective & in efficient canal shape - Magnified openings on side slop of the canal creating significant loss of water 	<ul style="list-style-type: none"> - Improper construction (In sufficient compaction) - Opening created by termites 	<ul style="list-style-type: none"> - Effect proper compaction - adopt termite prevention mechanism

Appendix Table 10 Inventory data for physical structure of the scheme

S.N	Type of Structure	Observed expected problem	Cause of the problem	Possible measures
5	Main canal from siphon No 1 to Turn out No1	- decrease of design flow	- Grass on the side slope	- Remove the grass from canal side slope
6	Field canals Tertiary canal	- Improper water application technical - Loss of water	Irregular alignment of furrow - Uneconomical /large/ spacing b/n furrows	- Provide the farmer intensive on job training about land preparation
7	Drop structure	- Loss of water (Instead of applying optimum amount of water lateral plastic tubes, the farmer is diverting max amount of water on economically before entering to each drop structures	- Perception of the farmer about the amount of water for Irrigation	- Train the farmer about gate operation and other related
8	Turn out No 1	- Leakage problem at the Turn- out gate (Clamping is not water tight) - Back water curving	- Sheet rode is lost from turn out gate - Piling of stone boulders	- Procure & weed sheet rode on turn out gate - Train the farmer would general operational provide. of all structure
9	Lined main canal from Turn out No 1 up to aqueduct	- Effective head of the applied water emanating from To No- 1 is not sufficient to Irrigate (cover) the respective command area. - Effective head of water after Turn out No- 1 is not sufficient to irrigate respective command area - Water loss (drain through side slope)	- Not considering the respective command area when designing & Installing Turn out No 1 - Longitudinal slope of 2 nd area canal just after Turn out No - 1 is not appropriate - Improper compaction of the canal - Water logging - Addition of unwanted amount of water over the tail land due to side drain from the main canal	- Conduct design revision and construct recommended structures - Maintain the appropriate slope - Actuate proper compaction of the canal - Temporarily develop water draining mechanism within the farm land

Appendix Table 10 Inventory data for physical structure of the scheme

S.N	Type of Structure	Observed expected problem	Cause of the problem	Possible measures
10	Lined main canal /from aqueduct up to siphon.	- Flood over flanking the main Canal	- Improper design of protection dike - Characteristics of the catchments area just above the existing protection dike is not considered when proposing the existing cross-drainage structure	- Redesign & construct Protection - Design and construct the required - cross-drainage structure
11	Turn out No. 2	- Difficulty of closing the turn out gate - Effective head of the applied water emanating from Turn out No 2 is not sufficient to irrigate/cover/ the respective command area	- One bolt & Nut, for clamping the turn out gate with sliding groove, is not there - Not considering the respective command area than designing and installing Turn out No 2	- Procure & fix the appropriate bolt & Nut. - Conduct design revision and Construct Recommended Structures
13	Aqueduct	- Leakage of water on the side wall of aqueduct just above masonry supports	- Vertical structural Crack	- Conduct & the appropriate curing Mechanism
14	Lined canal /Just after the aqueduct/	- Water loss (drain through side slope)	- Improper compaction of the canal	Activate proper compaction of the Canal
15	Turn out No.3	- The turn-out gate is difficult for operation during water Application	- Absence of working tool (wrench)	- Provide each farmer with working tool (wrench) and train the appropriate operational principle

Appendix Table 10 Inventory data for physical structure of the scheme

S.N	Type of Structure	Observed expected problem	Cause of the problem	Possible measures
16	Cross- drainage structure No-2	- Significant scouring just at the foot of masonry drop Structure	Absence of protection stone pitching just at the foot of each Masonry	Provide stone pitching which activate safe energy dissipation
17	Cross- drainage structure No-3	- Significant scouring just at the foot of masonry drop Structure - Loosening of embankment - Total destruction (demolishing) of the first Masonry drop	Absence of protection stone pitching just at the foot of each Masonry - Erosion High flooding through the cross drainage	Provide stone pitching which actuate safe energy dissipation - Conserve the soil by grass plantation Redesign and properly construct the drop
18	Lined main canal (Ranging b/n cross drainage No 3 and turn out No- 6	- Flooding of Main canal Magnified opening on side slop of the canal creating loss of water	Improper design of protection dike opening created by termites	Re-design & construct protection dike Adopt termite prevention mechanism
19	Turn-out No 6	Improper operation to the turn out gate	Accessories of gate groove are lost	Procure and Install missed accessories
20	Under sluice (Just before siphon No.2)	Perforation (bend) of sluice gate rode during operation	-Improper gate operation -Poor specification of material	-On job training about gate operation -Procure and fix the appropriate gate
21	Siphon No 2	-Exposure of pipe culvert Leakage on the pipe culvert	Flooding of the embankment Exposure of pipe culvert due to flooding embankment	Fill and compact the embankment with appropriate selected material Change the damaged pipe culvert
22	Turn out No 7	Improper operation of the turnout gate	Bolt and nuts of the gate are damaged	Procure and Install the missed accessories
23	Cross drainage structure No-1	Significant serving at the foot of masonry drop structure - Loosening of embankment	Absence of protection stone pitching just at the foot of each masonry drops Erosion	Provide stone pitching which actuate safe energy dissipation Conserve the soil by grass plantation

Appendix Table 10 Inventory data for physical structure of the scheme

S.N	Type of Structure	Observed expected problem	Cause of the problem	Possible measures
24	Lined main canal just after cross-drainage structure No 1	Flood over flanking the main canal	Improper design of protection dike	Redesign and construct protection dike
25	Plot of land of setting the canal ranging b/n cross-drainage structure No 1 and turn out No. 5	Not Utilizing the available resource there is un cultivated plot or land/	Improper design of protection dike	Pan & cultivated the plot by handing over to outstanding farmers
26	Torn out No.5	- Back water curving	- Piling of stone would immediately after T.O) gate	- Train the farmer about operational principle of all structures
27	Cross-drainage structure No 2	Significant scouring just at the foot of masonry drop structure	Absence of protection stone pitching at the foot of each masonry drop	Provide stone pitching which actuate safe energy deception
28	Cross-drainage No. 3	Significant scouring just at the foot of masonry drop structure	Absence of protection stone pitching at the foot of each masonry drop	Provide stone pitching which actuate safe energy deception
		Loosening of Embankment	Erosion	Conserve the soil by grass plantation
		Total destruction(demolishing) of the 1 st masonry	High flooding through the cross-drainage	Redesign properly constructs the drop.
29	Lined main canal/ranging b/n cross-drainage No 3 and turn out No-6	Flooding of main canal Magnified openings on side slope of the canal creating loss of water	Improper design of protection dike Opening created by termites	Re- design & construct protection dike Adopt termite prevention mechanism

Appendix Table 11 Generalized data on rooting depth of full grown crops, fraction of available soil water (p) and readily available soil water (p*Sa) for different soil types in (mm/m soil depth) when ETcrop is 5 – 6 mm/ day

Crop type	rooting depth(d) m	fraction (p) of available soil water	readily available soil water (p.Sa) mm/ml		
			fine	medium	coarse
Alfalfa	1.0 – 2.0	0.55	110	75	35
Banana	0.5 – 0.9	0.35	70	50	20
Barley	1.0 – 1.5	0.55	110	75	35
Beans	0.5 – 0.7	0.45	90	65	30
Beets	0.6 – 1.0	0.5	100	70	35
Cabbage	0.4 – 0.5	0.45	90	65	30
Carrots	0.5 – 1.0	0.35	70	50	20
Celery	0.3 – 0.5	0.2	40	30	10
Citrus	1.2 – 1.5	0.5	100	70	30
Clover	0.6 – 0.9	0.35	70	50	20
Cotton	1.0 – 1.7	0.65	130	90	40
Cucumber	0.7 – 1.2	0.5	100	70	30
Dates	1.5 – 2.5	0.5	100	70	30
Dec. orchards	1.0 – 2.0	0.5	100	70	30
Flax	1.0 – 1.5	0.5	100	70	30
Grapes	1.0 – 2.0	0.35	70	50	20
Grass	0.5 – 1.5	0.5	100	70	30
Groundnuts	0.5 – 1.0	0.4	80	55	25
Lettuce	0.3 – 0.5	0.3	60	40	20
Maize	1.0 – 1.7	0.6	120	80	40
Melons	1.0 – 1.5	0.35	70	50	25
Olives	1.2 – 1.7	0.65	130	95	45
Onions	0.3 – 0.5	0.25	50	35	15
Palm trees	0.7 – 1.1	0.65	130	90	40
Peas	0.6 – 1.0	0.35	70	50	25
Peppers	0.5 – 1.0	0.25	50	35	15
Pineapple	0.3 – 0.6	0.5	100	65	30
Potatoes	0.4 – 0.6	0.25	50	30	15
Safflower	1.0 – 2.0	0.6	120	80	40
Sisal	0.5 – 1.0	0.8	155	110	50
Sorghum	1.0 – 2.0	0.55	110	75	35
Soybeans	0.6 – 1.3	0.5	100	75	35
Spinach	0.3 – 0.5	0.2	40	30	15
Straw berries	0.2 – 0.3	0.15	30	20	10
Sugar beet	0.7 – 1.2	0.5	100	70	30
Sugar cane	1.2 – 2.0	0.65	130	90	40
Sunflower	0.8 – 1.5	0.45	90	60	30
Sweet potatoes	1.0 – 1.5	0.65	130	90	40
Tomatoes	0.7 – 1.5	0.4	180	60	25
Vegetables	0.3 – 0.6	0.2	40	30	15
Total available soil water (Sa)			200	140	60

Part I. Questionnaires Prepared for Sample Households

1. What is the source of water for the irrigation scheme?
1. river 2. pond 3.spring 4.others, specify...
2. Is there any significant variation in the quantity of water source? 1. Yes 2. No
If yes, which season?
3. Is there any competition for water use during shortage? 1. Yes 2. No
In relation with shortage is there any interruption among the users? 1. Yes 2. No
If your answer is yes, how do you solve the problem?
4. How is irrigation water delivered? Using pump_____ or by gravity_____others...
5. Do farmers level their irrigation land before cropping? 1. Yes 2.No
If yes, what are the main implements used? 1. hand equipment 2.animal power 3.others...
6. Which month do farmers start usually irrigation farming? Why?
7. What crops are planted during the irrigation season?
1. onion 2.tomato 3.pepper 4. others...
8. What is the average duration of irrigation for the selected crops?
9. What are the criteria farmers used to irrigation scheduling?
1. water supply availability 2.condition of the crop
3. fixed time period 4.others, specify...
10. How do farmers know (measure) the following irrigation scheduling parameters?
1. depth of irrigation 2.irrigation interval
3. irrigation period 4.when irrigation started and terminated
11. Do farmers face the following problems by practicing irrigation? (Rank according to priority)
1. runoff loss 2.deep percolation 3.water logging
4. seepage loss 5.salt built up 6.silt deposit 7.others...
12. Have you recognized any problems on physical structure, water delivery and distribution system of the irrigation scheme?
13. Who is responsible for management, operation and maintenance of irrigation scheme?
1. Farmers 2.Government 3.NGOs 4.others...
14. Is there any financial support during maintenance and rehabilitation of the scheme?

15. Do you think that the performance of irrigation scheme is good? 1. Yes 2.No

If no, what are the problems for low level of performance?

1. lack of maintenance structures
2. poor water management
3. water loss problem
4. others...

16. How do you improve the performance of irrigation scheme?

17. Is irrigation scheme constructed using concrete or earthen canal?

18. Do farmers pay fee for irrigation water? If yes, how much they pay? (Kg/m³, Birr/m³)

19. What are the basic benefits achieved from the irrigation practice?

20. How do you compare irrigation practice before and after the introduction of the scheme?

21. Have you practiced crop rotation in irrigated farming?

Part II. Questionnaires Prepared for Interview

(Irrigation experts, water committee, water resources experts and respective team leaders)

1. What is the total irrigable area and number of beneficiaries of the irrigation scheme?

2. Do you think that the water source for irrigation purpose is sufficient? 1. Yes 2.No

If no, what are the other alternative water sources for irrigation in the area?

3. Is the water quality suitable and recommended for irrigation purpose?

4. What are the major problems in relation to irrigation development and its performance?

5. What are your suggestions to improve performance of irrigation and thereby improving productivity and food security?

6. Do the government and NGOs attempt to promote public participation in irrigation development activities and in what ways?

7. Do you think that the practice of farmers with economical water use, appropriate irrigation depth, and irrigation scheduling is recommended that it should be?

If not, as an irrigation expert, how do you solve the problem face by farmers?

8. Do you think the irrigation expert's technical support is sufficient? In what ways guide the farmers during irrigation practice?

9. How do you follow up for maintenance, operation and management of the irrigation scheme?

10. What do you recommend for future expansion of irrigation use for others nearby (non-irrigators) those cannot be benefited from the irrigation scheme?