EVALUATION OF WATER DELIVERY PERFORMANCE IN ROBIT SMALL - SCALE IRRIGATION SCHEME, AMHARA, ETHIOPIA

M.Sc. THESIS

ABRHA YBEYN GEBREMEDHN

ARBA MINCH, ETHIOPIA

NOVEMBER, 2017

EVALUATION OF WATER DELIVERY PERFORMANCE IN ROBIT SMALL-SCALE IRRIGATION SCHEME, AMHARA, ETHIOPIA

ABRHA YBEYN GEBREMEDHN

A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCES AND IRRIGATION ENGINEERING, INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES

ARBA MINCH UNIVERSITY

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

ARBA MINCH UNIVERSITY

NOVEMBER, 2017

DECLARATIONS

I, the researcher Abrha Ybeyn Gebremedhn declare that, this thesis is my own original work and it is not presented and will not be presented to any other University for perusing similar degree award. Moreover, all the source of materials used for the accomplishment of the thesis is duly acknowledged.

Name: Abrha Ybeyn Gebremedhn

Signature: ___________

Date: __________

ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled with "**Evaluation of Water Delivery Performance in Robit Small-scale Irrigation Scheme, Amhara, Ethiopia**" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Irrigation and Drainage Engineering, the Graduate Program of Department of Water Resource and Irrigation Engineering, and has been carried out by Abrha Ybeyn Gebremedhn ID No RMSc/087/08, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department for defense.

Professor Pratap Singh	_______________	______________
Name of Principal advisor	Signature	Date

APPROVAL PAGE

This M.Sc. thesis which is entitled with "**Evaluation of Water Delivery Performance in Robit Small-scale Irrigation Scheme, Amhara, Ethiopia**" is approved by the advisor, Examiners, SGS coordinators, and head Department of Water Resources and Irrigation Engineering for the partial fulfillment of the requirement for the degree of Master of Science in Irrigation and Drainage Engineering.

Date of Defense: November 3, 2017

Abrha Ybeyn Gebremedhn	__________	__________
Student name	Signature	Date
Ngede Abate (Dr.-ing)	__________	__________
External examiner	Signature	Date
Samuel Dagalo (PhD)	__________	__________
Internal examiner	Signature	Date
Mr. Agenehu Kitanbo	__________	__________
Chairperson	Signature	Date
Professor Pratap Singh	__________	__________
Principal advisor	Signature	Date
Mr. Sisay Simachew	__________	__________
Head of department	Signature	Date
Mr. Aschalew Cherie	__________	__________
PG coordinator	Signature	Date
Abera Uncha (PhD)	__________	__________
PG director	Signature	Date

DEDICATION

This thesis manuscript is dedicated to my Mother, Worknesh Bahta; she coped me to reach to this position and enabled me to be a good person. It is also devoted to my fiancée Selamawit Biruk, for her wholehearted love, moral, and technical support until the end of the study. I love you mom! I love you my fiancée!

ACKNOWLEDGMENT

First and above all, I would like to express my sincere gratitude to my respected advisor, Professor Pratap Singh for his unreserved support in giving very crucial and constructive comments starting from the proposal writing until the end of the thesis work. I would like to thank, for Arba Minch University that enabled me to have access the important instruments for my thesis. Especially, I thank to Mr. Aschalew Cherie, Mr. Melkamu Teshome, Mr. Alemayehu Kassaye, Mr. Aklilu Alemayehu and Mr. Demoze Eshetu for their kind response.

Sincerely thank for Mr. Agumasie Kindie and Mr. Bishaw Angaw from Bahirdar Ethiopia, and Mr. Ymesgen Delelegn and Mr. Shiferaw Delelegn from Kewet Agricultural office for their unlimited support during the whole data collection period. In addition to this, great thank is extended to my co-data collectors; Mr. Abushet Tilahun and Mr. Tadege Shiwangzaw for their kind and careful work during the whole period of data collection. Unlimited thank is extended for the Robit irrigation experts for giving me the important data for the accomplishment of the study and for creating conducive environment for discussion with the irrigation users and water committee. Moreover, I would like to thank the Farmers of Robit irrigation scheme for allowing me to access their farm freely for taking soil samples, flow measurements and for responding to my questions openly.

I would like to thank Mr. Getaneh Shegaw from Debre Berhan research center for kindly support in the laboratory work; and Mr. Kalayu Birhane from Debre Berhan University for giving me very critical comments. My thank is also extended to my dearest PhD candidates Tsfaye Mebratie and Fikrey Tesfay for their constructive and remarkable comments.

Many thank for Dr. Zeleke Agide, Mr. Alebachew Shumye, Mr. Mussie Alemayehu, Mr. Mamuye Tebebal, Mr. Efriem Tariku, Mr. Selomon Wondatir, and others that enabled me their paper as baseline information. I thank again, for Mr. Alebachew Shumye and Mr. Efriem Tariku for their technical and moral support during the study period. Finally, I would like to thank my beloved family members and my best friend Mr. Muley Fitsum for their heart full love, moral and financial support.

Name: Abrha Ybeyn Gebremedhn Signature__________

TABLE OF CONTENTS

CONTENTS PAGES

DECLARATIONS i

ADVISORS' APPROVAL SHEET ii

APPROVAL PAGE iii

DEDICATION iv

ACKNOWLEDGMENT v

LIST OF TABLES ix

LIST OF FIGURES x

LIST OF APENDICES xii

ACRONYMS AND ABRIVATIONS xiv

ABSTRACT xvi

1. INTRODUCTION 1

1.1. Background 1

1.2. Problem of the statement 2

1.3. Objective of the Study 3

1.3.1. General objective 3

1.3.2. Specific objectives 4

1.4. Research Questions 4

1.5. Significance of the Study 4

2. LITERATURE REVIEW 5

2.1. Over View of Irrigation Schemes 5

2.2. Performance Evaluation of Small-scale Irrigation Schemes 6

2.3. Crop Water and Irrigation Water Requirements 7

2.4. Performance Indicators of Irrigation Schemes 8

2.4.1. Water delivery indicators 8

2.5. Irrigation System Efficiency Measures 12
2.5.1. Water conveyance efficiency 12
2.6. Users Satisfaction with Irrigation Service 14
3. RESEARCH METHODOLOGY 17
3.1. Description of the Study Area 17
3.1.1. General background of Robit irrigation scheme 18
3.1.2. Climate 19
3.1.3. Soil 19
3.1.4. Crop 20
3.1.5. Topography 20
3.2. Sampling Techniques 20
3.3. Methods of Data Collection 22
3.3.1. Primary data collection 22
3.3.2. Secondary data 22
3.4. Materials Used 23
3.4.1. Physical materials 23
3.4.2. Software used 23
3.5. Data Analysis 23
3.5.1. Discharge measurement 24
3.5.2. Soil sample analysis 26
3.5.3. Crop water requirement 29
3.5.4. Water delivery indicators 30
3.5.5. Water conveyance efficiency 32
3.5.6. Users satisfaction 33
3.6. Conceptual Framework 36
4. RESULTS AND DISCUSSIONS 38
4.1. Soil Physical Properties 38
4.2. Estimated Crop Water Requirement 40
4.3. Determination of Required Flow 42
4.4. Determination of Delivered Flow 43

4.5. Water Delivery Performance Indicators 45
4.5.1. Adequacy (P_A) 45
4.5.2. Efficiency (P_F) 48
4.5.3. Equity (P_E) 50
4.5.4. Dependability (P_D) 50
4.6. Water Conveyance Efficiency 53
4.6.1. Main canal water conveyance efficiency and water conveyance losses 53
4.6.2. Water conveyance efficiency and water conveyance losses for secondary canals 56
4.7. Evaluation of Users Satisfaction 58
4.7.1. Evaluating users satisfaction for head reach users 58
4.7.2. Evaluating users satisfaction for middle reach users 59
4.7.3. Evaluating users satisfaction for tail reach users 60
4.7.4 Evaluating users satisfaction for the entire irrigation system 61
4.8. Factors Affecting Water Delivery Performance 62
5. CONCLUSIONS AND RECOMMENDATIONS 65
5.1. Conclusions 65
5.2. Recommendations 66
REFERENCES 68
APPENDICES 74
Appendix A: Climatic Data and Performance Indicators 74
Appendix B: Figures Showing the Existing Condition of the Scheme 102
Appendix C: Questionnaire Prepared Concerning Users Satisfaction 105

LIST OF TABLES

TABLE PAGES

Table 2.1 Water delivery performance standards (Molden & Gates, 1990) 11

Table 2.2 Water delivery indicators as estimated by different workers 12

Table 2.3 Values of water conveyance efficiency as recommended by FAO (1989b) 14

Table 3.1 Temperature correction values of Hydrometer readings 28

Table 4.1 Estimated values of required (Q_R) and delivered flow (Q_D) 44

Table 4.2 Estimated values of adequacy 47

Table 4.3 Estimated values of efficiency 49

Table 4.4 Estimated values of equity and dependability 52

Table 4.5 Main canal water conveyance efficiency and conveyance losses 55

Table 4.6 Secondary canals water conveyance efficiency and conveyance losses 58

Table 4.7 Parameter estimates of binary Logit model for head reach 59

Table 4.8 Parameter estimates of Logit model for middle reach users 60

Table 4.9 Parameter estimates of Logit model for tail reach users 60

Table 4.10 Parameter estimates of Logit model for entire system 61

Table 4.11 Logit model estimated satisfaction level of irrigation users........................... 62

LIST OF FIGURES

FIGURES PAGE NO

Figure 3.1 Location map of the study area 17

Figure 3.2 Layout of Robit irrigation scheme 19

Figure 3.3 Discharge measurement using Current meter and Parshall flume 26

Figure 3.4 Soil texture determination using Hydrometer 27

Figure 3.5 Questionnaire collection in Robit irrigation scheme 36

Figure 3.6 Research framework 37

Figure 4.1 Variation of instantaneous infiltration rate with time 39

Figure 4.2 Variation of cumulative infiltration depth with time 39

Figure 4.3 Variation of rainfall (RF), effective rainfall (Ref) and reference crop evapotranspiration (ET_O) 40

Figure 4.4 Variation of effective rainfall (Ref) and ET_O values (April to June) 41

Figure 4.5 Seasonal crop water requirement (ETc) for different Crops 41

Figure 4.6 spatial average values of required and delivered flow 43

Figure 4.7 Temporal average values of required and delivered flow 45

Figure 4.8 Reach wise variation of required (Q_R) and delivered flow (Q_D) 45

Figure 4.9 Average temporal adequacy of selected offtakes 46

Figure 4.10 Reach wise average temporal adequacy 46

Figure 4.11 Average spatial adequacy over different offtakes 47

Figure 4.12 Temporal average efficiency at different locations 48

Figure 4.13 Reach wise average efficiency 49

Figure 4.14 Time wise spatial average efficiency 49

Figure 4.15 Equity (P_E) during three months 50

Figure 4.16 Temporal coefficient of variation (CV_T) 51

Figure 4.17 Reach wise coefficient of variation 52

Figure 4.18 Main canal water conveyance efficiency (E_C) and water conveyance losses 53

Figure 4.19 Malfunctioned main canal water distributing structure 54

Figure 4.20 Main canal reach wise water conveyance efficiency (Ec) and water conveyance losses... 55

Figure 4.21 Variation of water conveyance efficiency and water conveyance losses for secondary canal SC1 56

Figure 4.22 Variation of water conveyance efficiency (Ec) and water conveyance losses for secondary canal SC2... 57

Figure 4.23 Level of users' satisfaction for Robit irrigation scheme................................ 62

Figure 4.24 Traditional diversion structure and current condition of the designed intake structure.. 63

Figure 4.25 Remarkable improvement in canal sediment cleaning (October 2, 2017).... 64

LIST OF APENDICES

Appendix A- 1 25 years (1990- 2015) average daily minimum temperature (^{O}C) 74

Appendix A-2 25 years (1990- 2015) average daily maximum temperature (^{O}C)........... 75

Appendix A-3 25 years (1990- 2015) average daily relative humidity........................... 76

Appendix A-4 25 years (1990- 2015) average daily wind speed.................................... 77

Appendix A-5 25 years (1990- 2015) average daily sun shine hours 79

Appendix A-6 25 Years (1990- 2015) average daily precipitation (mm) 80

Appendix A-7 Yearly average climatic data 81

Appendix A-8 Soil textural analysis using Hydrometer... 82

Appendix A-9 Estimated total available moisture (TAM) 84

Appendix A-10 Estimated soil infiltration rates for Robit irrigation scheme 85

Appendix A-11 Area coverage, arranged irrigation schedule by WUAs and crops grown in each offtake structure 86

Appendix A-12 CROPWAT estimated reference crop evapotranspiration (ET_O) and effective rainfall values 87

Appendix A-13 CROPWAT estimated soil and crop data for onion crop 88

Appendix A-14: CROPWAT estimated crop water requirement (ET_C) and irrigation requirement (IR) for onion crop 88

Appendix A-15 CROPWAT estimated irrigation schedule and duty for onion crop 89

Appendix A-16 CROPWAT estimated crop water requirement (ETc) and irrigation requirement (IR) for mung bean crop.. 90

Appendix A-17 CROPWAT estimated irrigation schedule and flow duty for mung bean crop 91

Appendix A-18 CROPWAT estimated crop water requirement (ETc) and irrigation requirement for maize crop 92

Appendix A-19 Estimated irrigation schedule and flow duty for maize crop.................. 93

Appendix A-20 CROPWAT estimated average required flow (Q_R)............................... 94

Appendix A-21: Measured flow depths and corresponding observed discharge 95

Appendix A -22 Design flow rate and currently delivered flow of tertiary offtake structures (Q_D) 99

Appendix A-23 Parameter estimates of binary Logit Model for head reach users 100

Appendix A-24 Parameter estimates of Logit Model in middle reach users 101

Appendix B-1 Installation of Current meter instrument and figure showing Malfunctioned flow regulator 102

Appendix B-2 Flow diverting by the farmer to the Mung bean crop 103

Appendix B-3 Dimensions of 3-inch Parshall flume 104

Appendix C Questionnaire Prepared Concerning Users Satisfaction 105

ACRONYMS AND ABRIVATIONS

CV_R	Spatial Coefficient of Variation
CWR	Crop Water Requirement
D	Duty
E_C	Conveyance Efficiency
Ei	Overall Irrigation Efficiency
ET_C	Crop Evapotranspiration
ET_O	Reference Crop Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
GIR	Gross Irrigation Requirement
GPS	Geographic Positioning System
ISRIC	International Soil Reference and Information Center
Kc	Crop Coefficient
L	Location of Tertiary Offtakes
LPM	Linear Programming Model
MoWR	Ministry of Water Resource
MP	Main Canal Control Points
NIR	Net Irrigation Requirement
P_A	Adequacy
P_D	Dependability
P_E	Equity
P_F	Efficiency
PF	Water Retention Curve
PWP	Permanent Wilting Point
Q_D	Actual Delivered Discharge

Q_I	Inflow Discharge
Q_O	Outflow Discharge
Q_R	Actual required discharge
R	Region Bounded by Certain Offtake
Ref	Effective Rainfall
RF	Rainfall
S1P	Control Points on the First Secondary Canal
S2P	Control Point on the Second Secondary Canal
SC1	First Secondary Canal
SC2	Second Secondary Canal
SCS	Soil Conservation Service
SSI	Small-scale Irrigation
STATA	Statistical Data Analysis
T	Time Period
TAM	Total Available Moisture
TO	Tertiary Offtake
USA	United States of America
USDA	United States Department of Agriculture
WUAs	Water User Associations
X^2	Probability of Chi Square
β	Logit Regression Coefficient

ABSTRACT

Robit small-scale irrigation scheme is located in the Amhara National Regional State and was constructed in 2012. However, the performance of the irrigation scheme has not been evaluated yet. In the present study, the performance of the scheme was evaluated by estimating water delivery performance indicators, water conveyance efficiency, water conveyance losses, and satisfaction of irrigation users. The water delivery performance adequacy, efficiency, equity and dependability were evaluated by monitoring discharge at nine selected offtakes; three each at the head, middle and tail end of the scheme command area during the crop season from April to June 2017. The water conveyance efficiency of the main and secondary canals and thus the water losses in water conveyance were estimated by measuring irrigation water flow at different locations along the canals. The satisfaction of the irrigation water users from the irrigation service received was evaluated using the binary Logit Model at the head, middle and tail end of the irrigation scheme, and for the entire irrigation scheme. Irrigation water flow in the main and secondary canals, as well as at nine tertiary offtakes was measured using Current meter and 3-inch Parshall flume. The data were analyzed using STATA, CROPWAT, ARC GIS software, and Microsoft Excel. The water delivery performance indicators adequacy, efficiency, equity and dependability varied widely from head to tail reach and, during the crop season from April to June with overall average value equal to 0.88, 0.92, 0.09 and 0.11 respectively. Thus, the irrigation scheme when compared with Molden and Gates (1990) standards was found under fair condition in adequacy and dependability and under good condition in efficiency and equity. The estimated overall water conveyance efficiencies of the main canal and first and second secondary canals were 90.3%, 82.88% and 82.83% respectively. Similarly, the water conveyance losses per 100 m were 2.62, 1.56 and 1.18 ls^{-1} for the main canal and first and second secondary canals respectively. The level of irrigation users' satisfaction from the irrigation service received was 57.33%, 48%, 42.67% and 49.33% at the head, middle, tail reach and the entire system respectively. Satisfaction of irrigation users was found highly associated with the variation in the availability of adequate water, water availability in time and farm location from the canal head.

Keywords: *Robit irrigation scheme, Water delivery performance, conveyance efficiency, users' satisfaction*

1. INTRODUCTION

1.1. Background

Rain-fed agriculture has failed to produce enough food, to meet the increasing demand of food for the rapidly growing population. To meet this demand, significant investment in irrigation with improved performance of irrigation schemes is important. It was identified that globally 60% of the diverted fresh water for agriculture does not contribute directly to food production (Dejen, 2015). It depicts that only about 40% global fresh water abstracted for irrigation is being effectively used for consumptive use in agriculture. This amount of water is lost because of poor water management, inefficient irrigation systems with leaky conveyance and distribution, and poor on-farm water management practices, etc. Therefore, performance of irrigation schemes should be evaluated to minimize the losses of water, improve the irrigation water use efficiency, and improve scheme performance accordingly.

Performance assessment in irrigation and drainage is systematic observation and interpretation of the management of irrigation schemes, with the objective of ensuring that the input of resources, operational schedules and required actions proceed as planned. Performance can be assessed for a variety of reasons: to improve system operation, to assess progress against strategic goals, as an integral part of performance-oriented management, to assess the general health of a system, to assess impact of interventions, to diagnose constraints, to better understand determinants of performance, and compare the performance of a system with the same system over time or with other systems (Alemayehu, 2016). The performance of an irrigation scheme is evaluated by using both internal and external indicators. Water delivery indicators are one of the internal indicators (Bos et al., 2005).

Water delivery performance indicators are used to facilitate the analysis of irrigation water delivery system in terms of adequacy, efficiency, dependability, and equity of water delivery. The measurements provide quantitative evaluation of overall system performance. Spatial and temporal distribution of required and delivered water is used to determine the water delivery performance indicators. These indicators are estimated by a combination of field measurements and model outputs. Frequent monitoring of the performance of the irrigation system assists to distinguish whether the targets and requirements are being met or not (Dejen, 2015). It also provides system managers, farmers and policy makers a better understanding as to how a system operates.

The water delivery and performance in conveying irrigation water of many irrigation schemes are significantly below their potential (Svendsen & Murray-Rust, 2001). The shortcomings of low performance include poor design, construction, operation, maintenance, malfunctioning of control structures and weak management (Degirmenci et al., 2003 & Aklilu, 2006). This is because; governments pay attention for construction of new irrigation projects than the operation and maintenance of existing irrigation schemes. Giving due consideration for the existing irrigation projects and evaluating their performance is therefore a crucial issue.

Irrigation users may be satisfied or dissatisfied with the irrigation service obtained. The level of satisfaction depends on different factors such as adequacy, water availability in time, farm location from the water source, farm size, and farmer schooling years etc. Therefore, users' satisfaction is the dependent variable and the above listed factors are the independent variables. Using the perception of users concerning these explanatory variables as an input data, the Logit Model may be used to analyze the satisfaction level of users to the irrigation service obtained.

Many researchers conducted studies on performance evaluation of different irrigation schemes. Some of the researchers used the water delivery indicators and others the irrigation efficiency measures to evaluate the performance of irrigation schemes. Dejen et al. (2012; 2014 & 2016), Dejen (2015), Shumye (2017) and Tariku (2017) evaluated the performance of different irrigation schemes using the water delivery indicators. Hailu (2011) and Alemayehu (2016) evaluated the conveyance efficiency of Adami Tulu and Meki-Ziway irrigation schemes respectively. The present study was conducted in Robit small-scale irrigation scheme located in the Amhara National, Regional State, North Shewa Zone, Kewet Woreda. During the study period, the water delivery performance, conveyance efficiency of the main and secondary canals, and the satisfaction of users were addressed.

1.2. Problem of the statement

Developing countries have made huge investments in the development of irrigation infrastructures and created irrigation facilities for farmers. This investment, together with improved crop production technologies, has enabled many countries to increase food production and move towards achieving self-sufficiency in food production.

The performance of irrigation infrastructure is the result of a large number of activities such as planning, design, and construction of operational facilities, and maintenance and application of water to the land (Small & Svendsen, 1990). The performance of the entire irrigation scheme is not according to the intended objectives if the scheme is not managed and operated properly. Many irrigation schemes, particularly in least developed and emerging countries, are characterized by a low level of overall performance (Dejen, 2015; 2016). The technical and economic performance of pubic irrigation schemes in these countries has generally been far below potential. Evaluation of the performance of the irrigation schemes is thus necessary to ensure the well-functioning of the scheme, identify gaps and take remedial measure. Improving the performance of irrigation schemes through various interventions is considered a key issue for addressing the need for increased productivity of irrigated lands under pressure on water resources

Irrigation users may be satisfied or dissatisfied with irrigation water supplied from the scheme. The level of dissatisfaction may result in some cases due to the lack of awareness to the disadvantage of excess water in crop production and a willingness to apply more water than an actual crop water requirement. On the other hand, the level of dissatisfaction may arise from the reliability of irrigation water supply to satisfy the timely demand of the users. But in some irrigation schemes, the users may be satisfied with the level of service they get from the scheme. Therefore, evaluation of the users level of satisfaction and creating awareness concerning the disadvantage of excess water is necessary.

Robit small-scale irrigation scheme costs Ethiopian Birr 4,187,179.55 for construction of the scheme and creation of irrigation facilities. This irrigation scheme enables the irrigation users to enhance crop production and improve their livelihood. However, the performance of the irrigation scheme as well as the level of users' satisfaction to the supplied irrigation water was not evaluated yet. As a result, this study is aimed at evaluating the water delivery performance of the irrigation scheme and assesses the users' satisfaction with the supplied irrigation water from the irrigation scheme.

1.3. Objective of the Study

1.3.1. General objective

The general objective of the study is to evaluate the water delivery performance and level of users satisfaction with irrigation service

1.3.2. Specific objectives

The specific objectives of the study are:

i) To evaluate water delivery performance of Robit small-scale irrigation scheme.

ii) To evaluate water conveyance efficiency of the main and secondary canals.

iii) To determine the satisfaction of users from the irrigation service received.

iv) To identify the gaps and recommend remedial measures that improves the performance of the scheme.

1.4. Research Questions

i) Is the performance of water delivery from the irrigation scheme good?

ii) Does the irrigation system convey water efficiently?

iii) Are the irrigation users satisfied with the irrigation service?

iv) Are there alternative options to improve the performance of the irrigation scheme?

1.5. Significance of the Study

This study will have a great contribution both to the irrigation users and scheme managers. Evaluating its performance means checking the effectiveness of the irrigation scheme. Therefore, this will enable to decide as to whether maintenance and other improvement options are required or not. Different stakeholders (farmers, scheme managers and policy makers) will identify the strengths and weaknesses, consequently alternatives that may be both effective and feasible in improving system performance to achieve maximum efficiency. Furthermore, this study will be baseline information for similar studies in the future for the development of new irrigation schemes in other command areas.

2. LITERATURE REVIEW

2.1. Over View of Irrigation Schemes

The Ethiopian ministry of water resource (MoWR) (2002), classifies irrigation schemes based on the size of the command area into small-scale (less than 200 ha), medium scale (between 200-3,000 ha) and large-scale (greater than 3,000 ha) irrigation schemes. Accordingly, 46% of the proposed irrigation developments in Ethiopia are small-scale irrigation schemes (Wambua et al., 2011). Similarly, based on the history of establishment, management system and the nature of the structures (Wambua et al., 2011). classified irrigation schemes into traditional, modern, private and public irrigation schemes.

Small-scale irrigation (traditional and modern) accounts for more than 70% of the total irrigated land in Ethiopia. These schemes belong to smallholder farmers with average landholding sizes of 0.15 to 0.5 ha (Awulachew et al., 2005). Smallholder farming (irrigated and rain fed) dominates the agriculture in Ethiopia and is the major sources of food supply in the country.

Modern schemes are those equipped with permanent irrigation infrastructure such as water diversion (head works), flow control structures, and conveyance and distribution systems (Dejen et al., 2012). Traditional schemes do not have permanent structures for water acquisition and flow control, and are made using local knowledge with local materials; including stones, soils, wooden logs, sand bags, etc. These are constructed by the efforts and own initiatives of the farmers and are reconstructed every year.

The irrigation scheme in which the present study was carried out is categorized under modern small-scale irrigation scheme. The question here is to understand if such classification has connotation in terms of efficiency and water delivery performance. Therefore, the study aimed at evaluating the irrigation scheme performance in terms of water delivery and conveyance efficiency. In addition to this, during the study period the satisfaction of irrigation users was also evaluated.

2.2. Performance Evaluation of Small-scale Irrigation Schemes

Small-scale irrigation (SSI) schemes are operated and managed by the farmers with little involvement of government agencies in some cases (Dejen et al., 2012**).** As explained previously it has area coverage of less than 200ha. These schemes have been playing a significant role in ensuring food security and in improving the livelihood of Ethiopian rural society.

The formal determination of a contribution of individual component related to outcome of a project within a particular setting to measure the achievements above or below the standard is termed as performance evaluation. Performance evaluation provides different stakeholders (system managers, farmers, and policy makers) with a better understanding of how a system operates (Bouml & Demir 2009). It can help to determine problems and identify ways and means of improving system performance (Svendsen & Murray-Rust, 2001).

The responsibilities of irrigation managers in irrigation performance assessment encompass; evaluating the existing situation of irrigation performance in the systems, identifying the constraints to proper performance if the performance is not satisfactory, and implementing management interventions to improve the performance. At all levels, performance must be assessed using a combination of targets and associated set of standards that describe the acceptable range of values around that target (Bos et al., 1994)

Performance evaluation can be carried out at sector level, scheme level, main system level and at on-farm level (Bos et al., 2005). At the sector level when assessing how irrigation and drainage is performing in comparison with the objectives set for the sector, and in comparison with other uses of water. At the scheme level, performance evaluation is carried out to assess how individual schemes are performing against their own explicitly or implicitly stated objectives (Awulachew & Ayana, 2011).

At the main system level where the performance of the water delivery service is assessed; on this level performance assessment is focused on water delivery, which will depend on the management, operation and maintenance processes and procedures of the main system service provider. At the on-farm level where the performance of the on-farm water delivery, water use and water application is assessed. The present study has focused on the main system level performance evaluation.

2.3. Crop Water and Irrigation Water Requirements

Crop water requirement is defined as the depth of water required to meet the water lost through evapotranspiration (ET_C) of a disease -free crop, growing in a large field under non restricted soil conditions. Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between them. Evapotranspiration is the combination of the two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration. When the crop is small, water is predominantly lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process (FAO, 1998). To calculate ET_C a three-stage procedure is recommended (FAO, 1986). The first procedure is determination of reference crop evapotranspiration (ET_O). It is defined as the rate of evapotranspiration from an extensive surface of 8 to 15cm tall green grass cover of uniform height, actively growing, completely shading the ground and no shortage of water. This tells us the effect of climate on crop water requirement. Blaney Craddile method, modified Penman-Monteith method, radiation method and pan evapotranspiration method are some of the ET_O estimation methods. The modified penman Montieth method was used to estimate ET_O using CROPWAT software for the present study. This is because; the method has been found more accurate than the other methods (FAO, 1998). For computation of ET_O using CROPWAT software, the FAO modified Penman-Monteith method requires radiation, air temperature, air humidity and wind speed climatic data.

Irrigation is required when rainfall is insufficient to compensate the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right time and in the right amount. If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for the inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement. The irrigation requirement (IR) is one of the principal parameters for the planning, design and operation of irrigation and water resources systems (FAO, 1998).

Not all dependable rainfall is effective and some may be lost through surface runoff, deep percolation or evaporation (FAO, 1978). Only part of the rainfall can be effectively used by the crop, depending on its root zone depth and the soil storage capacity. In its simplest sense, effective rainfall means useful or utilizable rainfall FAO (1978). Rainfall is not necessarily useful or desirable at the time, rate or amount in which it is received. Some of it may be unavoidably wasted while some may even be destructive. Different methods exist to estimate the effective rainfall; one of the most commonly used methods is the USDA Soil Conservation Service Method (FAO, 1986).

2.4. Performance Indicators of Irrigation Schemes

Performance indicators currently used in the Research Program on Irrigation Performance are summarized into multi-disciplinary performance indicators (Bos ,1997). The type of indicators used depends on the individuals' interest (research, management, information to the public) and on the type of discipline in which one needs to look at (water balance, economics, environment, management).

There are two types of performance indicators in irrigation schemes. These are internal and external performance indicators. External (comparative) performance indicators are indicators used for cross comparison of schemes without looking at internal system specific performance targets (Molden et al., 1998). Comparison aims at improving the performance of the schemes by identifying the shortcomings and benchmarking (best practices) (Malano et al., 2001).

According to Dejen et al. (2012), internal (process) indicators are related to the internal management targets (adequacy, efficiency, equity, and dependability). These are useful to assess performance against system specific operational targets. Much effort has been made to evaluate internal irrigation performance in terms of flow rate, flexibility and duration of flow at the point of demand, mainly the tertiary canals.

The internal performance indicators are categorized into i) Water delivery performance indicators ii) Maintenance indicators (effectiveness of infrastructure, delivery performance ratio, water delivery duration ratio, water surface elevation ratio, and iii) physical sustainable performance indicators (sustainability of irrigated area and irrigation ratio. However, the present study is focused only on the water delivery indicators.

2.4.1. Water delivery indicators

An indicator is some number that describes the level of actual achievement in respect of one of the objectives of irrigation system. Indicators are used to simplify the otherwise complex internal and external factors affecting the performance of irrigated agricultural system. The characteristic activity during water delivery performance evaluation is a comparison of the actual or measured value with the targeted or intended values of this parameter. In general, performance can be evaluated using four indicators; i) Water balance and water service indicators, ii) Environmental indicators, iii) Economic indicators and iv) Emerging indicators (Bos et al., 2005). Water delivery indicators are grouped under the first category. Internal water delivery indicators are useful tools for understanding the internal operational processes that affect water distribution and delivery (Clemmens, 2006). Water delivery indicators are concerned with how well water supply matches demand, whether services are reliable, adequate and timely and whether social equity has been met. The water delivery system is analyzed for the distribution of its output (discharge) over space and time with the help of these indicators. Therefore delivery indicators are determined using the actual value of key parameter to the intended value of the key parameter. The parameter for the intended value is the discharge required by the crops where as the actual value is the delivered discharge in each offtakes structure. This helps in finding ways to enhance the water delivery process.

The main water delivery indicators used by different researchers and also used in this study are i) Adequacy (P_A) ii) Equity (P_E), Dependability (P_D) and Efficiency (P_F). The purpose of these indicators is to evaluate whether the system delivers water at the required rate at the right place and time, and to assess whether the water delivery service is effective. Molden and Gates (1990) set standards for the water delivery indicators and so many researchers use these standards as a baseline. Unal et al. (2004) applied the four water delivery indicators to evaluate the performance of a water delivery system at the tertiary canal level. Dejen et al. (2015) also applied these water delivery indicators to evaluate the Metahara gravity irrigation scheme during the year of 2012 and 2013 for three months each. Similarly Tebebal (2015), Shumye (2017) and Tariku (2017) also carried out studies using these water delivery indicators. The results were based on daily monitored flow at different offtake structures to evaluate performance of the irrigation schemes.

I. Adequacy

Adequacy is the capacity of an irrigation system to meet demands of farmers both spatially and temporally. It is an important parameter, which displays the extent to which total water deliveries are sufficient to fulfill the needs of the crops in a specific growing season and the command area. Adequacy is managed in two ways: i) by matching cropping plans and calendars with an estimated seasonal water availability before the start of the season, and ii) by adjusting operational targets in response to actual demand during a season. A distinction must be made here between supply-based and demand-based systems. Supply-based systems do not attempt to make short-term adjustments in discharge even though demand is varied; demand-based systems do. All irrigation users' are interested in obtaining adequate irrigation water to their farms; but in scare water resource regions it is difficult to achieve for to the entire irrigated area (Tebebal & Ayana, 2015).

II. Efficiency

Water delivery performance of a farm irrigation system is determined by the efficiency with which water is diverted, conveyed and applied. It is also determined by the adequacy and the uniformity of the application in each field on the farm to evaluate the irrigation system. Improved management of irrigation water can provide various benefits including conserving scarce water supplies, reducing the impacts of irrigation on water quality, detaining conflict due to water scarcity and enhancing producer returns. People do not always agree on the meaning of efficiency" because there are various degrees of efficiency. While there is no universally accepted definition of water efficiency, this term is often used in the sense of "saving water" through efficient mechanisms or wise use. The competition for freshwater often implies that, water for irrigation is not always available in the required quantity and/or quality (FAO, 2002).

III. Equity

Equitable share of water is a difficult task in allocating irrigation water in different irrigation systems. These systems have long and complex conveyance networks, which carry a limited amount of water to a vast command area. Two forfeitures of these systems are that extra supplies to one section of a canal may cause a water shortage in another section, and that deteriorated maintenance condition can disturb the water carrying capacity of the canal system (Zagiham, 1998). To confront these limitations, equitable distribution of water has been presented as a primary measure. Therefore, equitable or fair distribution of water to the farmers in the command area has always been a major concern of the management of the irrigation scheme (Tariku, 2017). To achieve equity in irrigation water; appropriate planning of water regulation and distribution (through scheduling), appropriate maintenance and operation of the irrigation networks, and helping and guiding water users to follow strict predefined water- turn is necessary.

IV. Dependability

Dependability is defined as the degree to which water deliveries accommodate the expectation of the system manager or water users' and match the planned schedule of the irrigation development. Dependability is a more difficult objective to assess because it is subjective, dealing with the quality of irrigation service rather than the quantity. It covers both the reliability of discharges or water depth and the reliability of timing of deliveries. If the operational plans have been properly prepared and advertised by the irrigation managers, farmers can know about the timing of the supply even if they are not timely for the crop water requirement. Zagiham (1998) measured the dependability of the supplies by estimating the weekly coefficient of variation for the ratio of actual to the targeted values for different reaches. The result indicates that, the supply was dependable starting from the first week of May to the third week of August, while for the rest of periods dependability was quite poor.

Molden and Gates (1990) formulated standard table for the water delivery indicators. The values and their corresponding system performance levels are given in Table 2.1.

Table 2.1 Water delivery performance standards (Molden & Gates, 1990)

Indicators	Poor	Fair	Good
Adequacy (P_A)	<0.80	0.80–0.89	0.90–1.00
Efficiency (P_F)	<0.70	0.70–0.84	0.85–1.00
Equity (P_E)	>0.25	0.11–0.25	0.00–0.10
Dependability (P_D)	>0.20	0.11–0.20	0.00–0.10

In the same way, the average overall values of the water delivery performance indicators and their performance levels as proposed by different workers are summarized in Table 2.2.

Table 2.2 Water delivery indicators as estimated by different workers

Workers	Year	Adequacy (P_A)		Efficiency (P_F)		Equity (P_E)		Dependability (P_D)	
		Value	Perfo. level	Value	Perfo. level	Value	Perfo. level	Value	Perfo. level
Dejen et.al (2015)	2012	0.87	Fair	0.98	Good	0.21	Fair	0.2	Fair
	2013	0.96	Good	0.94	Good	0.24	Fair	0.1	Good
Tebebal (2015)		0.64	Poor	0.89	Good	0.34	Poor	0.21	Good
Shumye (2017)		0.84	Fair	0.93	Good	0.47	Poor	0.24	Good
Tariku (2017)		0.84	Fair	0.79	Fair	0.11	Fair	0.05	Good

2.5. Irrigation System Efficiency Measures

The efficiency of an irrigation system is expressed as the ratio of the actual output value to the actual input value. Irrigation efficiencies are evaluated at scheme or farm level for the purpose of identifying the losses that occur in the irrigation system. The overall irrigation efficiency may be evaluated starting at the water abstraction point, through the conveyance system down to water application in the field. To measure the performance of irrigation system different efficiency measures are available. Conveyance efficiency, application efficiency, distribution efficiency, storage efficiency and water use efficiency etc. are the major efficiency performance measures. In the present study, only the water conveyance efficiency of the main and secondary canals was evaluated.

2.5.1. Water conveyance efficiency

Conveyance is the movement of water from its source through the mains and sub mains or canals to the farm block offtakes. Water conveyance efficiency may be defined as the percentage ratio of the amount of water delivered to the fields or farms to the amount of water diverted from sources. Conveyance efficiency is used to evaluate the efficiency of the system conveying water. It is also used to measure the efficiency of channels conveying water from wells and ponds to fields. Water conveyance loss consists mainly of operating losses, evaporation and seepage into the soil from the sloping surfaces and bed of the canal. The most important of these is seepage. Evaporation loss in irrigation networks is generally not taken into consideration. The seepage loss in the irrigation canals accounts for the major portion of the water conveyance loss, 98.37%, while approximately 0.3 percent of the total stream is lost due to evaporation (FAO, 1982). The lining of an irrigation canal has the advantages of reduction in seepage losses from canals. It can be viewed as an evaluation of the water balance of the main, lateral and sub-lateral canals (Rust & Snellen, 1993). The seepage loss through canal network was calculated by measuring the difference between the discharges at two points in the canal section. The dimensions of canal section and field channel were measured by measuring tape. Current meter is one of the important instruments used for measuring the flow velocity at different points of certain canal sections.

The loss of water due to seepage and evaporation from irrigation canals constitutes a substantial part of the usable water. By the time the water reaches the field, more than half of the water supplied at the head of the canal is lost through seepage and evaporation (FAO, 1982). Thus, care must be taken in the design of such canals to account for evaporation losses along with seepage loss. The conveyance loss per meter of the canal network is calculated by dividing the total conveyance loss by respective length of the canal network. Losses can be divided into unavoidable losses and avoidable losses. Unavoidable losses include the major system losses in open farm water distribution systems. Evaporation and seepage losses and they may be as high as 50 % of total volume available (Shumye, 2017). Avoidable losses include operational losses resulting from improper management with one of the most critical faults being incorrect run times varying climatic and demand conditions, which can account up to 9- 17%.

As per FAO (1982 & 1989b), the estimated overall conveyance efficiency of the lined canals was estimated as 75% and 95% respectively. The remaining was lost through seepage and other losses. Similarly, Alemayehu (2016), Shumye (2017) and Wondatir (2016) also evaluated the conveyance efficiency of the main and secondary canals of different irrigation schemes. As per the respective researchers, the overall conveyance efficiency values of (43.82%, 89.72%), (86.2%, 86.26%) and (85%, 79%) were obtained for the main and secondary canals respectively. The values were below the FAO (1989b) recommended values. FAO (1989b) recommended values of conveyance efficiency for the lined and unlined canals are given in Table 2.2 below.

Table 2.3 Values of water conveyance efficiency as recommended by FAO (1989b)

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

2.6. Users Satisfaction with Irrigation Service

It is an extremely important matter in water management to make serious attempts in determining true economic value of water due to the increasing demand for limited available water throughout the world. According to Keramatzadeh et al. (2011), the optimal allocation of water to agriculture can be achieved by managing the allocation of water based on optimal models. To implement an effective water management, knowledge about farmers' demand for irrigation water is important to assess reactions to water policy, and to determine the optimal water allocation to different users. In community managed irrigation schemes in least developed countries, where adequate data on water deliveries is not available; irrigation service levels can be well evaluated from qualitative and linguistic expression of the water users' perceptions (Dejen, 2015). Farmers' perspectives and assessments of irrigation scheme performance are thus critically important. However, several problems such as subjective judgments and multi co- linearity among the factors considered are commonly encountered when analyzing survey data and assessing the performance of community managed irrigation schemes from the farmers' point of view (Magingxa et al, 2006). Multi-Co linearity is a situation whereby some of the explanatory variables are dependent on others. In this case, it becomes very difficult to analyze data as the factors might be highly correlated leading to biased parameter estimates.

Customer satisfaction with the service received may be defined with a customer's positive or negative feeling about the value of using a service in a specific situation. This feeling may be a reaction to an immediate use situation or an overall reaction to a series of use situation experiences (Woodroofe, 1993). Satisfaction is, therefore, related to customer value. Customer value (or client's value) is a perception of what a customer wants to accomplish with the help of a service, in order to reach a desired goal.

Internationally, irrigation performance has been the subject of research in the agricultural sector for more than 5 decades (Gomo et al., 2014). However, these studies have had little impact to date, due to lack of collaborative implementation of recommendations on the part of irrigation stakeholders, among the farmers, policy-makers, and donors. Research has been done from the point of view of the various stakeholders, yet the performance of irrigation schemes, especially in the communally managed smallholder schemes, has remained low (Gomo et al., 2009). The performance of irrigation schemes is affected by a complex set of factors. An understanding of these variables can contribute towards enhancing the performance of irrigation schemes, improving the livelihoods of the rural poor and ensuring sustainability of the schemes. Key performance issues in small scale irrigation schemes range from technical, agronomic, economic and social to institutional issues. These can be explored from different stakeholders' perspectives. Several studies have been carried out on smallholder irrigation performance from the farmers` perspective (Kuscu et al*.,* 2009).

Technical performance research studies have focused on water conveyance, delivery and use in the smallholder irrigation schemes (Plusquellec, 2002; Kuscu et al*.*, 2009). Implementation of the recommendations has usually ignored the input of farmer's perspective; probably due to the misplaced belief that they are unable to understand and contribute to technical issues (FAO, 2002). In the wake of new approaches such as participatory irrigation management and irrigation management transfer, farmers can find themselves entrusted with the responsibility to operate and maintain the schemes. However, without technical information and proper management skills, the schemes deteriorate quickly, and frequently require rehabilitation only a few years after construction (FAO, 1982).

Irrigation service is measured at the level to which an irrigation system and all its components meet the set objectives of the irrigation scheme. In addition, the service specifies the roles of all parties, which include farmers, Water User Associations (WUAs), operators of the tertiary canal, operators of the secondary canals, operators of the main canals, and project authorities, in operating and maintaining all elements of the system (FAO, 1993). Most irrigation sector administrators and technical experts would agree that the primary source of funds to pay for the costs of irrigation operations and maintenance ought to be the payment of water charges by water users. If given the choice between (a) farmers receive full government subsidy for operation and maintenance, but get poor service, and (b) farmers pay for the cost of operation and maintenance, but get full control over service provision, it is likely that most farmers would opt for the later.

Logit model

A model which measures satisfaction is important to examine variables in determining farmers' satisfaction with the irrigation system. Different models are used for evaluating probability of framers' satisfaction. Linear probability model, Logit model and probit model are the three models developed for a binary response variable (Vasisht, 2012).

According to Vasisht (2012), Logit model regression analysis is a uni/multivariate technique which allows for estimating the probability that an event occurs or not, by predicting a binary dependent outcome from a set of independent variables. In this model on every occasion the dependent variable is binary (also called dummy) which takes values 0 or 1, that forces the output (predicted values) to be either 0 or 1 (Reyna, 2014). The dependent variable takes the value of 1 if the farmer is currently satisfied with irrigation system and otherwise 0 when not satisfied.

Tebebal (2015) used the Logit model to analyze the users' level of satisfaction in the Hare irrigation scheme. According to his study, the satisfaction of users' with irrigation service at head, middle and tail reaches was nearly 40.00, 33.33 and 33.33 percent respectively. As per the observed result in the entire system about 35.6 percent of beneficiaries were satisfied with irrigation service. Similarly, Aydogdu (2015) in Turkey and Gomo (2014) in South Africa had also used the Logit model and conducted the study. The level of users' satisfaction for the irrigation service obtained was 47.4% and 57% respectively. The satisfaction of users was less than 50% in most of the studies.

The use of Logit model to analyze the users' satisfaction has the following advantages over the others:

i) It is easier to compute and interpret than the probit model.

ii) Unlike the Linear programming model (LPM), the probability does not increase linearly with a unit change in the value of the explanatory variables (Mundial, 1999).

iii) The computation of the Logistic distribution guaranties the rate of the probabilities estimated always lay between 0 and 1.

Therefore, Logit model was used in the present study to determine the satisfaction level of the selected farmers from the irrigation scheme.

3. RESEARCH METHODOLOGY

3.1. Description of the Study Area

Robit small-scale irrigation scheme is located in the Amhara National, Regional State, North Shewa Zone, Kewet Woreda. The study area is found in the border of Kewet and Tarmabir Woredas separated by the Shewa-robit River. The irrigation scheme as per the project design document is referred as 'Robit irrigation scheme'. But the irrigation scheme locally among the users is popularly known as 'Debalkew irrigation scheme'. In the present study, the irrigation scheme is referred as 'Robit irrigation scheme' as per the project design document.

The study area is located to the left side of the Shewa-robit River when it was observed from the upstream to downstream of the river. Geographically, it is located between 9^{o} 57' 21'' and 9^{o} 57' 30'' North, and 39^{o} 50' 21'' and 39^{o} 51' 00''East. The area has an average elevation of 1417 m above mean sea level. The irrigation scheme is 220 km far from Addis Ababa and 90 km from the Town of Debre Berhan. It has 3 km on foot journey from the main road of the Addis Ababa-Dessie. The study area is categorized in the Kola Agro Ecologic Zone, where irrigation is highly practiced. The location map of the study area of Robit irrigation scheme is shown in Figure 3.1.

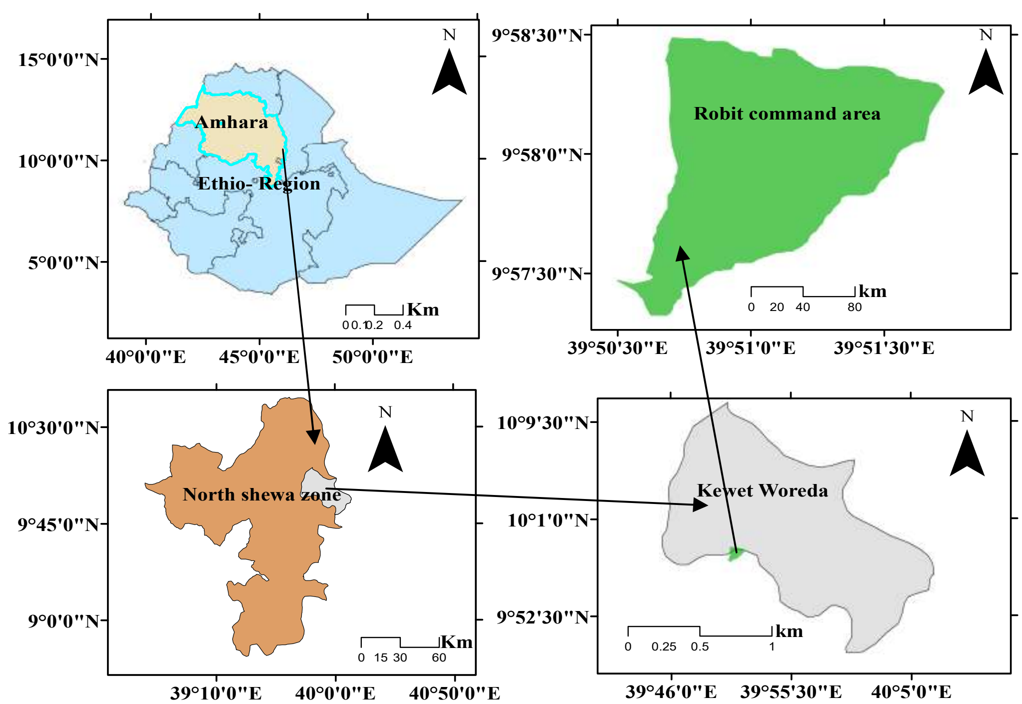


Figure 3.1 Location map of the study area

3.1.1. General background of Robit irrigation scheme

Robit small-scale irrigation (SSI) scheme was constructed in 2012 and gives four years operational service period. The irrigation scheme was designed and constructed by the Amhara National Regional State Water Resources Development Bureau in collaboration with Amhara water works enterprise. Robit small scale irrigation scheme was designed and constructed to give service both as productive and protective approaches. During winter season it gives productive service and during summer as protective to supplement the rain fall. The irrigation scheme has a main canal length of 2.75 km and two secondary canals with 0.82 km and 1 km length. The first and second secondary canals are located at a distance of 1.64 and 2.05 km, respectively from the traditional intake structure. In addition to this, 13 tertiary canals are available and each tertiary offtake has its own command area. Both the main and secondary canals are lined canals, except the 100 m lengths, starting from the traditional diversion structure to the designed intake structure. The tertiary canals are partly lined and partly unlined canals. As shown in Figure 3.2 nine tertiary canals receive irrigation water directly from the main canal. In the stone masonry structure of the main canal, plastic pipes were installed in the direction of the irrigated area and discharge was delivered by these pipes. The pipe offtakes were closed with a sack which was removed during the irrigation time. Even though the pipes were closed by the sacks, some irrigation water was lost through the pipe. The main canal is one sided canal due to non-suitability of topographic condition. As reported in the design document, the design discharge of the main canal intake, and first and second secondary canals were 0.275 m^3s^{-1}, 45.03 and 43.32 ls^{-1} respectively. The design discharge for each tertiary offtake is given in Appendix A-22. The flow duty taken during the design period for the command area was 1.14 $ls^{-1}ha^{-1}$. The layout of Robit irrigation scheme is shown in Figure 3.2.

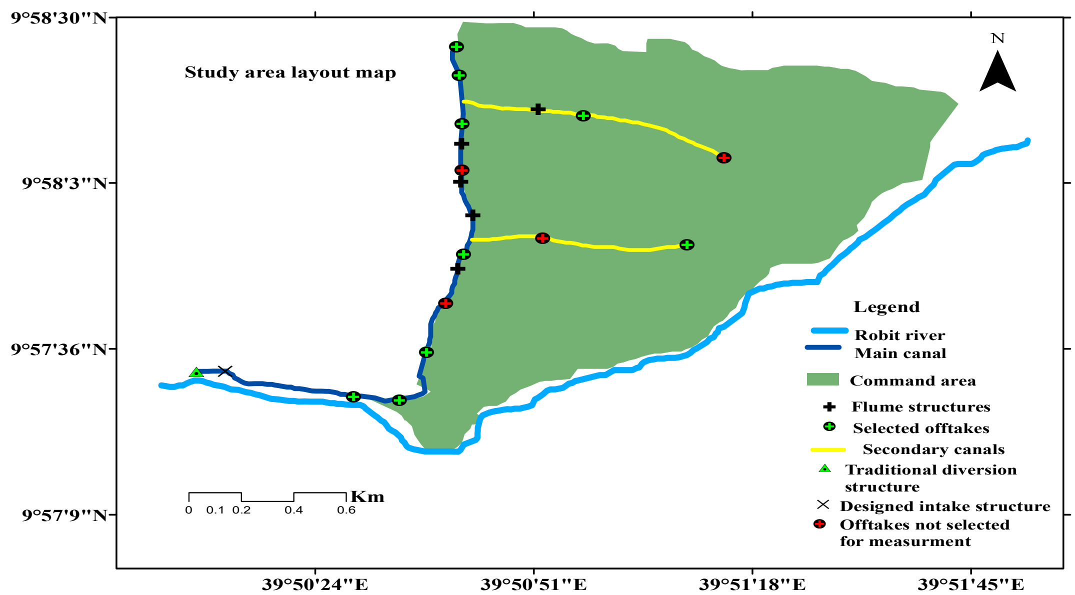


Figure 3.2 Layout of Robit irrigation scheme

The initial command area of the Robit SSI scheme was 250 ha, however, currently the command area reduced to 194 ha, out of which, the irrigated area was 174.5 ha. The reasons for the decrease in command area were: shortage of irrigation water, failure of physical infrastructures and sedimentation problem. In the irrigation scheme, 518 irrigation users with 12 groups of water user associations (WUAs) are benefited. Even though the irrigation users are categorized into 12 groups, their communication within the group members and among the groups was too weak.

The land holding size of the farmers in the Robit SSI scheme varies from 0.15-0.5 ha. The irrigation users apply rotational way of water distribution system to irrigate their fields. The irrigation interval of the Robit irrigation scheme was constant throughout the crop growing season and every irrigation user received irrigation water after six days.

3.1.2. Climate

The climate of the rift valley in which the present study was carried out is Kola Ecological Zone with semi-arid climatic zone. The area has an average maximum and minimum temperature values of 27.72 ^{O}C and 12.94 ^{O}C respectively.

3.1.3. Soil

The soil type for Robit irrigation scheme is vertisols as reported in the design document. These types of soils are characterized by water logging during rainy season and cracking during dry periods. In general, it is categorized as deep soil (>1.5m) and favorable for growing different crops.

3.1.4. Crop

The irrigation users grow different crops and vary from one season to another season. Such crops include onion, maize, teff, mung bean, cabbage and tomato etc. But during the study period the only crops that were grown were onion, mung bean and maize.

3.1.5. Topography

The topography of the study area is plain and surrounded by mountains. The topographic feature of the study area consists of slope gradient ranging from gently sloping (2%) to steeply sloping (4%). The topography is somewhat sloping from the South-west to North direction and the main canal also runs following this slope direction.

3.2. Sampling Techniques

Conducting measurement in all canal branches and each offtake is a difficult task; time consuming and costly. To simplify this difficulty, taking representative samples from the whole canal network was mandatory. The water supply and delivery vary from one part of the scheme to the other depending on various factors related to the scheme infrastructure, such as maintenance conditions, functioning of flow control structures, operation and etc. (Dejen et al., 2016). Thus, the canal branch of the present study was stratified as head, middle and tail reaches to measure the delivered flow in each offtake. Nine tertiary offtakes three each at head, middle and tail reaches were selected from the total 13 tertiary offtakes. The total offtakes were identified as TO1, TO2, TO3, TO4, TO5, TO6, TO7, TO8, TO9, TO10, TO11, TO12 and TO13. From these tertiary offtakes, offtakes which grow one crop per tertiary offtake were selected. Thus, the selected tertiary offtakes were: TO1, TO2, TO3, TO5, TO7, TO9, TO10, TO12 and TO13 (Appendix A-9). The irrigation fields found at the remaining four tertiary offtakes (TO4, TO6, TO8 and TO11) were growing more than one crop. The area covered by each crop in the four offtakes was not known and thus, estimation of crop water requirement for these offtakes was difficult. Therefore, these four offtakes were not selected for the present study. The nine tertiary offtakes which grow the same crop per tertiary offtake were selected for the present work. For simplicity in discussion the selected tertiary offtakes (TO1, TO2, TO3, TO5, TO7, TO9, TO10, TO12 and TO13) were symbolized as locations; L1, L2, L3, L4, L5, L6, L7, L8, and L9 respectively. The offtake locations L1, L2 and L3 were located at head reach. Similarly, L4, L5 and L6 were located at middle reach, and L7, L8 and L9 were located in the tail reach (Table 4.2 and appendix A-9).

To evaluate the water conveyance efficiency of the main and secondary canals, the canal branch was stratified as head, middle and tail reaches. Before selection of the control points careful field observation were carried out. The control points were marked at interval of 200 m for the main and second secondary canals, but at 150 m for the first secondary canal. Due to the failure of the head work structure, the irrigation users diverted the irrigation water 100 m back of the designed head work structure (Figure 4.23). Therefore, the 100 m unlined canal was evaluated separately. The control points were represented as; MP1, MP2, MP3, MP4, MP5, MP6, MP7, MP8, MP9, MP10, MP11, MP12, MP13 and MP14 for the main canal. Similarly, the control points for the first and second secondary canals were symbolized as; S1P1, S1P2, S1P3, S1P4 S1P5 and S1P6, and S2P1, S2P2, S2P3, S2P4 S2P5 respectively. Therefore, 14 control points were selected in the main canal. While 6 and 5 control points were selected in first and second secondary canals respectively. It was assumed that the canal branches have similar physical condition within the selected interval of field observations.

The total beneficiaries in the selected command area were 518. The representative sample size was determined using a simplified Equation 3.1. Finally, the representative respondents were selected randomly.

$$n = \frac{N}{1+N(e)^2} \text{--} 3.1$$

Where:

n = Sample size

N = Population size or total irrigation users

e = Level of precision

The level of precision for 95% confidence interval (α = 5% = 0.05) with degree of variability (P) = 50%.

Accordingly;

$$n = \frac{518}{1 + 518(0.05^2)}$$

n = 225

3.3. Methods of Data Collection

The study was conducted for one irrigation season from April to June 2017. In addition to this, the perception of irrigation users concerning the current and previous irrigation seasons was also collected to enrich the one season performance evaluation. During the study period, both primary and secondary data were collected. The primary data were collected from direct field measurement, field visit, laboratory analysis and questionnaire. The secondary data were obtained from the Kewet Woreda agricultural office, design document, Debre Berhan research center, National Meteorological Agency, related journals, published and unpublished thesis and from FAO documents.

3.3.1. Primary data collection

Transect walk was conducted for observing the general condition of the study area and for proper selection of control points. After careful selection of the control points the canal branch was divided into three reaches as head, middle and tail reach. In each reach and control points water flow depth, water flow velocity and canal width of the main and secondary canals were measured. These control points were representative of the whole irrigation scheme. The soil texture, infiltration rate and total available water were determined. In addition to the above data, perceptions of users regarding the irrigation service received were collected from 225 irrigation users. To identify the factors affecting water delivery performance of Robit irrigation scheme field observation was carried out during the three months data collection period.

In general, the primary data collected for the study were:

i) Observation and selection of control points as shown in Figure 3.2
ii) Soil physical properties which are relevant for this study
iii) Water infiltration rate
iv) Delivered discharge at each selected control point of main and secondary canals
v) Depth of water flow at each selected offtake structure
vi) Perception of irrigation users using the questionnaire as given in Appendix C
vii) Problems that hinder the scheme water delivery performance

3.3.2. Secondary data

The important secondary data collected for the study were; crop coefficient (K_C) values for each growth stage for the crops grown in the study area, crop root zone depth, critical moisture depletion, meteorological data, total irrigated area, area irrigated under each offtake structure and total number of beneficiaries.

3.4. Materials Used

3.4.1. Physical materials

- Current meter
- Tape meter
- 3-inch Phrasal flume
- Double ring infiltrometer
- Sieves having different size
- Hydrometer
- Sensitive balance
- Core samplers
- GPS

3.4.2. Software used

- ARC GIS 10.1
- CROPWAT 8.0
- STATA software

3.5. Data Analysis

Before starting the measurements, field observations were done to select the points where measurements are to be carried out. To determine hydraulic indicators measurements were done fortnightly at nine locations, three each at head, middle and tail. The offtake and canal branches flow velocity and geometric dimensions of the main and secondary canals were measured. The measured offtake flow depth was used to calculate the delivered amount of water (Q_D). Similarly, for estimation of water conveyance efficiency measurements were taken at the marked points. To evaluate the water conveyance efficiency of the main and secondary canals measurements were taken 4 days (during April and May) and 2 days during June twice a day during each month. However, in the offtake structures, measurement was taken following the irrigation interval during the crop growing season. The amount of crop water requirement (Q_R) for the crops grown in the study area was estimated using CROPWAT software for the crop duration.

3.5.1. Discharge measurement

The discharge of the main canal, secondary canals and tertiary offtakes was measured to evaluate the water conveyance efficiency and water delivery indicators. The above measurements were done using Current meter and 3-inch Parshall flume (Figure 3.3). Current meter was used to measure the water flow velocity in the main canal and some control points in the secondary canals. The 3-inch Parshall flume was used to measure the flow depth in the remaining control points of the secondary canals and in the tertiary offtakes. The water flow depth to the tail end of the secondary canals between 600-750 m and 750-820 m was shallow in depth and it was difficult to make discharge measurements by using current meter. As a result, the measurements in these sections were done using 3-inch Partial flume. Similarly, for the canal sections between 400-600 m, 600-800 m and 800-100 m discharge were measured by using 3-inch Parshall flume in the second secondary canal. The water flow condition in the Parshall flume is free flow (Figure 3.3). In the Parshall flume the flow depth was measured in the $\frac{2}{3}$ A measured from the crest (Appendix B). The delivered discharge was estimated using Equation 3.2.

$$Q = KH^{n} \qquad 3.2$$

Where:

Q = Delivered discharge (m^3s^{-1})

H = Upstream flow depth in the converging inlet section (m),

K = Free flow coefficient and

n = Free flow exponent.

For 3-inch Parshall flume the value of the coefficients K and n is 0.1771 and 1.55 respectively. In the 3-inch Parshall flume the recommended maximum and minimum head was 0.03 m and 0.33 m; thus the maximum and minimum flow that can be delivered through the Parshall flume is 32.1 ls^{-1} and 0.77 $l\ s^{-1}$ respectively.

The validity of the coefficients (free flow coefficient, K and free flow exponent, n) for the study area was examined by measuring the water flow velocity at two control points using Current meter. The locations S1P5 in a first secondary canal and S2P3 on the second secondary canal were selected to cross check the delivered discharge measured using Parshall flume. The results obtained from Parshall flume and current meter for the selected control points were almost similar. Therefore, the selected values of the coefficient K= 0.1771 and n = 1.55 for the 3-inch size Parshall flume were correct and further calibration of these coefficients was not mandatory.

OGAWA SEIKI HIROI'S electric current meter used in the present study measures the number of revolutions of the propeller (conical cups) per second. The current meter revolutions were measured at the selected control points. Since the canal flow was shallow in depth one-point measurement method was applied. For the OGAWA SEIKI HIROI'S electric current meter, the minimum recommended operation time at one control point is 40 seconds. For the present study, measurements were taken for 45 seconds at each measuring point. The water flow velocity was estimated using Equation 3.3

$$V = 0.132N + 0.001 \quad \text{--} \quad 3.3$$

Where;

V = Water flow velocity (ms^{-1})

N = Number of propeller revolution per second

Note: The applicable range of velocity for the OGAWA SEIKI HIROI'S current meter is from 0.15 ms^{-1}-1.8 ms^{-1}.

The delivered discharge conveyed at each control point was calculated by multiplying the flow cross-sectional area by the flow velocity using Equation 3.4. The main and secondary canals were rectangular in shape. Therefore, the cross-sectional area of the canal was the product of the water flow depth and bottom canal width as expressed by Equation 3.5

$$Q = A * V \text{---} 3.4$$

Where:

Q = Delivered discharge (m^3s^{-1}),

A = Flow cross-sectional area (m^2) and

V = Flow velocity (ms^{-1})

$$A = b * d \text{---} 3.5$$

Where:

A= Flow cross-sectional area (m^2),

b = Canal bottom width (m) and

d = Flow depth (m)

Figure 3.3 Discharge measurement using Current meter and Parshall flume

3.5.2. Soil sample analysis

I. Soil texture

The soil textural class of the study area was determined during the study period using the hydrometer method. Six soil samples each at the head, middle and tail reach of the study area were taken. The maximum effective root zone depth of Onion and Mung bean crops is 60 cm. Therefore, the soil samples at each location were taken at 0-30 cm and 30-60 cm soil depth. The soil samples were taken using Auger and Core samplers.

The hydrometric method of analysis required: weighing balance, sieves (50 microns and 250 microns), 500 ml graduated cylinders, hydrometer (standard Bouyoucos hydrometer, ASTM NO 152H graduated in gram per liter), thermometer, stop watch and oscillatory shaker (Figure 3.4). The soil samples were first air dried and grinded using pestle and mortar, and then sieved using 50 and 250 micron size sieves. After that 25 gm of soil and 50 ml dispersing agent (40 gm sodium Hexametaphosphate, Napo3 and 10 gm of Sodium carbonate, Na2co3) was mixed in distilled water in 500 ml flask. The soil and solution were then transferred to mechanical stirrer and shake for 5 minutes. The dispersed soil suspension was then transferred to hydrometer jar and the volume in the hydrometer was adjusted to 500 ml by adding distilled water. The readings were taken after 40 seconds and after 2 hours. The results were corrected to a 20 ^{O}C.

Figure 3.4 Soil texture determination using Hydrometer

For temperature readings above 20 ^{O}C correction values are added to the hydrometer reading, but for temperature readings below 20 ^{O}C correction values are subtracted to the hydrometer reading ISRIC (2000). This is because, for example for the 40 second readings when the temperature is above 20 ^{O}C the movement of particles is high. So, some sand particles may suspend in addition to the clay and silt particles. However, if temperature value is less than 20 ^{0}C the kinetic energy is low and all clay and silt particles may not be suspended. The other correction factor is salt correction. A constant value of 2 is subtracted from every hydrometer reading to correct the effect of salt on the hydrometer results. The corresponding temperature correction values are presented in Table 3.1. The results were calculated according to the national soil research center for Ethiopian agricultural research organization (2000) formula as given by Equations 3.6 to 3.8.

$$\% \text{ sand} = 100 - \left[(d1 \pm C_1 - 2) * \frac{100}{25}\right] \text{ ---} 3.6$$

$$\% \text{ clay} = (d2 \pm C_2 - 2) * \frac{100}{25} \text{ ---} 3.7$$

$$\% \text{ silt} = 100 - (\% \text{ sand} + \% \text{clay}) \text{ ---} 3.8$$

Where:

d1, d2 = Hydrometer readings at 40 second and 2 hours respectively

C_1, C_2 = Temperature corrections at 40 second and 2 hours respectively

$\frac{100}{25}$ = to convert sample weight to 100

2 = Salt correction factor

The soil textural class was determined using the USDA textural triangle method for the percent soil fraction as determined from the hydrometric analysis.

Table 3.1 Temperature correction values of Hydrometer readings

Temperature (^{O}C)	15	16	17	18	19	20	21	22	23	24	25
Correction value	-2	-1.5	-1	-1	-0.5	0	0.5	1	1	1.5	1.5

II. Total available soil moisture

To determine the total available soil moisture undisturbed soil sample was taken from the soil surface up to the crop root zone depth from three representative fields. The crops in first, second and third fields were onion, mung bean and maize crops respectively. The effective root zone depth of onion, mung bean and maize was 60 cm, 60 cm and 100 cm respectively. Therefore, the soil samples were taken from 0 to 30 cm and 30 to 60 cm in the first two fields. But in the third field, soil samples were collected from 0 to 25 cm, 25 to 50 cm, 50 to 75 cm and 75 to 100 cm. Therefore, overall eight soil samples were taken for the study. As observed from soil textural classification the soil texture of the study area was relatively the same at all locations (Appendix A-8). Therefore, the researcher assumed the selected soil samples represent the whole command area.

The total soil moisture was considered as a difference of the soil moisture at field capacity and permanent wilting point (Appendix A-9). The soil moisture characteristics were determined in the laboratory using the pressure plate apparatus. The permanent wilting point and field capacity were considered as the moisture content at 4.2 PF or 15 bars and at 2.5 PF or 1/3 bar respectively.

III. Soil infiltration rate

The soil infiltration rate was determined using double ring infiltrometer. Water was added to the soil with certain interval of time. The cumulative depth of infiltration and the time elapsed was recorded carefully. Measurements were taken in the internal ring, but the external ring protected the lateral movement of water. After a long time, the infiltration rate of the soil reached nearly constant and this was termed as basic infiltration rate. The constant value of the basic infiltration rate expressed in mm per day obtained after a long time was used as an input data for the CROPWAT Model.

3.5.3. Crop water requirement

The crop water requirement for different crops grown in the study area was determined by CROPWAT software using Equation 3.9. The required important data, planting and harvesting dates, and the length of growth periods for each crop was collected from the irrigation users. The crop coefficient for different growth stages, maximum root zone depth and yield reduction factors, and crop height values for each crop were adopted from FAO 56. Chancellor and Hide (1997) recommended overall irrigation efficiency for small-scale irrigation, equal to 45%. As per the design document, the designers of Robit irrigation scheme also adopted this value. Therefore, the overall irrigation efficiency for estimation of irrigation water requirement in the present analysis was assumed equal to 45%. To accomplish the study 25 years (1990-2015) climatic data were collected from the National Meteorological Agency and Debre Berhan research center and are given in Appendices A-1 to A-6.

The CROPWAT software estimates the reference crop evapotranspiration (ET_O) using the Penman-Montieth method. After estimation of ET_O values for each crop, the crop water requirement and the duty of each crop was determined from the CROPWAT Model. The crop water requirement was determined by multiplying the crop coefficient (Kc) by the reference crop evapotranspiration as expressed in Equation 3.9. The duty of the crops was determined using Equation 3.10.

$$ET_C = K_C * ET_O \qquad (3.9)$$

Where:

ET_C = Crop evapotranspiration

ET_O = Reference crop evapotranspiration

K_C = Crop coefficient

$$D = \frac{GIR}{8.64} \qquad (3.10)$$

Where:

D = Flow duty ($ls^{-1}ha^{-1}$),

GIR = Gross irrigation requirement (mm/day)

8.64 = Unit conversion factor

The gross irrigation water requirement considering the entire irrigation system may be expressed as

$$GIR = \frac{NIR}{Ei} \text{ -- } 3.11$$

Where:

GIR= Gross irrigation requirement (mm/day)

NIR = Net irrigation requirement (mm/day)

Ei= Over all irrigation efficiency (fraction)

The net irrigation requirement was determined using Equation 3.12

$$NIR = ET_C - Ref \text{ -- } 3.12$$

Where:

NIR = Net irrigation requirement (mm/day)

ET_C = Crop evapotranspiration (mm/day)

Ref = Effective rainfall (mm/day)

Finally, the water required (Q_R) for each crop was determined by multiplying the cultivated area of each crop by the duty of each crop as expressed by Equation 3.13.

$$Q_R = D * A \text{ -- } 3.13$$

Where:

QR = Water required for the crop in each offtake structure (ls^{-1})

D = Duty of each crop ($ls^{-1}ha^{-1}$)

A = Area covered by each crop and irrigated by each offtake (ha)

The input data required for CROPWAT software were; average values of different climatic data, soil type, crop type, total available moisture (mm/m), maximum basic infiltration rate (mm/day), rooting depth, crop coefficient (Kc) values of each crop for different growth stages, total number of days per growth stage for each crop and depletion fraction. The estimated values of crop water required (Q_R) and water delivered (Q_D) in the study were expressed in liter per second (ls^{-1}).

3.5.4. Water delivery indicators

To evaluate the water delivery performance of the irrigation scheme, four water delivery performance indicators were important. These performance indicators were; adequacy, efficiency, equity and dependability. After estimation of the required discharge and discharge delivered at each of the nine-selected offtake structures, the water delivery performance of the irrigation scheme was evaluated using the water delivery indicators as described below.

I. Adequacy (P_A)

For a single offtake, Adequacy is the ratio of water delivered (Q_D) to water required (Q_R) in terms of flow rate or volume as expressed by Equation 3.14. Adequacy may, however, also be determined for an irrigation system as a whole or for a subsystem. In this case, it is aggregated for a service area (R) averaged over a time period of consideration (T). In order to assess the spatial variation of adequacy levels, it was determined for head, middle and tail offtake. Similarly to evaluate the temporal variation of adequacy the study was carried out for three months.

$$P_A = \frac{1}{T}\sum_T \frac{1}{R}\sum_R \left(\frac{Q_D}{Q_R}\right) \qquad 3.14$$

If $Q_D < Q_R$ otherwise 1

Where:

P_A = Adequacy indicator over an area R and time period T,

Q_D = Delivered amount of discharge at each offtake for a specific time period, and

Q_R = Crop water required at a specific point during growing period.

II. Efficiency (P_F)

Efficiency refers to the water conservation property of the irrigation system. The ratio of required to delivered flows ($\frac{Q_R}{Q_D}$) indicates the offtake efficiency as expressed by Equation 3.15. Efficiency was determined to head, middle and tail reach offtake in order to distinguish any variations in efficiency. It is given as

$$P_F = \frac{1}{T}\sum_T \frac{1}{R}\sum_R \left(\frac{Q_R}{Q_D}\right) \qquad 3.15$$

Where:

P_F = Efficiency indicator over an area R and time period T

III. Equity (P_E)

Equity is the spatial variation of adequacy. It refers to the fairness of water deliveries and reflects the spatial uniformity. The coefficient of variation (C_V) of the ratio of delivered to required flows $\frac{Q_D}{Q_R}$ over a region R and for time period T provides a measure of the fairness of the water distribution over R as expressed by Equation 3.16.

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_D}{Q_R}\right) \text{---} 3.16$$

Where:

P_E = Equity indicator over an area R for a time period T and

CV_R = Spatial coefficient of variation of the ratio $\frac{Q_D}{Q_R}$ over a region R.

IV. Dependability (P_D)

Dependability is an indicator for the degree of conformity of water deliveries to prior expectations. It implies the achievement of temporal uniformity of the relative water delivery over a region R as expressed by Equation 3.17. It is an important indicator as it indicates the reliability of the system to meet preset water deliveries.

$$P_D = \frac{1}{R}\sum_R CV_T\left(\frac{Q_D}{Q_R}\right) \text{--} 3.17$$

Where:

P_D = Dependability indicator over a time period T for a region R and

CV_T = Temporal coefficient of variation of the ratio $\frac{Q_D}{Q_R}$ over time period T.

3.5.5. Water conveyance efficiency

From the various types of irrigation system efficiency measures, water conveyance efficiency of the main and secondary canals was evaluated. Conveyance system diverts water from its source, conveys and distributes water to the target point. As water is transported from the diversion site to the irrigation field, some amount of water is lost in different ways such as seepage and evaporation. Efficient irrigation system transports water with minimum losses and hence has high water conveyance efficiency. In order to determine the amount of water lost through a conveyance system in the main and secondary canals, the amount of flow rate in the first point and the amount of flow rate conveyed in the second point was measured. Water conveyance efficiency from the source to the field is therefore the ratio of discharge measured at the field to the discharge measured at the source as expressed by Equation 3.18. The water conveyance losses of the canal system were estimated using Equation 3.19.

$$Ec = \frac{Q_O}{Q_I} * 100 \text{ -- } 3.18$$

$$L = Q_I - Q_O \text{ --- } 3.19$$

Where:

Ec = Water conveyance efficiency (%)

Q_I = Discharge measured at the first point (ls^{-1})

Q_o = Discharge measured at the second point (ls^{-1})

L = Water conveyance losses (ls^{-1}) between first and second point

3.5.6. Users satisfaction

Satisfaction captures the customers' response to a particular service - how the customer feels about the service received. There are different factors that can influence farmer satisfaction in irrigation schemes. Some of the factors are technical, agricultural, social or economic while some are institutional (Hill et al. 2008). The focus of the study was mainly on the technical factors that affect satisfaction of users.

There is no statistical model which is the right one for a specific research problem, but there is the best, which can be described as offering more ways to infer about specific characteristics (Corty, 2007). Different models are used for evaluating the probability of farmers' satisfaction. The three methods, developing a probability model for a binary response variable: (i.e. Linear probability model, Logit model and Probit model) are mostly utilized (Gujarati, 2003 & Vasisht, 2012). This study employs the Logit model to evaluate the level of users' satisfaction.

Logit model

Logit model was used in this study to analyze the level of users' satisfaction. This model was selected because it is easier in interpreting the results as compared to other models. In addition to this, its result is binary and converges rapidly than the Probit model (Torres, 2012). The Binary Logit model can therefore be employed to estimate the satisfaction status of randomly selected farmers from irrigation scheme. It describes the relationship between one or more independent variables and a grouped response variable (Kuscu et al., 2009; Dolgun & Saracbasi, 2014). The Model estimates the probability of the dependent variable to be 1. This is the probability that some event happens (Reyna, 2014). The input of the model was run on STATA software version 12.

The factors that were listed by the farmers and that were expected to have an effect on the satisfaction status of the farmer were availability of adequate water, water availability in time, farm location from canal head, farm size and schooling years. These were the independent variables and users' satisfaction status with regards to irrigation service depends on these factors. In the Logit Model the effect of the explanatory variables on the farmers' satisfaction with irrigation service received is expressed by Equation 3.20.

$$Zi = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 \text{-------------------------------} 3.20$$

Where:

Z = Farmers satisfaction for irrigation service (dummy, 1= Satisfied; 0 = Unsatisfied),

X_1 = Availability of adequate water (dummy, 1= Yes; 0 = No),

X_2 = Water availability in time (dummy, 1 = Yes; 0 = No),

X_3 = Farm location from canal head (dummy1 = near; 0 = far),

X_4 = Farm size,

X_5 = Schooling years,

β_0 = Constant term,

β_1............... β_5 = Coefficients of the independent variables and

i = integer

The hypothesized relationships of the independent variables were described as below.

Availability of adequate water: it was hypothesized that farmers become more and more satisfied with irrigation service when the adequacy of water increased.

Water availability at the time: it was hypothesized that when the irrigation users received water timely the satisfaction of the users' increased.

Farm location from the main canal: this variable measures the distance of the canal to each farm plot. It was expected that farmers with farm plots near the canal head get more water than the tail end. It was, therefore, hypothesized that farmers, farm plots near to the head end of the canal are more satisfied with the irrigation service.

Farm size: land size determines the amount of water needed by a farmer for irrigation, so it might be an important factor for satisfaction for irrigation service. Here, it was hypothesized that the smaller the farm size the more likely would irrigation users' satisfied with the delivered flow.

Schooling years: it was hypothesized that education level has a positive effect on satisfaction. This is because; the ability of educated farmers to understand regarding the required depth of water and irrigation schedule when trained. In addition to this, educated and trained farmers may easily adopt new technologies and improved innovation than the less educated farmers.

The basic ideas underlying the Logit Model are given below: transformations estimate cumulative distribution, thereby eliminating the interval 0, 1 problem associated with linear probability Model (Gujarati, 2003 & Kuscu et al., 2009). The logistic cumulative probability function is represented by Equation 3.21

$$P_i = \frac{1}{1+e^{-(\beta o+\beta ixi)}} \text{--} 3.21$$

For the ease of expression Equation 3.21 may also be expressed as

$$P_i = \frac{1}{1+e^{-zi}} = \frac{e^{zi}}{1+e^{zi}} \text{--} 3.22$$

Where:

P_i = Probability of the farmer being satisfied with irrigation services and

e = Base of natural logarithm equal to 2.71.

It is easy to verify as Zi ranges from $-\infty$ to $+\infty$, and Pi ranges between 0 and 1.

If P is the probability of users satisfied with the service, then the probability of user being dissatisfied with the service is (1-P) which may be represented by Equation (3.23).

$$1-P = \frac{1}{1+e^{zi}} \text{--} 3.23$$

Or

$$\frac{P_i}{1-P_i} = \frac{1+e^{zi}}{1+e^{-zi}} = e^{zi} \text{--} 3.24$$

Taking logs of both sides Equation 3.24 may be expressed as

$$Li = \ln\left(\frac{P}{1-P}\right) = Zi \text{--} 3.25$$

Where:

Li = Logit probability Model

To determine the satisfaction of users' questionnaire concerning the independent variables affecting satisfaction was prepared as given in Appendix C. As determined in the sampling technique the sample size was 225. Therefore, the perception of irrigation users regarding the five explanatory variables were collected from the randomly selected irrigation users as shown in Figure 3.5. The above listed five explanatory variables were listed by majority of the irrigation users, irrigation expert and water committees as factors affecting satisfaction of irrigation users. The data collected from the questionnaire was uploaded to STATA software. The important outputs of the STATA software were the P-value, Logit regression coefficient and probability of chi square (X^2). In order to check whether the explanatory variables have really association with the dependent variable, the explanatory variables were regressed in the Logit model both in bi-variant and multi-variant cases. In the bi-variant, the dependent variable was regressed with the one independent variable. While in multi-variant case all the independent variables were regressed at the same time with the dependent variable. If there is an association between the variables, the P value would be least less than 10%. In addition to this, the probability chi square (X^2) value would be below 0.05. Therefore, the present study was done considering these conditions.

Figure 3.5 Questionnaire collection in Robit irrigation scheme

3.6. Conceptual Framework

To accomplish the study both primary and secondary data were collected. Discharge measured at the selected offtakes and control points, soil data and users perception regarding the selected explanatory variables were the primary data required for the study. Meteorological and agronomic data were the secondary data. After collecting the data, the delivered discharge, required discharge, P-values, Logit regression coefficients (β) and the probability chi square (X^2) values were determined. Finally, the water delivery performance, conveyance efficiency and user satisfaction were evaluated. The conceptual framework for the study may be expressed as shown in Figure 3.5.

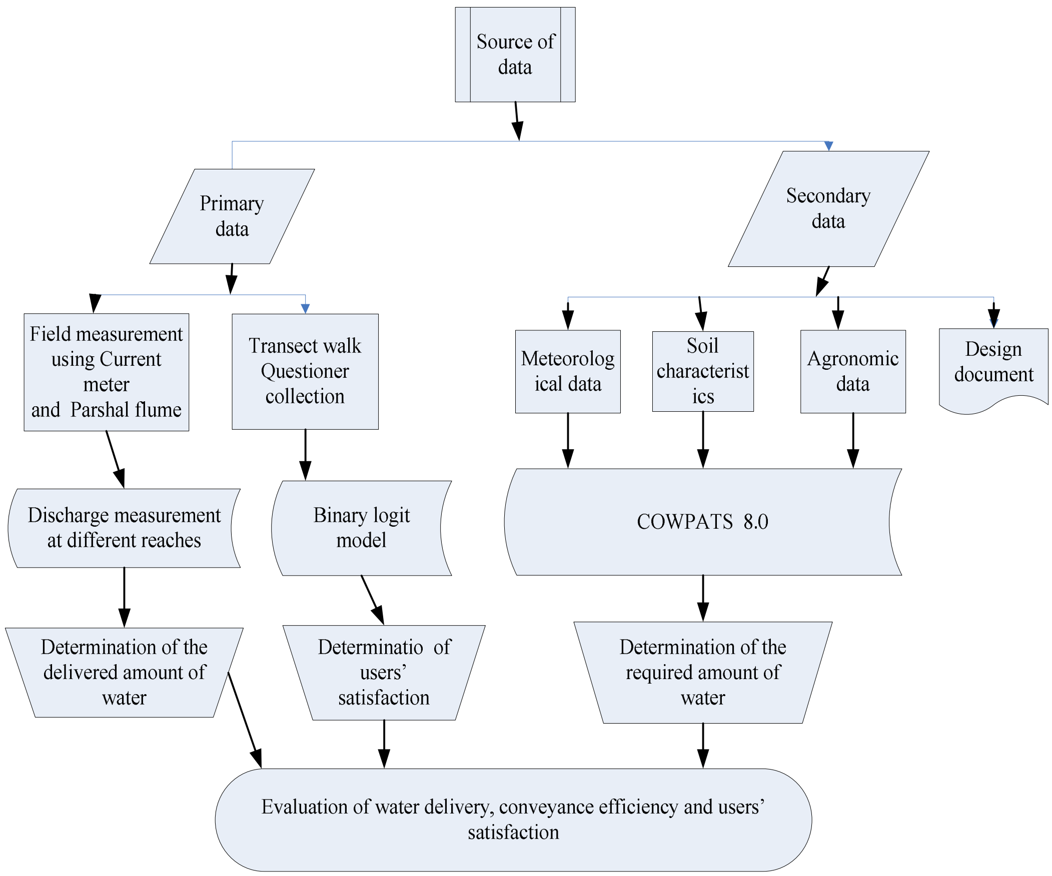


Figure 3.6 Research framework

4. RESULTS AND DISCUSSIONS

4.1. Soil Physical Properties

I. Soil texture

The soil fractions in percent sand, clay and silt for each location at each depth are given in Appendix A-8. The proportion of the soil varied from 16 to 24%, 52 to 60 % and 18 to 26% for the sand, clay, and silt soil fractions respectively. According to the USDA SCS Soil textural triangle, the textural class for Robit irrigation scheme for all the selected fields was found to be clay soil, which is consistence with the report in the design document.

II. Total available moisture

The field capacity (FC), permanent wilting point (PWP) and total available moisture (TAM) was estimated up to the crop root zone depth for Onion, Mung bean and Maize crops. The estimated values of different soil moisture characteristics at each soil depths for each of the head, middle and tail reaches are given in Appendix A-9. The average value of total available moisture (TAM) varied from 171.6 to 172 mm/m. The variation in TAM in different locations was insignificant. FAO (1998) recommended FC, PWP and TAM values for clay soil ranges from 320-400 mm/m, 200-240 mm/m and 120-200 mm/m respectively. Therefore, the estimated values of TAM for the study area are within the acceptable range. The average values of TAM were used as input for estimation of the crop water requirement in the CROPWAT software.

III. Soil Infiltration rate

The measured values of instantaneous infiltration rate and cumulative depth of infiltration are given in Appendix A-10. The variation of instantaneous and cumulative water infiltration is shown in Figures 4.1 and 4.2. The instantaneous infiltration rate was high at the beginning and decreases with an increase in time and approached almost a constant value at large value of time. The almost constant value of infiltration is known as basic infiltration. In the present study, the basic infiltration rate was attained after 180 minutes and was equal to 0.7 cm hr^{-1}. According to FAO (2001), the recommended basic infiltration rate for clay soil is 0.1- 0.5 cm hr^{-1}. The estimated basic infiltration rate of the present study area was slightly higher than the recommended value. To determine the crop water requirement using the CROPWAT software, the maximum recommended value of the basic infiltration rate for clay soil (0.5 cm hr^{-1}) was used.

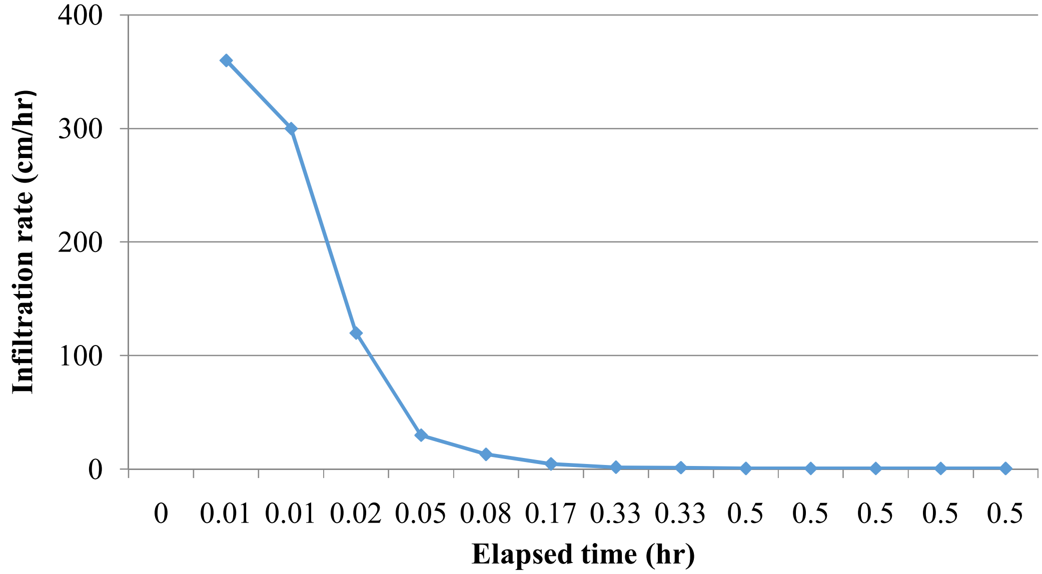


Figure 4.1 Variation of instantaneous infiltration rate with time

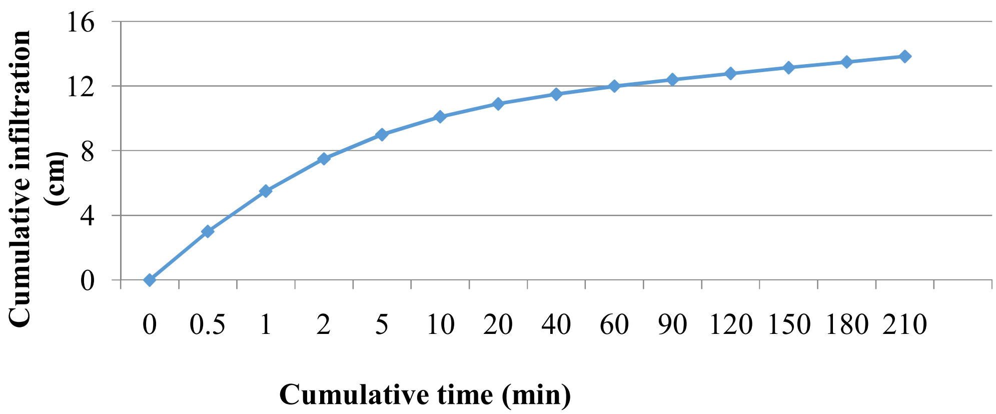


Figure 4.2 Variation of cumulative infiltration depth with time

The cumulative water infiltration increased with time at a decreasing rate. Mathematically the cumulative water infiltration rate of the soils of Robit irrigation scheme can be expressed as

$$Ic = 5.36T^{0.194} \qquad R^2 = 0.844$$

Where:

Ic = Cumulative water infiltration (cm)

T = Time (minute)

4.2. Estimated Crop Water Requirement

I. Reference crop evapotranspiration

The monthly values of ET_O and effective rainfall as estimated from CROPWAT are given in Appendix A-12. The graphical variation of monthly values of ET_O, effective rainfall and average monthly rainfall is shown in Figure 4.3. The estimated effective rainfall for the whole year from January to December as well as for the study period April to June was much smaller than the corresponding values of ET_O values. The maximum and minimum ET_O values were 5.91 and 3.77 mm/day in May and January respectively. The monthly ET_O values for the study period from April to June 2017 were 5.27, 5.91 and 5.90 mm/day during April, May and June respectively. The monthly average ET_O value from January to December was 4.92 mm/day. But the monthly average ET_O value for the study period (from April to June) was 5.693 mm/day. The yearly reference crop evapotranspiration of the study area was 1795.8 mm, while the total ET_O value for the three months (April to June) was 512.4 mm.

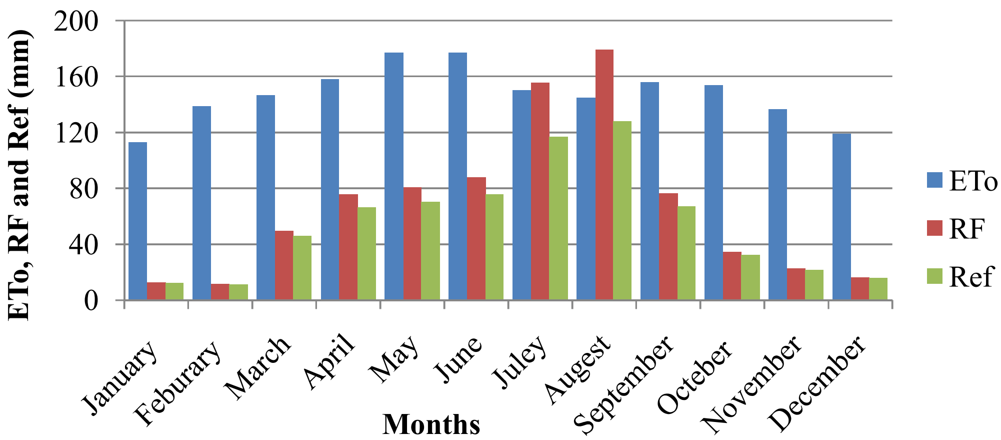


Figure 4.3 Variation of rainfall (RF), effective rainfall (Ref) and reference crop evapotranspiration (ET_O)

II. Total rainfall and effective rainfall

The total yearly rainfall (RF) and yearly effective rainfall (Ref) was 802.8 and 663.7 mm respectively (Appendix A-12). The effective rainfall of the study area from April to June varied from 66.5 to 75.7 mm. The total rainfall and effective rainfall for the study period from April to June was 244.4 mm and 212.5 mm respectively. The maximum value was observed during June while the minimum was in April. The variation of effective rainfall in different months of the study period is presented in Figure 4.4.

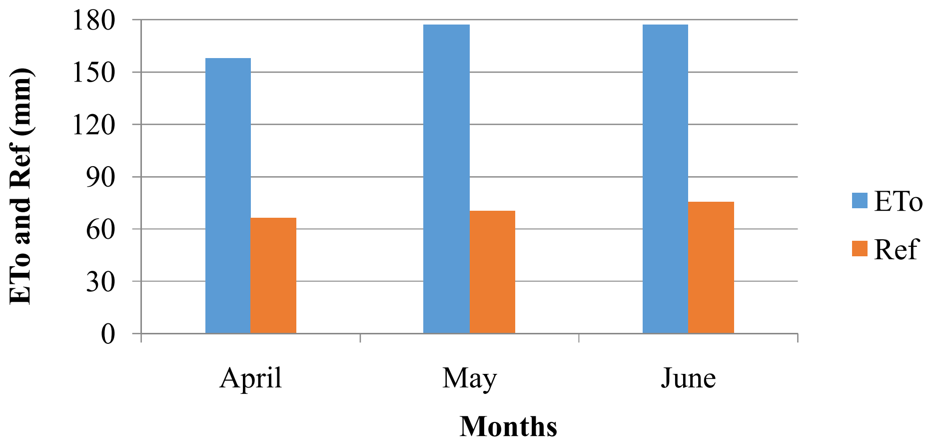


Figure 4.4 Variation of effective rainfall (Ref) and ET_O values (April to June)

III. Crop water requirement

The estimated values of crop water requirement (ETc), effective rainfall (Ref) and irrigation water requirement (IR) for the onion, mung bean and maize crops are given in Appendices A-14, 16 and 18 respectively. Total seasonal crop water requirement (ET_C) was 409.5 mm, 353.7 mm and 594.1 mm for onion, mung bean and maize crop respectively. The variation of seasonal ET_C for the crops grown in the study area is shown in Figure 4.5. Maize crop takes higher growth period as compared to mung bean and onion crops, thus the seasonal crop water requirement was high for maize crop.

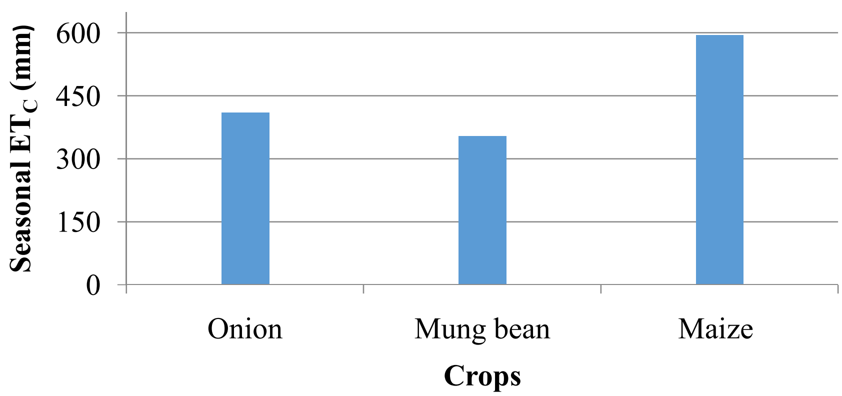


Figure 4.5 Seasonal crop water requirement (ETc) for different Crops

The irrigation users of Robit irrigation scheme followed their own schedule which is arranged by the WUAs. However, some irrigation users were not applying the arranged schedule; they irrigated their field whenever they wanted and this was directed to conflict among the irrigation users. As given in Appendix A-11 the irrigation users apply constant way of irrigation scheduling during the whole growing season for all crops. However, the

CROPWAT estimated irrigation schedule varied from growth stage to growth stage as well as from crop to crop (Appendices A-15, 17 and 19). The schedule arranged by the irrigation users indicates that, at the initial crop growth stage, crops received water at higher irrigation intervals than CROPWAT estimated schedule. Therefore, the crops might be water stressed during the initial crop growth stage. During other crop growth stages, crops were irrigated earlier than the CROPWAT estimated irrigation schedule. Weak management of the WUAs and absence of strong bylaws in the scheme were the reasons for the unfortunate irrigation schedule

The water flow duty (D) of each offtake structure was estimated for each growth stage and for each month during the study period. The estimated values are given in Appendices A-15, 17 and 19 for Onion, Mung bean and Maize crops respectively. The flow duty (D) varied from 0.19 to 1.19 $ls^{-1}ha^{-1}$. The lowest value equal to 0.19 $ls^{-1}ha^{-1}$ was observed during April month for Maize crop, while the highest value equal to 1.19 $ls^{-1}ha^{-1}$ was during May for the same crop. The result indicates that; for a unit hectare of land Maize crop required more water as compared to the Onion and Mung bean crops. At the same time, Maize crop requires more water to irrigate a unit hectare of land, during May and less water during April. This was because; crops required minimum water at initial growth stage and maximum during mid and development stage.

4.3. Determination of Required Flow

The required amount of discharge (Q_R) for the farmer's field was estimated both temporally and spatially using the estimated crop water requirement and duty. The estimated values of the required discharge are given in Table 4.1. The variation of the spatial average values of required discharge during different months is shown in Figure 4.6. The spatial averaged values of required discharge for the nine offtakes were 5.17 ls^{-1}, 10.99 ls^{-1} and 11.89 ls^{-1} during April, May and June respectively. The discharge requirement of each field was low during the first month, because, at the initial stage small depth with frequent irrigation was required. But during June and May months, mostly at mid growth stage, greater discharge with large irrigation interval was required.

The variation of the required flow at different location for the crop duration is shown in Figure 4.7. The required flow of the nine offtakes varied from month to month, from 0.97 to 18.33 ls^{-1}. The minimum value was observed in location L1, while the maximum value was for location L4. Since the area irrigated under location L1 was small, the required discharge was low. However, the area irrigated by location L4 was large; hence the discharge requirement was high. The variation of crop water requirement in the head, middle and tail reaches is shown in Figure 4.8. The reach wise required discharge of the study area was 7.28, 11.04 and 9.73 ls^{-1} for the head, middle and tail reach respectively. The water requirements of the head reach offtakes were low, while the middle reach offtakes required more water. This may be, due to the difference in area coverage under each offtake and the difference in crop water need between different crops. In general, in the study area, the overall mean required discharge value was 9.35 ls^{-1}. This value meets the ET_C values of each crop, and helps in producing better yields of crops.

4.4. Determination of Delivered Flow

The delivered flow (Q_D) for the study area was estimated for the selected nine tertiary offtakes during the study period. The variation of the spatial average values of the delivered flow is shown in Figure 4.6. The estimated delivered flow values were 5.23, 8.53 and 13.66 ls^{-1} for April, May and June. In the nine tertiary offtakes, the delivered flow was low during April, while maximum value was observed during June. Since the crops were at their initial growth stage, the crop water demand was low during the month of April. But during the month of June, each crop was at higher water demand, and thus the delivered discharge was increased to meet the discharge required for each offtake.

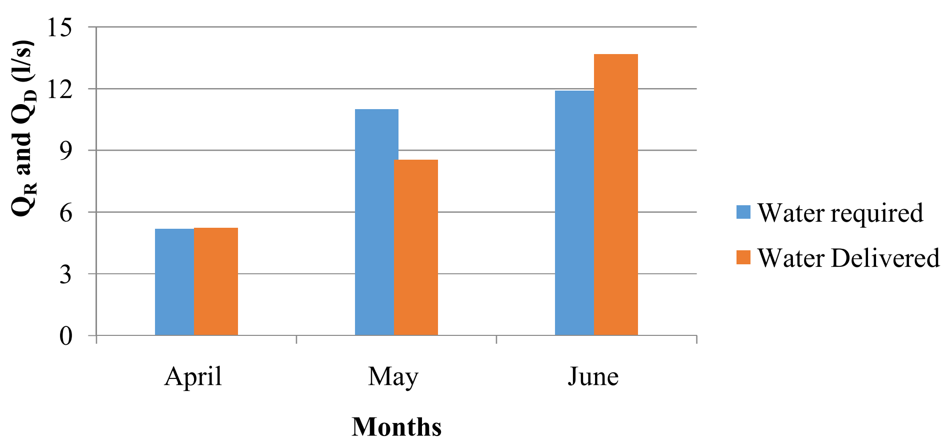


Figure 4.6 spatial average values of required and delivered flow

The delivered flow also varied temporally. The variation of the delivered flow in different locations is shown in Figure 4.7. The delivered discharge was varied from 1.15 to 20.49 ls^{-1}; smaller for location L1 and larger for location L4. The area irrigated by location L1 was small accordingly the delivered flow to the tertiary offtake was also low. The location L4 required higher discharge in all months; due to large area coverage under this offtake. The reach wise variation of time averaged delivered flow values are shown in Figure 4.8. The average value of delivered flow for head, middle and tail reach was 8.35, 11.45 and 7.63 ls^{-1} respectively. As shown in Figure 4.8 the delivered flow was high in the middle reach. This was because, due to larger irrigated area coverage under the middle reach. The irrigated area coverage was 27.5, 45 and 38 ha for head, middle and tail reaches. The overall mean delivered flow for all of the nine offtakes during the study period was 9.14 ls^{-1}. Therefore, the overall mean delivered flow was slightly lower than the overall mean required flow. As presented in Appendix A-22 the design flow rate for each offtake structure was higher than the currently delivered flow. This might be, due to the failure of the intake structure, canal sedimentation problem and lack of regular maintenance works.

Table 4.1 Estimated values of required (Q_R) and delivered flow (Q_D)

Reach location	Months	April		May		June		Temporal mean of	Temporal mean of
		Q_R	Q_D	Q_R	Q_D	Q_R	Q_D	Q_R (ls^{-1})	Q_D (ls^{-1})
Head	L1	0.87	1.21	0.96	0.77	1.07	1.46	0.97	1.15
	L2	4.05	5.01	9.27	8.10	9.18	11.41	7.50	8.17
	L3	3.23	4.49	16.66	13.87	20.23	28.83	13.37	15.73
	Mean	2.72	3.57	8.96	7.58	10.16	13.90	7.28	8.35
Middle	L4	9.90	12.42	22.66	18.77	22.44	30.28	18.33	20.49
	L5	7.23	6.41	8.00	6.42	8.88	10.34	8.04	7.72
	L6	6.07	5.52	6.72	5.80	7.46	7.06	6.75	6.13
	Mean	7.73	8.12	12.46	10.33	12.93	15.89	11.04	11.45
Tail	L7	2.38	1.86	12.25	8.42	14.88	14.01	9.84	8.10
	L8	5.78	4.80	6.40	4.62	7.10	6.62	6.43	5.35
	L9	6.98	5.39	15.97	10.01	15.81	12.96	12.92	9.45
	Mean	5.05	4.02	11.54	7.68	12.60	11.20	9.73	7.63
Spatial mean		5.17	5.23	10.99	8.53	11.89	13.66	9.35	9.14

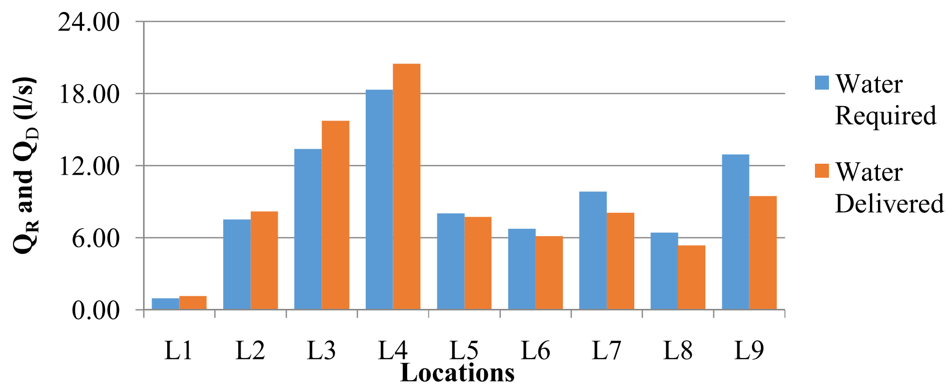


Figure 4.7 Temporal average values of required and delivered flow

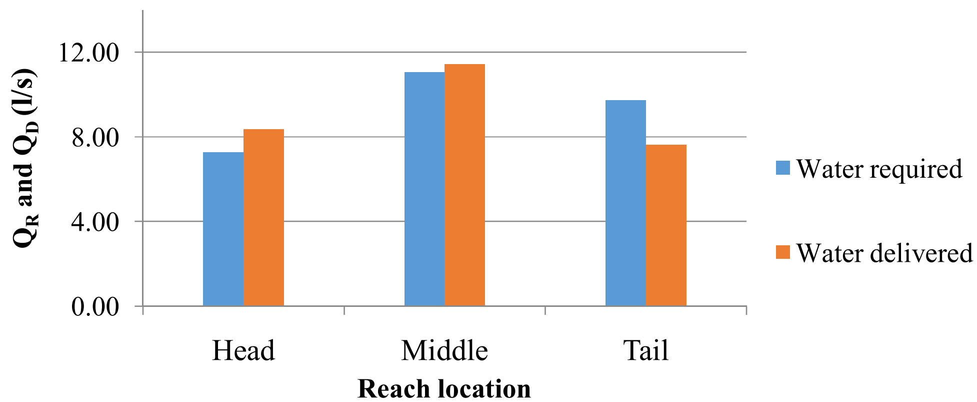


Figure 4.8 Reach wise variation of required (Q_R) and delivered flow (Q_D)

4.5. Water Delivery Performance Indicators

4.5.1. Adequacy (P_A)

Adequacy is given by Equation 3.14 and was determined for each of the nine selected locations at the head, middle and tail end for the study period. The estimated values are given in Table 4.2. The variations of the average temporal adequacy for each of the selected nine locations are shown in Figure 4.9. The temporal adequacy of the study area varied from 0.74 to 0.96 in the nine offtakes. As shown in Figure 4.9 the lower values of temporal adequacy were observed at tail end offtakes while the higher values were at head end offtakes. The adequacy values for the tail end locations were 0.8, 0.83 and 0.74 for L7, L8 and L9 respectively. According to Molden and Gates (1990) standards given in Table 2.1, the adequacy for tail reach offtakes at locations L7 and L8 are grouped under fair performance conditions and tail end offtake location L9 is under poor condition. Adequacy for the remaining six offtakes located at the head and middle reaches were found in a good performance condition. The water delivered to the tail end tertiary offtakes was lower than the required one. Consequently, the adequacy value was low at these offtakes. The reverse was true, for the tertiary offtake locations, L1, L2, L3 and L4.

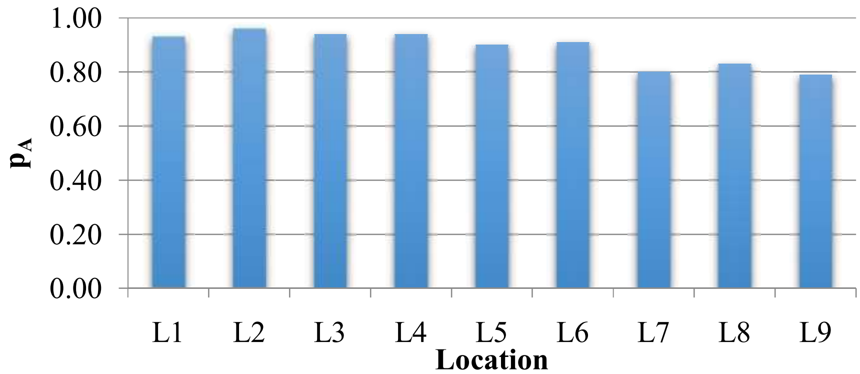


Figure 4.9 Average temporal adequacy of selected offtakes

The average adequacy at the head, middle and tail reaches is presented in Figure 4.10 and was 0.95, 0.92, and 0.79 respectively. Therefore, average level of adequacy was good in the head and middle reaches but poor in the tail reach. The major problems for the poor level of adequacy in the tail reach were inequitable water distribution due to weak management of the WUAs, absence of water regulating structures, malfunctioned water control structures at the head and middle reaches. Hence, the irrigation users located at the head and middle reach abstracted more of the delivered flow and below the crop demand was supplied to the tail reach offtakes.

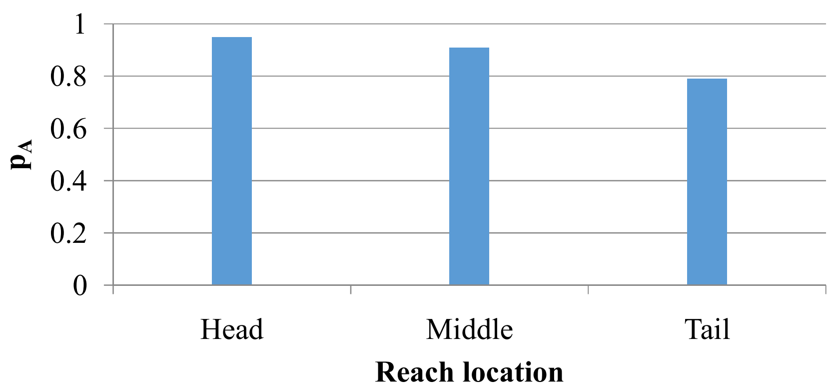


Figure 4.10 Reach wise average temporal adequacy

The estimated spatial average value of adequacy was 0.91, 0.78 and 0.96 in April, May and June months respectively. The variation with adequacy between the three months is presented in Figure 4.11. The amount of water delivered during May was lesser at each offtake as compared to April and June. The reasons for the lower water deliverance during May were increased in crop water requirements demand, and availability of low flow in the river. While during June, discharged water from each offtake was good. Even though there was no rainfall during the first two weeks of June in the study area, the river stage increased due to the incoming runoff from upstream catchments. In addition to this, it was harvest time for Mung bean crop; and therefore, the water demand for this crop was minimal. As a result, Adequacy was in the acceptable range in April and June but poor in May. The overall adequacy level of the scheme was rated as fair with a mean value of 0.88.

Table 4.2 Estimated values of adequacy

Time duration		April	May	June	Temporal mean values
Reach location		$\frac{Q_D}{Q_R}$	$\frac{Q_D}{Q_R}$	$\frac{Q_D}{Q_R}$	$\frac{Q_D}{Q_R}$
Head	L1	1.00	0.8	1.00	0.93
	L2	1.00	0.87	1.00	0.96
	L3	1.00	0.83	1.00	0.94
	Mean	1.00	0.84	1.00	0.95
Middle	L4	1.00	0.83	1.00	0.94
	L5	0.89	0.8	1.00	0.90
	L6	0.91	0.86	0.95	0.91
	Mean	0.93	0.83	0.98	0.92
Tail	L7	0.78	0.69	0.94	0.80
	L8	0.83	0.72	0.93	0.83
	L9	0.77	0.63	0.82	0.74
	Mean	0.8	0.68	0.9	0.79
Spatial mean		0.91	0.78	0.96	0.88

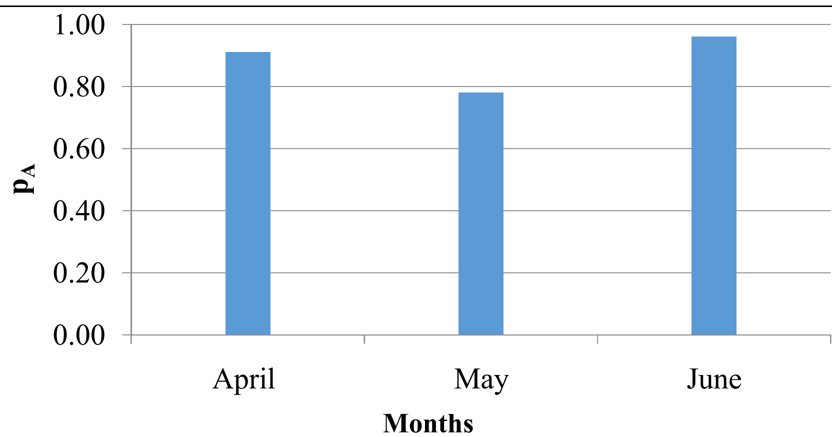


Figure 4.11 Average spatial adequacy over different offtakes

4.5.2. Efficiency (P_F)

Efficiency of the nine offtake structures was evaluated for the study period using Equation 3.15. The estimated values are given in Table 4.3. The temporal efficiency of the nine offtakes varied from 0.81 to 1.0. Efficiency was lower at the head end offtakes especially at locations L1 and L3, with respective values of 0.82 and 0.81, while it was high at all middle and tail end offtake locations. The variation of the temporal average values of efficiency for different locations is shown in Figure 4.12. According to Molden and Gates (1990), locations L1 and L3 were grouped under fair efficiency level, while the remaining offtakes were found under good performance level. The irrigation users located at the head end abstracted more water and used it less efficiently. But farmers located at middle and tail end offtakes received irrigation water below their demand and used the received water efficiently.

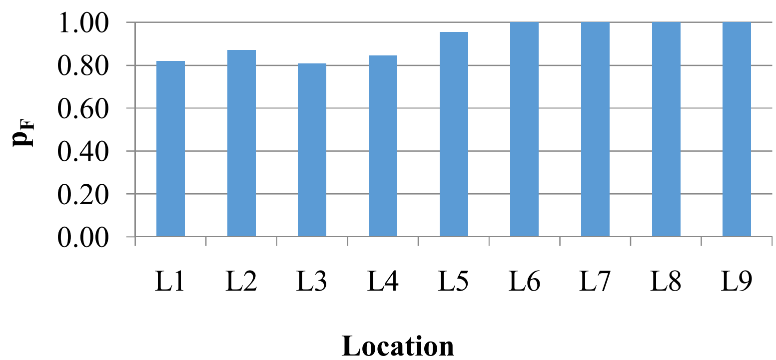


Figure 4.12 Temporal average efficiency at different locations

The variation of the temporal average values at different reach is shown in Figure 4.13. The mean values of efficiency at the head, middle and tail end reaches were 0.83, 0.93 and 1.0 respectively. Therefore, the irrigation water users located at head reach were grouped under fair performance condition, and the users located at middle and tail reaches were grouped under good performance condition.

The spatial variation in efficiency values during the crop season is shown in Figure 4.14. The average efficiency values observed during April, May and June were 0.89, 1 and 0.87 respectively. All crops found in the nine offtakes required more water during May. Consequently, there was high computation in water consumption for their plot of land, and thus used the received irrigation water more efficiently than April and June. But in general, the performance level was good in April, May and June months. The overall efficiency (P_F) of the scheme was 0.92, and was categorized under good performance level.

Table 4.3 Estimated values of efficiency

Time duration		April	May	June	
Reach location		$\frac{Q_R}{Q_D}$	$\frac{Q_R}{Q_D}$	$\frac{Q_R}{Q_D}$	Temporal mean
Head	L1	0.72	1.00	0.73	0.82
	L2	0.81	1.00	0.8	0.87
	L3	0.72	1.00	0.7	0.81
	Mean	0.75	1.00	0.75	0.83
Middle	L4	0.8	1.00	0.74	0.85
	L5	1.00	1.00	0.86	0.95
	L6	1.00	1.00	1.00	1.00
	Mean	0.93	1.00	0.87	0.93
Tail	L7	1.00	1.00	1.00	1.00
	L8	1.00	1.00	1.00	1.00
	L9	1.00	1.00	1.00	1.00
	Mean	1.00	1.00	1.00	1.00
	Spatial mean	0.89	1.00	0.87	0.92

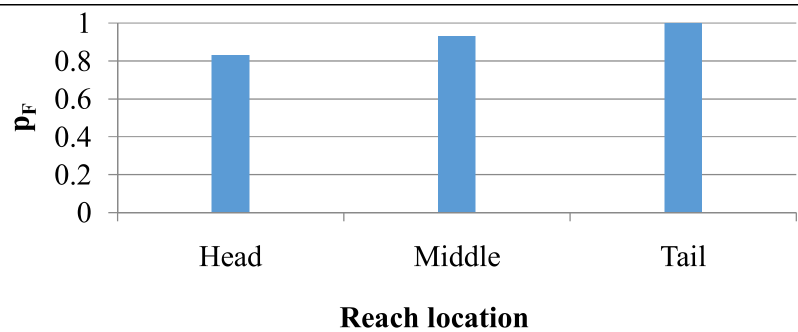


Figure 4.13 Reach wise average efficiency

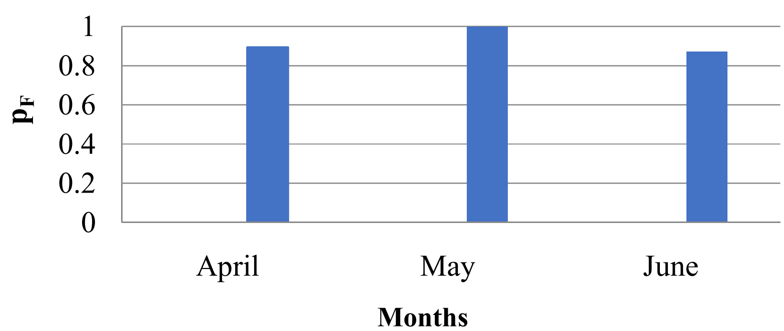


Figure 4.14 Time wise spatial average efficiency

4.5.3. Equity (P_E)

Equity indicator as given by Equation 3.16 was estimated for the nine selected tertiary offtakes during April, May and June months. The estimated values are given in Table 4.4. The spatial coefficient of variation of the selected offtakes during the study period is shown in Figure 4.15. The spatial coefficient of variation of equity during April, May and June was 0.11, 0.11 and 0.06 respectively. The variation in equity was higher during April and May. While during June, each offtake structure distributed irrigation water with small variation. The water stress was less during June. Hence, variation in proportional share of water in the nine offtakes was small during June. According to Molden and Gates (1990), equitable share of water in the nine tertiary offtakes was fair during April and May, but good in June. The overall average spatial coefficient of variation of the study area was 0.09. Thus, the irrigation scheme was found under good performance conditions in sharing irrigation water in the tertiary offtakes during the study period.

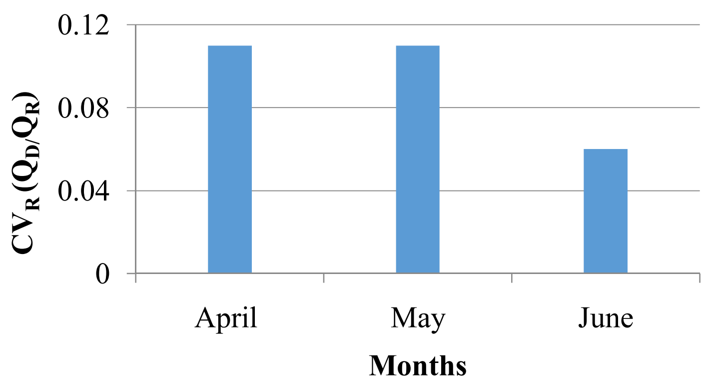


Figure 4.15 Equity (P_E) during three months

4.5.4. Dependability (P_D)

The values of dependability for each tertiary offtake for three months were estimated using Equation 3.17. The estimated values are given in Table 4.4. This delivery indicator answers the reliability of the delivered amount and reliability of timing. The temporal coefficient of variation for different offtakes is shown in Figure 4.16. The values for the coefficient of variation varied widely for different offtakes. It varied from 0.05 to 0.16. The minimum and the maximum values were observed at locations L6 and L7 respectively. The delivered flow highly varied from one month to another month at location L7, while at location L6 temporal variation was low during April, May and June. As per Molden and Gates (1990), locations L2, L3 and L6 were categorized under good performance in reliability of the delivered flow. The remaining tertiary offtakes were found under fair performance condition. The assigned water committee locally called them ''Yewuha Abat'' in the three lactations (L2, L3 and L6) was follow up the timely water distribution in each field effectively. Thus the temporal coefficient of variation in these locations was minimal.

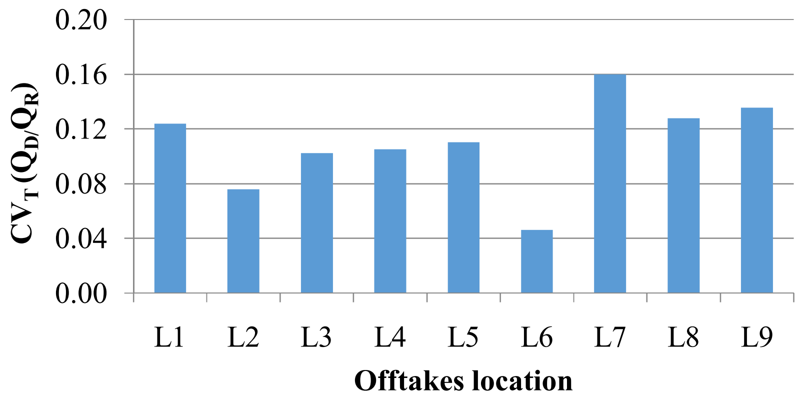


Figure 4.16 Temporal coefficient of variation (CV_T)

The tertiary offtakes coefficient of variation reach wise for the study period is shown in Figure 4.17. The estimated values of coefficient of variation in the head, middle and tail end reach were 0.1, 0.09 and 0.14 respectively (Table 4.4). The head and middle offtakes were found in good performance condition, while the tail reach was under fair condition in the reliability of the irrigation water. The irrigation users located at the head and middle reach was abstracted more water due to weak management in distributing irrigation water as per the arranged schedule. As a result, the tail reach irrigation users were not receiving the delivered flow timely and in the required amount. That's why, dependability was low at the tail reach. The overall temporal coefficient of variation for the nine offtakes was equal to 0.11. This indicates, the irrigation scheme was under a fair performance condition with respect to reliability of water delivery.

Table 4.4 Estimated values of equity and dependability

	Months	April	May	June	Mean	Stdev.	CV_T, P_D
Head	L1	1.00	0.8	1.00	0.93	0.12	0.12
	L2	1.00	0.87	1.00	0.96	0.07	0.08
	L3	1.00	0.83	1.00	0.94	0.10	0.10
	Mean	1.00	0.83	1.00	0.94	0.10	0.1
Middle	L4	1.00	0.83	1.00	0.94	0.10	0.11
	L5	0.89	0.8	1.00	0.90	0.10	0.11
	L6	0.91	0.86	0.95	0.91	0.04	0.05
	Mean	0.93	0.83	0.98	0.92	0.08	0.09
Tail	L7	0.78	0.69	0.94	0.80	0.13	0.16
	L8	0.83	0.72	0.93	0.83	0.11	0.13
	L9	0.77	0.63	0.82	0.79	0.10	0.14
	Mean	0.79	0.68	0.90	0.81	0.11	0.14
	Over all mean	0.91	0.78	0.96	0.89	0.10	0.11
	Stdev.	0.10	0.08	0.06	0.08		
	CV_R, P_E	0.11	0.11	0.06	0.09		

CV_T = Temporal coefficient of variation, CV_R = Spatial coefficient of variation

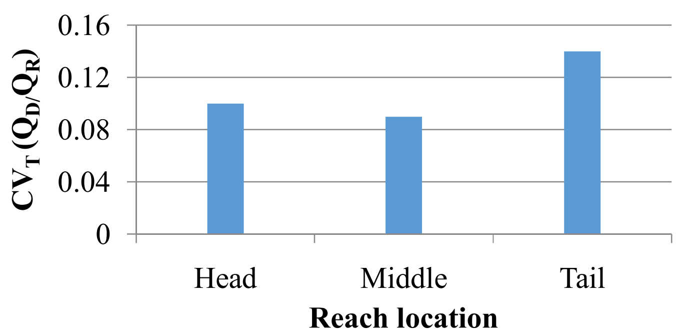


Figure 4.17 Reach wise coefficient of variation

Generally, the water delivery performance of Robit irrigation scheme was fair; in delivering adequate amount of irrigation water and in its dependability with their time of expectation. The irrigation scheme was found under good water delivery performance in the water conservation properties of tertiary offtakes and equitable share of water to the users.

4.6. Water Conveyance Efficiency

4.6.1. Main canal water conveyance efficiency and water conveyance losses

The water conveyance efficiencies and water conveyance losses of Robit irrigation scheme were estimated using Equations 3.18 and 3.19 respectively. The measured values of discharge, the estimated values of water conveyance efficiency and water conveyance losses for the main canal are given in Table 4.5. The variation of the water conveyance efficiency and water conveyance losses along the main canal in all the selected control points is shown in Figure 4.18. The main canal average water conveyance efficiency and water conveyance losses varied from 75.6% to 93.47% and 6.53 to 24.4% respectively. Conveyance efficiency was low at the canal section located between 1500-1700 m (MP9) with an average value of 75.6%. However, the main canal sections located between 500-700 (MP4), 1700-1900 (MP10) and 1900-2100 m (MP11) conveyed irrigation water with better efficiency and lesser water conveyance losses.

The average loss of water per 100 m canal length was high in the canal section between 0-100 m (MP1) but low in MP14 (2500-2750) m. The highest and lowest values were 15.17 and 0.616 liter respectively. The loss in the canal section between 0-100 m (MP1) was high as the section was unlined and more water was lost before reaching to the next control point. While the physical infrastructure of canal section MP14 was under good condition, so that, its efficiency was better.

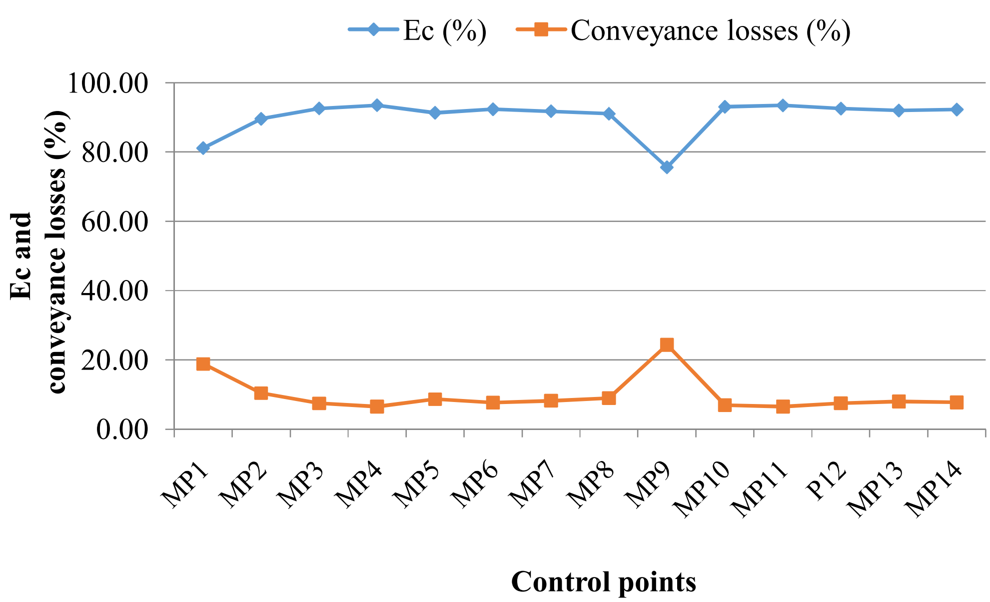


Figure 4.18 Main canal water conveyance efficiency (E_C) and water conveyance losses

The reasons for the poor in conveyance efficiency at MP9 were: leaking of significant amounts of irrigation water through the flume structures and absence of water controlling structures located in this canal section. The installed water control structure was removed and water was controlled in the traditional manner using stones and mud (Figure 4.19).

Figure 4.19 Malfunctioned main canal water distributing structure

The reach wise variation in water conveyance efficiency and water conveyance losses are shown in Figure 4.20. The reach wise conveyance efficiency of the main canal system was 89.61, 88.75 and 92.55 % for the head, middle and tail reach respectively. The tail reach of the main canal system conveyed irrigation water more efficiently with higher water conveyance efficiency as compared to the head and middle reaches. The average water conveyance losses per 100 m were 4.94 ls^{-1}, 2.11 ls^{-1} and 0.795 ls^{-1} for the head, middle and tail reaches respectively. Relatively, the physical infrastructures of the main canal located at the tail were found under good condition; thus irrigation water was conveyed with minimum loss. But at the middle reach of the main canal, water controlling structures were damaged and which is the reason for low conveyance efficiency.

The overall water conveyance efficiency and water conveyance loss per 100 m in the main canal system were 90.3% and 2.62 ls^{-1}. Thus, at an average 9.7% irrigation water was lost from the main canal before reaching the secondary and tertiary offtakes. The reach wise conveyance efficiency as well as the overall conveyance efficiency of Robit main canal system was below the FAO recommended value (95%) as given in Table 2.3.

Table 4.5 Main canal water conveyance efficiency and conveyance losses

The main canal reaches	Location along canal	Canal section distance from head end (m)	Q_I (ls^{-1})	Q_O (ls^{-1})	Water conveyance efficiency (%)	Water loss (%)	Loss/100 m (ls^{-1})
Head	MP1	0-100	80.39	65.22	81.13	18.87	15.17
	MP2	100 - 300	65.22	58.42	89.58	10.42	3.40
	MP3	300 - 500	58.42	54.06	92.54	7.46	2.18
	MP4	500 - 700	54.06	50.54	93.47	6.53	1.76
	MP5	700 - 900	50.54	46.15	91.32	8.68	2.20
	Mean				89.61	10.39	4.94
Middle	MP6	900 - 1100	46.15	42.61	92.33	7.67	1.77
	MP7	1100 - 1300	42.61	39.10	90.30	38.13	1.76
	MP8	1300 - 1500	39.10	35.59	91.02	8.98	1.755
	MP9	1500 - 1700	35.59	26.91	75.06	24.4	4.34
	MP10	1700- 1900	26.91	25.03	93.01	6.99	0.94
	Mean				88.75	11.25	2.11
Tail	MP11	1900 - 2100	25.03	23.39	93.43	6.57	0.82
	MP12	2100 - 2300	23.39	21.64	92.52	7.48	0.875
	MP13	2300 - 2500	21.64	19.9	91.98	8.02	0.87
	MP14	2500 - 2750	19.9	18.36	92.25	7.75	0.616
	Mean				92.55	7.45	0.795
	Overall mean				90.30	12.0	2.62

Note: MP = Main canal control point; 1, 2, 3……14, and Q_I and Q_O measured discharge at first and second control points respectively.

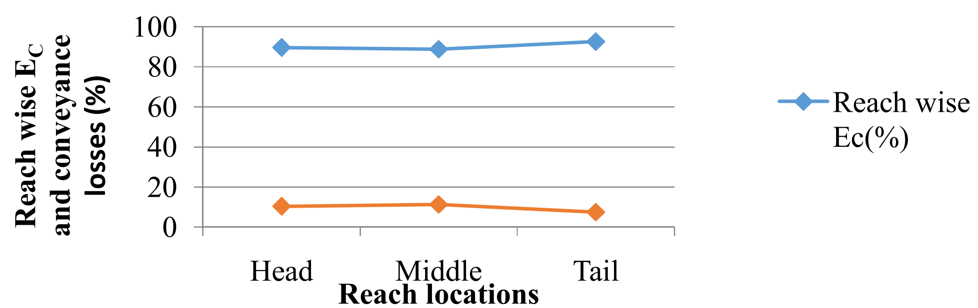


Figure 4.20 Main canal reach wise water conveyance efficiency (Ec) and water conveyance losses

4.6.2. Water conveyance efficiency and water conveyance losses for secondary canals

Water conveyance efficiencies and water conveyance losses for secondary canals were estimated using Equation 3.18 and 3.19 respectively. The estimated values of water conveyance efficiencies, for the first secondary canal (SC1) and second secondary canal (SC2) are given in Table 4.8. The water conveyance efficiency and water conveyance losses of SC1 varied from 78.07% to 87.93% and 12.07 to 21.93% respectively. The canal section located at a distance of 450-600 m (S1P4) conveyed irrigation water at lower water conveyance efficiency. However, the canal sections located at a distance between 750-820 m (S1P6) and 0-150 m (S1P1) conveyed irrigation water with better water conveyance efficiency. The variation in water conveyance efficiency and water conveyance losses for SC1 in the selected control points are shown in Figure 4.21. The water conveyance loss per 100 m was high in S1P2 and low in S1P5 with respective values of 2.05 and 0.91 ls^{-1}.

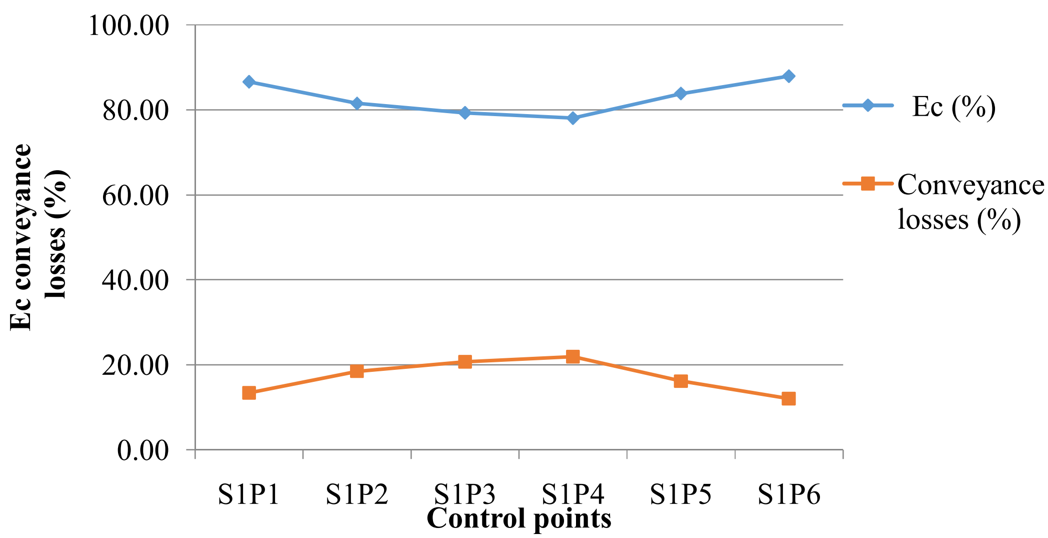


Figure 4.21 Variation of water conveyance efficiency and water conveyance losses for secondary canal SC1

The variation in water conveyance efficiency and water conveyance losses for the second secondary canal SC2 at the selected control points are shown in Figure 4.22. The water conveyance efficiencies and water conveyance losses varied from 80.13 to 88.17% and 11.83 to 19.87% respectively. The lowest value of water conveyance efficiency was observed at S2P5 (800-1000 m), while the canal section located at distance between 0-200 m (S2P1) conveyed irrigation water with better efficiency. The estimated average water conveyance loss per 100 m was high in S2P2 (1.5 ls^{-1}) and low in S2P5 (0.93 ls^{-1}).

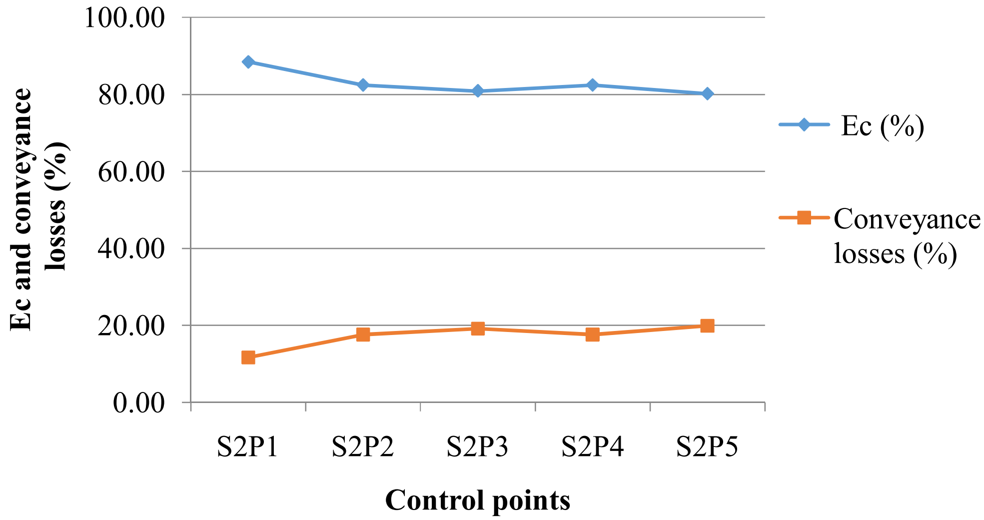


Figure 4.22 Variation of water conveyance efficiency (Ec) and water conveyance losses for secondary canal SC2

Leakage of irrigation water through the water control structures, canal sedimentation and breakage of pipes placed for crossing drainage works were the reasons for higher water losses at SC1 and SC2. In Ethiopia, Wondatir (2015) obtained conveyance loss of 2.4 ls^{-1} per 100 m, Shumye (2017) estimated 2.62 ls^{-1} per 100 m conveyance losses. As compared to these findings, the water conveyance losses per 100 m of Robit secondary canals were lower. However, the estimated losses were significantly higher than the findings reported abroad. Bakry and Awad (1997) reported 0.17 to 0.70% per 100 m canal water losses. Akkuzu et al. (2007) also reported about 1.1% average water loss from lined secondary canals for small-scale irrigation scheme in Turkey. The observed minimum loss per 100 m in the present study was 5.81%. Therefore, additional maintenance activity was required to minimize the water conveyance losses and to improve the effectiveness of the scheme.

The values of the discharge (Q_I and Q_0) measured using current meter in the selected reaches (S1P5 and S2P3) for secondary canals SC1 and SC2 were 8.63 and 6.99 ls^{-1}, and 14.22 and 11.52 ls^{-1} respectively. While the Parshall flume measured discharge were 8.408 and 7.05 ls^{-1}, and 14.05 and 11.361 ls^{-1} (Table 4.6).

The respective overall mean water conveyance efficiency of secondary canal, SC1 and SC2 was 82.88% and 82.91% respectively. On average, both secondary canals were found under similar performance condition in conveying the irrigation water. But efficiency was varied from one location to another location within one canal and between the two canals. The estimated conveyance efficiency values of each reach as well as the average values for both secondary canals were below the FAO (1989b) recommended value (95%) for lined canals.

Table 4.6 Secondary canals water conveyance efficiency and conveyance losses

Canal code	Control points	Distance (m)	Q_I ($l\ s^{-1}$)	Q_O ($l\ s^{-1}$)	Water Ec (%)	Conveyance loss (%)	Loss/100m (ls^{-1})	%Loss/ 100m
SC1	S1P1	0-150	19.24	16.66	86.59	13.41	1.72	8.94
	S1P2	150-300	16.66	13.58	81.51	18.49	2.05	12.32
	S1P3	300-450	13.58	10.77	79.31	20.69	1.87	13.79
	S1P4	450-600	10.77	8.408	78.07	21.93	1.57	14.62
	S1P5	600-750	8.408	7.05	83.85	16.15	0.91	10.77
	S1P6	750-820	7.05	6.199	87.93	12.07	1.22	17.24
	Mean				82.88	17.12	1.56	12.95
SC2	S2P1	0-200	19.30	17.05	88.37	11.63	1.12	5.81
	S2P2	200-400	17.05	14.05	82.40	17.60	1.5	8.8
	S2P3	400-600	14.05	11.36	80.85	19.07	1.34	9.58
	S2P4	600-800	11.36	9.36	82.39	17.61	1.0	8.80
	S2P5	800-1000	9.36	7.50	80.13	19.87	0.93	9.94
	Mean		14.22	11.86	82.83	17.17	1.18	8.59

4.7. Evaluation of Users Satisfaction

The five determinant explanatory variables selected to estimate the satisfaction of users were: i) availability of adequate water (X_1), ii) water availability at time (X_2), iii) farm location from canal head (X_3), iv) farm size (X_4) and v) farmer schooling years (X_5). The Logit model works for three significance levels: 1%, 5% and 10%. The explanatory variables have a very strong effect; strong significant effect and weak significance effect depending on the P-value; less than 0.01, between 0.01 and 0.05, and 0.05 and 0.1 respectively.

4.7.1. Evaluating users satisfaction for head reach users

The estimated values of different parameters of Logit model for the head reach are given in Table 4.7. The availability of adequate water (X_1) had very strong positive association with the satisfaction of head users as the P-value for X_1 was less than 0.01. The model result indicated that, a unit increase in the adequacy of irrigation water increased the satisfaction of irrigation users by 3.723 units. Whereas the effect of the remaining selected explanatory variables (X_2, X_3, X_4 and X_5) on the satisfaction of irrigation users from the service obtained at head reach was not significant.

Table 4.7 Parameter estimates of binary Logit model for head reach

Independent variables	Coefficient (β)	Std. Err.	Z	P-values
X_1	3.723	0.852	4.37	0.000***
X_2	0.981	0.691	1.42	0.156
X_3	-0.920	0.663	-1.39	0.165
X_4	-1.435	2.506	-0.57	0.567
X_5	1.083	0.089	1.22	0.223
Constant	-1.047	0.933	-1.12	0.262

Note: Number of observations = 75, Probability chi square (X^2) = 0.000, and *** = very strong significant effect.

4.7.2. Evaluating users satisfaction for middle reach users

Logit model output for middle reach results are given in Table 4.8. It is observed from the table that satisfaction of users was influenced by the explanatory variables such as water availability in time (X_2) and farm location from the canal head (X_3). However, availability of adequate water (X_1), farm size (X_4) and farmers schooling years (X_5) had no significant effect on the satisfaction of middle reach irrigation users. The Logit regression coefficient (β) values showed that; water availability in time (X_2) and farm location from canal head (X_3) had positive and negative effect on users satisfaction respectively. The water availability in time (X_2) had a very strong significant effect on the satisfaction of users (P-value, $0.001 \leq 0.01$). But farm location from the canal head (X_3) had weak significant effect (P-value, $0.05 \leq 0.06 \leq 0.1$) on the irrigation users' satisfaction. A unit increase in availability of water in time (X_2) increased the satisfaction of users by 1.897 units. On the other hand, a unit increase in farm location from canal head (X_3) decreased users' satisfaction by 1.053 units.

Table 4.8 Parameter estimates of Logit model for middle reach users

Independent variables	Coefficient (β)	Std. Err.	Z	P-values
X_1	0.909	0.563	1.61	0.106
X_2	1.897	0.562	3.38	0.001***
X_3	-1.053	0.559	-1.88	0.060*
X_4	-3.295	2.236	-1.47	0.141
X_5	0.083	0.072	1.15	0.25
Constant	-0.733	0.805	-0.91	0.362

Note: Number of observations = 75, probability chi square (X^2) = 0.004, and *, *** = weak significant effect and very strong significant effect respectively.

4.7.3. Evaluating users satisfaction for tail reach users

The parameter estimates of the Logit model for the tail reach are given in Table 4.9. It indicated that availability of adequate water (X_1), water availability in time (X_2) and farm location from the canal head (X_3) were the factors affecting irrigation users' satisfaction. Availability of Adequate water (X_1) and water availability in time (X_2) had a very strong level of significant effect and farm location from the canal head (X_3) had weak significant effect on the satisfaction of irrigation users. The satisfaction of irrigation users increased by 3.895 and 2.354 units with a unit increase in adequate water availability (X_1) and water availability in time (X_2) respectively. However, satisfaction of irrigation users decreased by 1.366 units with a unit increase in farm location from the canal head (X_3). The satisfaction of irrigation users was not influenced by the remaining two parameters (X_4 and X_5).

Table 4.9 Parameter estimates of Logit model for tail reach users

Independent variables	Coefficient (β)	Std. Err.	Z	P-values
X_1	3.895	0.859	4.53	0.000***
X_2	2.354	0.854	2.76	0.006***
X_3	-1.366	0.825	-1.66	0.098*
X_4	1.009	2.185	0.46	0.644
X_5	0.063	0.0947	0.66	0.507
Constant	-3.682	1.179	-3.12	0.002

Note: Number of observations = 75, probability chi square (X^2) = 0.000, *, *** weak significant effect and very strong significant effect respectively.

4.7.4 Evaluating users satisfaction for the entire irrigation system

The satisfaction of irrigation users from the service received was also evaluated for the entire system. The estimated values of different parameters of Logit model are given in Table 4.10. The Logit model regression coefficients for availability of adequate water (X_1), water availability in time (X_2) and farmer schooling years (X_5) were 2.31, 1.519 and 0.085, respectively. Therefore, a unit increase in the adequacy (X_1), water availability in time (X_2), and schooling years (X_5) increased the users' satisfaction by 2.31, 1.519 and 0.085 units respectively. But the satisfaction of users decreased by 0.972 units with a unit increase in farm location from the canal head (X_3). The availability of adequate water (X_1), water availability in time (X_2) and farm location (X_3) strongly affected the users' satisfaction. However, farmer schooling years (X_5) had weak levels of significance to the satisfaction of irrigation users. Even though the farm size (X_4) was taken as explanatory variable; its effect on the irrigation users was found insignificant for each reach as well as for the entire system.

Table 4.10 Parameter estimates of Logit model for entire system

Independent variables	Coefficient (β)	Std. Err.	Z	P- values
X_1	2.31	0.348	6.64	0.000***
X_2	1.519	0.346	4.39	0.000***
X_3	-0.972	0.345	-2.82	0.005***
X_4	-0.508	1.156	-0.44	0.660
X_5	0.085	0.045	0.189	0.058*
Constant	-1.702	0.477	3.57	0.000

Note: Number of observations = 225, probability chi square (X^2) = 0.000, *, *** weak significant effect and very strong significant effect.

The estimated values of satisfaction at head, middle, tail reaches; and for the entire irrigation system are given in Table 4.11 and graphical variation is shown in Figure 4.23. The satisfaction level of irrigation users was 57.33%, 48%, 42.67% and 49.33% for the head, middle, tail reach and entire irrigation system respectively. The irrigation users situated at the head reach had higher satisfaction (57.33%) from the irrigation service obtained and the tail reach users were less satisfied (42.67%) with the service obtained. This was because the irrigation users located at head reach received more water and timely than the other reaches. As a result, the satisfaction level was higher in the head reach irrigation users. The level of satisfaction for the entire irrigation system was 49.33%. Thus, 50.67% users were dissatisfied with the irrigation services. The selected explanatory variables adequacy and dependability for the head, middle and tail reaches were substantiate the findings evaluated quantitatively. In both cases, Adequacy and dependability were decreased from head to tail reaches. While the explanatory variables farm location from canal head, farm size and farmers schooling years are not interlinked in the study as they are not estimated quantitatively.

Table 4.11 Logit model estimated satisfaction level of irrigation users

Reach location	satisfaction level of irrigation users	
	Satisfied (%)	Dissatisfied (%)
Head	57.33	42.67
Middle	48	52
Tail	42.67	57.33
Entire system	49.33	50.67

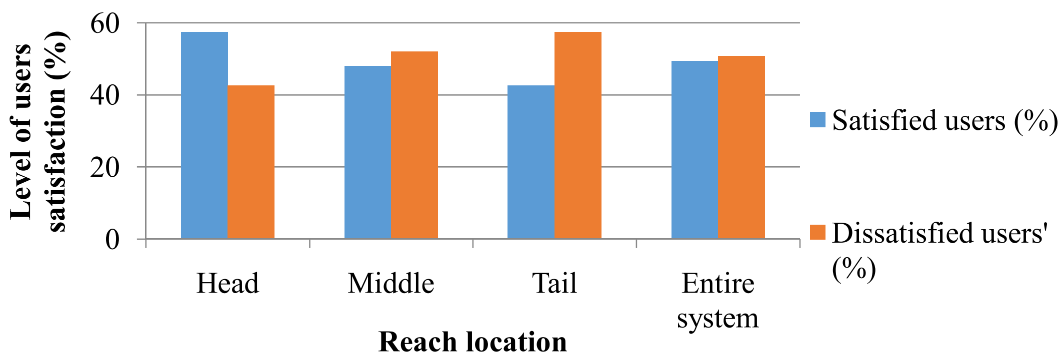


Figure 4.23 Level of users' satisfaction for Robit irrigation scheme

4.8. Factors Affecting Water Delivery Performance

The water delivery performance of Robit irrigation scheme was not according to the intended objective. During the study period, so many problems were observed. Non-existence of the designed intake structure, inadequate supply of water from the source, over-abstraction of water by the head reach users, poor management of the scheme, mal-functionality of water controlling structures, canal sedimentation and accumulation of plant leaves in the canal, leakage and seepage of water, lack of continuous maintenance activities, poor control and distribution of water, stolen tertiary offtake gates, and absence of supportive training concerning water management and irrigation scheduling were the main factors affecting water distribution and delivery in the irrigation scheme. All these problems were observed simultaneously during the data collection period. To divert the irrigation water, an intake with small diversion head work structure was constructed. But it was not given its planned service (Figure 4.23); it was covered with boulders and sand. Hence, water was diverted by traditional manner using locally available materials (Figure 4.23); adequate discharge was not diverted with this obstruction, moreover huge amount of sediment and sand particles entered into the main canal. As a result, the supply of water was not adequate to fulfill the demand of all irrigation users and the farmers near the source of water abstracted more water than the downstream users. This indicates that; the irrigation schedule and distribution of irrigation water was poorly managed. The management in the operation and maintenance of the irrigation scheme was also very weak. Except cleaning of some weeds and sediments in the canal system; regular maintenance, including the maintenance of the damaged controlling structures and protecting leakage and seepage were not carried out. Some of the water distribution and controlling gates were out of function and some of them were stolen (Figure 4.19). These all problems lead to the performance of the scheme to be below its design.

Figure 4.24 Traditional diversion structure and current condition of the designed intake structure

In order to solve the problems, discussion was held with the water committees and the irrigation users regarding the above issues: the irrigation users agreed to pay 5 birr per irrigation fee to facilitate the operation and maintenance activities; replace the damaged control structures and other maintenance activities. This fee was collected and will be collected in the future by the water committee of each group. To avoid the water abstraction out of the scheduled time, all irrigation users agreed and established bylaws that regulates all users. According to their agreement; if somebody abstracts water out of his or her schedule, he or she was to be punished 100 Birr for the first time, 300 Birr for the second time and 500 Birr if more three times. This agreement was announced in the Kebele and get acceptability. In addition to this, all irrigation users agreed to clean the canal regularly according to the arranged schedule. The researcher was visited the irrigation scheme after three months of the data collection. During this time (October 02, 2017), very significant improvement was observed in canal sediment cleaning as per the arranged schedule (Figure 4.25).

Figure 4.25 Remarkable improvement in canal sediment cleaning (October 2, 2017)

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The performance of Robit small-scale irrigation scheme was evaluated at; head, middle and tail reaches of the command area during the crop season between April and June 2017. The conclusions which may be drawn from the data analysis are:

i) The overall average irrigation water demand for the selected crops Onion, Mung bean, and Maize grown in the canal command area as compared to water delivered by the canal was more during May but less during June and April. But water delivered by the canal was more than a crop water requirement at head and middle reach and less at tail reach. The discrepancies in canal water supply were due to weak management of WUAs in irrigation scheduling, cleaning canals sedimentation, water losses in canals and damaged water control structures.

ii) The water delivery performance of the irrigation scheme was evaluated using adequacy, efficiency, equity and dependability water delivery indicators. The water delivery performance of the irrigation scheme as per Molden and Gates (1990) standard was found fair in adequacy and dependability, but good in efficiency and equity. Even though the overall water distribution in the irrigation scheme was good, the tail end users were affected due to inequitable distribution of irrigation water.

iii) The overall water conveyance efficiencies of the main canal, first and second secondary canals were found to be 90.3%, 81.23% and 80.89% respectively. The main canal conveyed irrigation water with higher water conveyance efficiency than the secondary canals. Thus the estimated water conveyance losses were higher in the secondary canals as compared to the main canal system. The conveyance efficiency of the main and secondary canals was lower than the recommended value by FAO.

iv) The main determinant factors affecting satisfaction of irrigation users were; availability of adequate water, water availability in time, and farm location from the canal head. Irrigation users located at head reach were most satisfied, while the tail end users were least satisfied from the irrigation service obtained.

v) The water delivery performance and water conveyance efficiency of Robit irrigation scheme was below the intended objectives; this was due to the failure of the small diversion weir and intake structure, canal sedimentation, broke and stolen water control structures, weak management of WUAs and water committees, illegal abstraction of irrigation water out of the planned schedule, absence of established bylaws in the irrigation scheme, and lack of regular maintenance activities.

vi) Agreements were reached as per discussion and persuasion with the irrigation users; so that problems could be solved with their contribution.

5.2. Recommendations

The following recommendations may be drawn based on the finding of the performance evaluation of Robit small-scale irrigation scheme:

i) Supply of irrigation water should be increased by rehabilitating the irrigation scheme. Damaged physical infrastructures of the irrigation scheme should be repaired and maintained. The sediments, plant leaves and other unnecessary materials deposited in and around the canal system should be cleaned regularly.

ii) The farmers in the command area of the irrigation scheme should follow a scientific irrigation schedule determined from the CROPWAT Model for each crop. The rrigation experts should support the farmers in doing this. The miss-match between canal water supply and crop water demand may be minimized by adopting appropriate cropping pattern and adjusting crop planting schedule. The balancing reservoirs may be constructed in the canal command area to store excess canal water and use it during deficit canal water supply.

iii) Formal trainings are necessary to enhance the knowledge of farmers regarding advanced water management techniques, irrigation scheduling, and negative impact of excess water application to the crops. If irrigation users get awareness regarding these issues, their satisfaction may be increased.

iv) The assigned water committee and WUA should work sincerely and discharge the responsibilities given by the irrigation users. Every irrigation user should apply the irrigation water according to the scientific schedule set by the concerned body. The distribution of irrigation water should be fair at the requested time and in the required amount to all irrigation users. The irrigators shall adopt flexible method of irrigation scheduling so that tail end irrigators will get adequate water.

v) Appropriate fee collection mechanism should be established and the collected money should be utilized for relevant works in the irrigation scheme.

vi) Due attention should be given for installing irrigation flow control and water flow measuring structures at critical points for the success of fair water distribution and appropriate fee collection.

REFERENCES

Akkuzu, E., Ünal, H. B., & Karataş, B. S. (2007). Determination of water conveyance loss in the menemen open canal irrigation network. Turkish Journal of Agriculture and Forestry, 31(1), 11-22.

Aklilu, A. (2006). Assessment of irrigation system at Sille state farm, Ethiopia. Masters' thesis. Arba Minch University, Ethiopia.

Alemayehu, M. (2016). Conveyance and water use efficiency in thirty years old irrigation scheme: establishing baseline information to revitalize the Meki-Ziway irrigation scheme. Masters' thesis. Arba Minch University, Ethiopia.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements: FAO Irrigation and drainage paper 56. FAO, Rome, 300(9), D05109.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). FAO Irrigation and drainage paper No.56. Rome: Food and Agriculture Organization of the United Nations, 56(97), e156.

Awulachew, S. B., & Ayana, M. (2011). Performance of irrigation: An assessment at different scales in Ethiopia. Experimental Agriculture, 47(S1), 57-69.

Awulachew, S. B., Erkossa, T., & Namara, R. E. (2010). Irrigation Potential in Ethiopia: Constraints and Opportunities for Enhancing the System. Addis Ababa, Ethiopia, International Water Management Institute, P.30

Awulachew, S. B., Merrey, D. J., Kamara, A. B., Koppen, B. V., Vries, F. P. d. &Boelee, E. (2005). Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia. Working paper 98(IWMI): Colombo, Sri Lanka.

Aydogdu, M., & Yenigun, K. (2015). Factors Affecting Farmers' Satisfaction from Water Users Association in the Harran Plain-GAP Region, Turkey. Journal of Agricultural Science and Technology, 17, 1669-1684.

Bakry, M. F., & Awad, A. A. E. M. (1997). Practical estimation of seepage losses along earthen canals in Egypt. Water resources management, 11(3), 197-206.

Barry, J., et al. (2011). Binary logistic regression Models and statistical Software. Cornell University stastical consulting unit, Newark, USA, p 1-3.

Bhatta, N. D., Matsuoka, A., Sapkota, I. P., & Shrestha, K. (2010). Users' Satisfaction in Farmer Managed Irrigation System in Nepal: A Case Study of Chitwan District. Journal of Rainwater Catchment Systems, 15(2), 11-15.

Bos, M. G. (1997). Performance indicators for irrigation and drainage. Irrigation and Drainage Systems, 11(2), 119-137.

Bos, M. G., Burton, M. A., & Molden, D. J. (2005). Irrigation and drainage performance assessment: practical guidelines. Cabi Publishing.Clemmens, A. J. (2006).

Bos, M.G., Murray-Rust, D.H., Merry, D.J., Johnson, H.G and Snellen, W.B. (1994). Methodologies for assessing performance of irrigation and drainage management. Irrigation and Drainage Systems 7: 231-261.

Bouml, H. K. F. E., & Demir, A. O. (2009). Performance assessment for irrigation water management: A case study in the Karacabey irrigation scheme in Turkey. African Journal of Agricultural Research, 4(2), 124-132.

Chancellor, F. M.,& Hide, J. M. (1997). Smallholder Irrigation: ways forward. Guidelines for achieving appropriate scheme design, 2.

Clemmens, A. J. (2006). Improving irrigated agriculture performance through an understanding of the water delivery process. Irrigation and drainage, 55(3), 223-234.

Corty, E. (2007). Comparative indicators in the South Easter Anatolia Project, Using and interpreting statistics. Mosby, Inc. St. Louis, Missouri, USA.

Değirmencİ, H., Büyükcangaz, H., & Kuşcu, H. (2003). Assessment of irrigation schemes with comparative indicators in the Southeastern Anatolia Project. Turkish Journal of Agriculture and Forestry, 27(5), 293-303.

Dejen, Z. A. (2015). Hydraulic and operational performance of irrigation schemes in view of water saving and sustaina bility: sugar estates and community managed schemes In Ethiopia. CRC Press/Balkema.

Dejen, Z. A., et al. (2015). Water Delivery Performance at Metahara Large-Scale Irrigation Scheme, Ethiopia. Irrigation and drainage 64(4): 479-490.

Dejen, Z. A., Haileslassie, A., Sally, H., Erkossa, T., Schmitter, P., Langan, S., & Hoekstra, D. (2016). Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia: Diversity and lessons across schemes, typologies and reaches.

Dejen, Z. A., Schultz, B., & Hayde, L. (2012). Comparative irrigation performance assessment in community-managed schemes in Ethiopia. African Journal of Agricultural Research, 7(35), 4956-4970.

Dolgun, A., & Saracbasi, O. (2014). Assessing proportionality assumption in the adjacent category logistic regression model. Statistics and its Interface, 7(2), 275-295.

FAO (1978). Effective rainfall in Irrigated Agriculture: FAO Irrigation and drainage paper No. 24. Rome, Italy: Food and Agricultural organization of the United Nations.

FAO (1982). Small hydraulic structures: FAO Irrigation and Drainage paper No.26. Rome: Food and Agricultural Organizations of the United Nations.

FAO (1986). Irrigation water needs: Irrigation water management training manual no.3. Via delle Terme di Caracalla, 00100 Rome, Italy, international institute for land reclamation and improvement

FAO (1989b). Guidelines for Designing and Evaluating Surface Irrigation System: FAO Irrigation and Drainage paper. No.45. Rome, Italy: Food and Agricultural Organizations of the United Nations.

FAO (1992). Canals, Irrigation Water Management planning and management: FAO Training Manual No. 7. Rome: Food and Agricultural Organizations of the United Nations.

FAO (1993). Structures for water control and distributions: Irrigation water management training manual No. 8. Rome: Food and Agricultural Organizations of the United Nations

FAO (2001). Irrigation Water Management: Irrigation Methods. FAO Training manual no 5. Rome: Food and Agricultural Organization of the United Nations, P. 68.

FAO (2002). Deficit irrigation practices of the United Nations: FAO Water reports No.22. Rome: Food and Agricultural Organizations of the United Nations.

Gomo, T., Mudhara, M., & Senzanje, A. (2014). Farmer's satisfaction with the performance of the Mooi River Irrigation Scheme, KwaZulu-Natal, South Africa. Water SA, 40(3), 437-444.

Gujarati, D. N., & Porter, D. C. (2003). Evaluation of users' satisfaction from the service received. Journal of basic econometrics, 4, 78-79.

Hailu, H., & Shiberu, E. (2011). Performance Evaluation of Small-scale Irrigation Schemes in Adami Tullu Jido Kombolcha Woreda, Central Rift Valley of Ethiopia (Doctoral dissertation, Haramaya University).

Hill, R.C., Griffiths, W.E., and Lim, G.C. (2008). Principles of Econometrics (3rd ed). John Willey & Sons, New Jersey, USA.

International Soil Reference and Information Center (2000). Procedures for soil analysis sixth edition: Technical paper 9. ISRIC: Food and Agriculture Organizations of the United Nations.

ISRIC (2000). National soil research center for Ethiopian agricultural research organization. Food and Agricultural Organizations: P(9).

Keramatzadeh, A., Chizari, A. H., & Moore, R. (2011). Economic optimal allocation of agriculture water: mathematical programming approach. Journal of Agricultural Science and Technology, 13, 477-490.

Kuscu, H., Boluktepe, F.E., Demir, A.O. (2009). Performance assessment for irrigation water management: A case study in Karacabey Irrigation Scheme in Turkey. African Journal of Agricultural Research, 4(2), p 124 -132.

Magingxa, L. L., Alemu, Z. G., & van Schalkwyk, H. D. (2006). Factors influencing the success potential in smallholder irrigation projects of South Africa: A principal component regression. In 2006 Annual Meeting, August 12-18, 2006, Queensland, Australia (No. 25348). International Association of Agricultural Economists.

Malano, H. M., & Burton, M. (2001). Guidelines for benchmarking performance in the irrigation and drainage sector (No. 5). Food & Agriculture Org., P 20

Ministry of Water Resources (2002). Water sector development programme (2002-2016), irrigation development program. Main report, MoWR, Addis Ababa, Ethiopia: P142

Molden, D. J., & Gates, T. K. (1990). Performance measures for evaluation of irrigation-water-delivery systems. Journal of irrigation and drainage engineering, 116(6), 804-823.

Molden, D. J., Sakthivadivel, R., Perry, C. J., & De Fraiture, C. (1998). Indicators for comparing performance of irrigated agricultural systems (Vol. 20). IWMI.

Mundial, B. (1999). World Bank atlas from the world development indicators, 1999. In World Bank atlas from the world development indicators, 1999. World Bank.

Murray-Rust, D. H., & Svendsen, M. (2001). Performance of locally managed irrigation in Turkey: Gediz case study. Irrigation and Drainage Systems, 15(4), 373-388.

Murray-Rust, H. and Snellen, W. B. (1993). Irrigation system performance assessment and diagnosis. IWMI.

Plusquellec, H. (2002). How design, management and Policy affect the performance of irrigation projects, emerging modernization procedures and design standards. FAO publications, Bangkok, Thailand.

Reyna, O. T. (2014). Getting started in Logit and ordered logit regression. Princetion University accessed on 10/24/2014, from http://dss.princeton.edu.

Shumye, A.(2017). Evaluation of water delivery performance and irrigation efficiency: Acase study of Lemchek–Sewur small-scale irrigation scheme, Amhara, Ethiopia. Masters' thesis. Arba Mich Univesity, Ethiopia.

Small, L. E. & Svendsen, M. (1990). A framework for assessing irrigation performance. Irrigation and drainage systems, 4(4), 283-312.

Tariku, E.(2017). Comparative Performances Analysis of Two Small-Scale Irrigation Schemes: Case of Tahtay Tsalit and Mychew, Tigray, Ethiopia Masters' thesis. Arba Mich University, Ethiopia

Tebeba, M., & Ayana, M. (2015). Hydraulic Performance Evaluation of Hare Community Managed Irrigation Scheme, Southern, Ethiopia.

Tebebal, M.(2015). Evaluation of Hydraulic Performance of Community Managed Irrigation Scheme and Level of User's Satisfaction : A Case Study on Hare Irrigation Scheme, SNNPR, Ethiopia. Masters' thesis. Arba Minch University, Ethiopia

Torres-Reyna, O. (2012). Getting started in Logit and ordered logit regression. Princeton University, http://dss. princeton. edu/training/Logit. pdf.

Unal, H. B., Asik, S., Avci, M., Yasar, S., & Akkuzu, E. (2004). Performance of water delivery system at tertiary canal level: a case study of the Menemen Left Bank Irrigation System, Gediz Basin, Turkey. Agricultural water management, 65(3), 155-171.

Vasisht, A.K. (2012). Logit and Probit analysis.I.A.S.R.I. Library, Avenue 110012, New Walters, R. and Berisavijevic, N. (1991). Evaluation of irrigation efficiencies (ICID), International Printers: New Delhi.Willey & Sons, New Jersey, USA

Wambua, J. M., Makobe, M. N., Njue, E. M., & Nyende, B. A. (2011). Hydroponic screening of Sorghum (Sorghum bicolor L. Moench) cultivars for salinity tolerance. Journal of Agriculture Science and Technology, 12(2).

Wondatir, S. (2016). Performance evaluation of irrigation schemes: A case study of Jari and Aloma small irrigation schemes, Tehuledere District. Masters' thesis. Arba Minch University, Ethiopia.

Woodroofe, R. (1993). Monitoring and evaluation of irrigation projects.Technical manual, manual, Ministry of Water, Irrigation and Energy, Addis Ababa, Ethiopia.

Zagiham, H. (1998). Performance Assessment of the Water Regulation and Distribution System in the Chishtain Sub-basin in the Main and Secondary Canal Levels. Pakistan National Program, Report No.59

APPENDICES

Appendix A: Climatic Data and Performance Indicators

Appendix A- 1 25 years (1990- 2015) average daily minimum temperature (^{O}C)

Year	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1990	13.31	13.04	13.56	16.92	16.85	16.49	9.64	10.45	9.29	11.64	9.55	15.38
1991	10.56	14.05	15.31	13.8	15.52	13.84	6.56	6.79	11.7	12.1	13.3	11.95
1992	11.44	11.51	12.09	13.56	17.11	11.15	11.88	2.16	14.26	9.37	13.98	6.95
1993	7.74	16.59	15.66	16.68	17.75	9.93	16.54	14.68	10.69	11.27	13.2	10.09
1994	9.04	11.1	12.84	14.65	15.12	17.84	16.47	17.22	15.34	12.89	9.84	8.49
1995	9.28	11.81	13.2	13.84	15.11	17.46	17.66	13.33	15.53	13.18	10.14	9.4
1996	12.12	10.31	13.09	14.22	14.16	17.08	17.21	14.9	15.59	12.28	9.51	9.26
1997	12.48	10.11	13.07	14.31	14.92	16.83	15.32	17.5	16.09	13.86	12.62	10.38
1998	12.46	13.86	14.55	15.39	16.06	15.17	17.71	9	16.47	14.4	9.59	8.44
1999	9.91	10.63	13.03	12.81	16.04	13.84	8.48	9.46	16.68	14.08	9.96	8.13
2000	8.72	10.29	12.56	15.48	16.6	14.17	18.65	8.42	16.71	13.94	10.93	10.12
2001	10.65	11.16	14.68	14.86	16.78	16.17	11.45	18.34	15.56	14.48	10.05	9.32
2002	11.82	11.68	14.31	14.35	16.45	18.24	18.51	7.72	15.5	13.54	10.22	11.79
2003	11.06	12.24	13.16	17.25	15.97	12.78	7.58	13.68	16.01	12.99	10.53	9.49
2004	11.74	11.49	12.42	15.65	16.4	12.73	18.5	18.06	15.66	12.44	10.83	10.65
2005	11.71	11.17	13.67	18.7	16.24	15.1	13.32	9.9	16.82	12.61	9.8	8.66
2006	9.7	11.79	13.44	14.88	15.93	9.62	12.41	17.97	16.74	14.21	11.12	11.67
2007	10.73	13.56	13.39	17.59	16.23	17.96	9.15	12.46	16.88	12.4	10.06	8.09
2008	10.69	10.21	11.97	13.86	15.4	14.06	18.41	17.93	16.46	14.16	10.64	8.79
2009	10.71	11.4	12.83	15.21	16.43	15.95	8.54	9.99	17.12	13.59	9.9	11.97
2010	10.87	14.21	13.4	15.48	16.72	12.04	18.53	17.89	16.34	14.49	10.57	9.41
2011	8.45	9.36	9.84	17.7	18.65	13.24	14.89	14.63	11.51	9.24	8.68	5.98

2012	7.2	8.19	11.08	14.81	15.65	13.1	15.23	14.15	11.81	9.08	8.05	6.87
2013	7.41	9.15	11.07	11.61	11.46	12.97	15.22	13.84	11.72	10.55	7.67	6.79
2014	8.17	11.3	10.27	18.91	16.76	12.17	14.19	17.19	15.76	13.28	9.4	8.02
2015	14.31	13.37	12.69	12.02	15.45	14.66	11.63	9.68	10.73	12.96	15.2	14.39
Average	10.47	11.68	12.97	15.17	15.99	14.41	13.99	12.97	14.73	12.65	10.59	9.63

Appendix A-2 25 years (1990- 2015) average daily maximum temperature (^{O}C)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1990	24.54	26.96	27.2	27.45	30.25	29.1	23.7	22.9	27.41	27.54	24.88	24.76
1991	25.06	24.82	25.03	24.82	30.71	26.43	27.37	28.68	26.22	26.89	26.07	26.86
1992	23.87	25.8	28.74	30.78	31.82	30.06	23.81	23.91	23.67	23.23	23.21	24.45
1993	24.98	24.14	27.02	28.97	29.73	29.38	24.63	25.48	29.39	29.58	26.89	25.1
1994	24.83	26.65	27.99	29.84	30.22	31.49	26.53	28.1	29.7	27.08	25.06	25.01
1995	24.26	26.28	27.86	28.91	30.04	31.75	29.43	30.82	29.95	27.3	25.75	24.46
1996	24.02	26.91	27.79	29	29.51	28.84	28.73	29.25	29.68	27.39	24.57	25.77
1997	23.73	25.59	27.93	27.47	29.79	30.87	30.85	30.6	31.05	26.62	25.26	25.06
1998	24.56	26.78	27.89	30.24	30.67	32.45	29.24	28.77	29.61	27.38	25.9	24.69
1999	25.12	28.01	27.89	29.9	31.28	32.17	31.16	30.8	30.51	27.09	25.56	24.08
2000	25.2	27.05	28.79	29.78	30.93	32.92	31.92	32.04	30.89	28.11	26.27	25.24
2001	24.55	27.39	27.77	30.24	31.77	32.36	31.48	30.81	30.26	28.7	25.95	24.98
2002	24.81	27.1	28.61	29.75	32.06	32.94	33.24	31.55	30.59	28.13	26.5	25.09
2003	25.38	27.87	29.07	29.54	31.43	32.07	31.59	30.47	30.87	28.06	26.07	25.76
2004	26.2	25.73	28.33	29.07	31.84	31.85	31.98	31.42	30.32	27.08	26	26.77
2005	24.5	27.95	29.32	29.02	29.99	32.19	31.27	31.47	30.83	27.8	26.12	24.6
2006	25.67	27.49	28.44	28.51	31.09	32.43	31.27	30.5	30.55	27.92	25.99	25.14
2007	24.82	27.75	29.07	29.53	31.64	31.71	30.41	31.15	31.29	27.73	25.35	24.46
2008	25.94	26.06	29.26	28.43	30.8	31.56	31.37	30.69	30.62	27.67	24.79	24.29

2009	24.65	26.93	28.77	29.32	30.92	32.67	30.54	31.43	31.2	27.27	26.34	24.59
2010	24.72	26.34	26.63	28.72	29.79	32.68	30.73	29.43	29.95	28.3	25.49	24.18
2011	22.07	24.61	23.79	26.91	26.2	29	28.23	25.19	26.83	24.73	22.83	23.89
2012	22.98	24.68	25.87	24.83	27.64	29.25	27.61	26.52	27.48	24.97	24.13	22.89
2013	22.98	24.46	25.22	25.71	26.21	28.58	26.09	24.05	27.31	24.31	22.8	21.72
2014	22.18	22.35	24.17	24.46	26.26	29.04	28.69	29.45	30.14	27.42	25.49	24.41
2015	24.36	26.25	25.63	29.12	26.38	31.61	29.81	29.59	30.01	28.25	25.24	24.6
Average	24.46	26.23	27.46	28.47	29.96	30.98	29.30	29.04	29.47	27.18	25.33	24.73

Appendix A-3 25 years (1990- 2015) average daily relative humidity

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1990	0.49	0.46	0.43	0.42	0.40	0.48	0.53	0.51	0.48	0.48	0.41	0.40
1991	0.47	0.42	0.37	0.43	0.39	0.46	0.58	0.54	0.49	0.44	0.40	0.37
1992	0.45	0.44	0.43	0.44	0.36	0.45	0.49	0.50	0.40	0.44	0.41	0.43
1993	0.46	0.45	0.46	0.48	0.28	0.34	0.46	0.42	0.34	0.39	0.43	0.44
1994	0.45	0.42	0.52	0.41	0.35	0.29	0.59	0.57	0.41	0.38	0.51	0.54
1995	0.49	0.58	0.58	0.52	0.39	0.29	0.46	0.45	0.41	0.42	0.46	0.59
1996	0.67	0.47	0.57	0.46	0.44	0.43	0.51	0.52	0.42	0.40	0.50	0.52
1997	0.65	0.44	0.57	0.57	0.37	0.37	0.43	0.43	0.36	0.58	0.63	0.56
1998	0.67	0.61	0.57	0.45	0.39	0.30	0.52	0.56	0.45	0.49	0.38	0.39
1999	0.51	0.40	0.58	0.32	0.28	0.27	0.44	0.42	0.39	0.49	0.36	0.49
2000	0.43	0.35	0.37	0.37	0.32	0.23	0.39	0.45	0.37	0.43	0.48	0.51
2001	0.54	0.43	0.56	0.32	0.31	0.25	0.39	0.49	0.40	0.37	0.45	0.55
2002	0.59	0.51	0.51	0.46	0.28	0.24	0.30	0.39	0.41	0.36	0.41	0.61
2003	0.56	0.45	0.46	0.49	0.28	0.28	0.40	0.48	0.43	0.37	0.48	0.56
2004	0.58	0.50	0.40	0.53	0.22	0.30	0.37	0.41	0.42	0.45	0.49	0.59
2005	0.59	0.40	0.51	0.47	0.44	0.28	0.44	0.44	0.40	0.40	0.42	0.42

2006	0.56	0.54	0.49	0.48	0.30	0.26	0.41	0.48	0.41	0.45	0.48	0.60
2007	0.62	0.51	0.43	0.44	0.30	0.32	0.45	0.44	0.38	0.36	0.46	0.46
2008	0.52	0.44	0.23	0.38	0.35	0.30	0.39	0.43	0.39	0.41	0.53	0.49
2009	0.55	0.48	0.46	0.43	0.27	0.24	0.43	0.41	0.34	0.43	0.39	0.61
2010	0.52	0.57	0.56	0.53	0.47	0.27	0.46	0.57	0.46	0.37	0.47	0.45
2011	0.65	0.49	0.54	0.49	0.50	0.35	0.49	0.65	0.57	0.47	0.63	0.55
2012	0.57	0.45	0.46	0.62	0.41	0.33	0.53	0.59	0.50	0.46	0.51	0.55
2013	0.58	0.51	0.62	0.60	0.52	0.39	0.62	0.70	0.52	0.55	0.61	0.58
2014	0.63	0.70	0.59	0.56	0.53	0.35	0.47	0.47	0.42	0.46	0.45	0.47
2015	0.50	0.48	0.44	0.49	0.48	0.43	0.40	0.39	0.40	0.38	0.41	0.46
Average	0.57	0.49	0.50	0.47	0.37	0.30	0.45	0.49	0.42	0.43	0.48	0.53
%	56.81	48.81	50.38	47.14	36.76	30.19	45.19	49.29	42.19	43.33	48.10	52.81

Appendix A-4 25 years (1990- 2015) average daily wind speed

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1990	1.98	2.00	2.25	2.03	2.30	2.22	2.12	1.84	2.08	2.31	2.19	2.04
1991	2.14	1.87	2.04	2.09	2.32	2.13	2.14	1.78	1.85	2.12	2.12	2.13
1992	1.84	2.12	1.96	2.07	2.38	2.15	2.00	1.93	1.92	1.29	2.01	1.83
1993	1.95	1.94	2.06	2.08	2.43	2.19	1.99	1.78	1.56	2.06	2.07	2.05
1994	2.10	2.25	2.00	2.18	2.45	2.13	1.94	1.74	1.98	2.36	2.09	2.08
1995	2.15	1.95	2.03	1.92	2.14	2.29	1.90	1.88	1.98	2.17	2.00	1.82
1996	1.87	2.13	1.84	2.02	2.04	2.11	2.18	1.94	1.96	2.14	1.92	1.89
1997	1.97	2.36	2.01	1.90	2.36	2.18	1.93	2.01	2.11	1.93	1.84	2.03
1998	1.90	1.95	1.90	1.97	2.15	2.34	2.12	1.97	1.85	1.83	2.06	2.05
1999	2.03	2.14	1.99	2.28	2.47	2.30	1.91	2.00	2.04	1.83	2.11	2.09

2000	2.12	2.30	2.40	2.32	2.22	2.47	2.16	2.06	2.13	2.09	2.02	2.00
2001	2.06	2.16	1.80	2.35	2.21	2.32	2.03	1.97	2.08	2.27	2.19	2.02
2002	2.10	2.06	2.04	2.23	2.20	2.37	2.21	2.02	2.11	2.43	2.21	1.88
2003	1.97	2.16	2.14	2.01	2.46	2.33	1.97	1.88	1.97	2.19	2.22	1.97
2004	1.90	2.24	2.20	1.84	2.48	2.24	2.15	2.02	2.10	2.20	2.20	2.00
2005	1.90	2.15	2.13	2.04	2.11	2.36	2.03	1.97	1.98	2.12	2.10	2.13
2006	2.04	2.07	2.00	2.06	2.36	2.31	2.02	1.97	2.08	2.21	2.14	2.01
2007	2.06	2.08	2.18	2.18	2.34	2.24	1.84	1.95	2.06	2.15	2.13	2.11
2008	1.98	2.27	2.41	2.26	2.27	2.22	2.10	1.94	2.07	2.21	1.88	2.05
2009	1.89	2.06	2.12	2.29	2.51	2.35	1.99	2.09	2.25	2.04	2.08	1.71
2010	2.10	1.89	1.92	1.79	1.89	2.35	2.01	2.03	1.91	2.27	1.89	1.92
2011	1.75	2.00	1.82	1.85	1.80	1.89	1.76	1.50	1.61	2.12	1.89	1.88
2012	1.93	2.05	1.94	1.64	2.16	1.99	1.69	1.53	1.80	2.16	1.96	1.88
2013	1.82	1.91	1.72	1.73	1.62	1.78	1.83	1.34	1.74	1.78	1.86	1.81
2014	1.73	1.70	1.73	1.80	1.86	1.98	1.69	2.02	1.98	1.95	2.07	2.01
2015	1.93	2.03	2.10	2.13	2.13	2.15	1.97	1.89	1.95	2.03	1.97	2.05
Average (m/s)	1.97	2.09	2.02	2.03	2.19	2.22	1.97	1.90	1.99	2.12	2.04	1.97
Average (km/day)	170.21	180.53	174.12	175.52	189.41	191.52	170.58	163.87	171.94	182.88	176.34	170.08

Appendix A-5 25 years (1990- 2015) average daily sun shine hours

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1990	6.8	7.21	7.23	7.12	7.54	5.89	5.42	5.22	6.23	6.77	7.41	7.67
1991	4.35	8.28	8.41	9.35	8.74	7.15	6.37	6.65	7.15	8.76	9.39	7.08
1992	7.74	7.72	7.29	9.43	9.33	7.38	6.82	7.13	6.86	8.74	8.70	7.96
1993	5.29	7.19	7.32	8.70	9.18	6.68	6.08	7.20	7.31	8.24	9.50	7.50
1994	6.23	8.31	8.41	7.69	8.18	6.94	5.24	7.74	7.57	9.2	8.73	8.67
1995	6.8	8.83	9.2	8.4	7.92	7.45	6.45	5.62	7.86	8.75	8.08	7.22
1996	5.2	7.85	6.58	7.34	9.8	6.7	5.95	6.67	5.35	7.89	9.62	6.43
1997	7.79	7.89	7.18	6.27	8.9	8.42	6.54	5.62	4.86	8.54	8.65	7.37
1998	7.67	9.3	8.28	7.44	8.56	7.96	7.15	6.87	7.29	9.25	9.56	8.68
1999	6.79	7.42	7.69	9.05	8.44	7.53	5.64	5.62	5.64	8.06	8.57	6.78
2000	6.95	8.19	7.03	8.01	9.85	7.06	7.7	5.62	4.56	8.45	9.25	6.47
2001	6.61	9.2	7.8	7.32	8.79	5.86	7.69	6.19	6.83	8.74	8.65	8.57
2002	7.48	9.53	8.1	7.71	9.8	7.74	7.79	6.7	5.24	7.52	9.46	7.8
2003	7.15	7.5	7.01	6.32	8.56	7.17	6.23	7.25	7.31	7.97	8.48	8.48
2004	4.5	7.49	7.85	8.25	9.87	7.74	7.11	7.67	6.8	9.23	10.25	6.43
2005	7.84	7.41	7.38	8.5	8.65	8.04	7.84	7	6.81	7.56	8.18	8.69
2006	3.5	8.33	8.89	9.5	7.89	6.81	6.35	6.62	7.47	8.65	9.65	7.18
2007	8.4	7.88	8.16	8.7	9.23	7.65	6.77	7.13	6.95	8.78	8.65	6.83
2008	4.5	7.1	7.28	9.6	9.56	6.46	7.01	6.87	6.86	8.67	9.65	9.4
2009	8.4	7.68	7.49	7.89	9.12	7.3	5.68	7.49	7.33	8.02	8.75	7.09
2010	7.07	8.2	6.82	8.9	8.98	7.75	6.2	6.25	5.45	8.24	9.87	8.84

2011	4.5	8.05	7.87	8.6	8.76	8.15	5.9	5.64	5.21	9.24	8.65	7.89
2012	7.68	8.4	7.42	9.4	9.5	7.75	6.25	4.56	7.75	9.45	9.78	7.44
2013	7.63	7.31	7.95	8.63	9.65	9.38	5.68	5.65	8.05	7.06	10.25	7.24
2014	5.7	8.01	7.81	8.19	9.87	8.11	5.6	6.35	7.9	7.99	9.89	7.84
2015	6.32	7.12	7.31	6.88	6.59	5.11	4.89	5.97	7.13	7.88	8.55	8.99
Average	6.58	8.05	7.71	8.12	8.93	7.41	6.44	6.41	6.65	8.42	9.14	7.74

Appendix A-6 25 Years (1990- 2015) average daily precipitation (mm)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1990	4.96	3.85	15.75	41.88	10.75	58.1	237.57	189.59	70.28	34.68	24.89	2.57
1991	9.66	0.25	37.65	44.88	21.95	57.5	168.57	57.99	30.88	44.38	18.59	6.37
1992	2.46	7.05	10.05	31.68	55.15	69.3	293.57	256.59	79.68	59.58	2.39	6.47
1993	9.46	5.75	5.55	40.68	56.85	87.1	248.67	209.79	79.18	33.48	15.09	7.17
1994	2.46	3.65	45.25	29.88	13.85	127.2	247.87	128.99	17.98	-1.52	25.19	4.27
1995	2.96	13.55	60.35	116.58	14.95	16.1	58.07	121.49	28.48	0.58	2.39	5.07
1996	32.86	1.45	49.15	9.48	29.45	92.4	145.07	258.19	54.68	-0.52	9.99	2.57
1997	54.36	0.25	56.75	262.38	15.95	253.4	10.57	75.99	17.98	258.08	82.09	3.37
1998	18.06	14.45	83.05	48.48	61.65	9.7	242.57	144.19	311.18	49.78	2.39	2.57
1999	7.26	0.25	54.45	8.88	10.75	9.7	6.17	19.49	211.68	67.18	2.39	2.57
2000	2.46	0.25	5.85	46.98	234.25	49.2	171.17	158.39	54.68	3.58	2.39	74.07
2001	6.56	2.65	86.85	15.78	174.95	82.2	87.07	237.59	38.88	-1.52	3.29	2.57
2002	4.66	3.95	55.45	59.58	13.85	27	149.57	191.19	7.48	-1.52	2.39	46.57
2003	5.66	25.75	6.75	66.48	10.75	37.5	56.27	280.69	17.98	0.58	2.39	98.07
2004	33.96	7.85	22.55	151.08	10.75	137.9	249.37	134.49	65.08	0.58	5.19	18.37
2005	23.96	1.75	20.15	137.88	125.05	170.6	135.37	168.59	59.88	2.58	2.39	2.57
2006	2.66	12.85	26.95	127.38	10.75	58.3	286.37	25.69	23.18	63.08	2.39	7.57

2007	4.96	4.95	61.55	82.98	13.85	125.1	38.67	268.59	112.18	2.58	5.19	2.57
2008	7.26	1.25	5.55	9.18	68.95	86.7	23.77	49.09	38.88	33.38	227.19	2.57
2009	13.56	1.55	41.85	23.28	40.85	80.6	33.47	310.29	44.18	92.88	2.39	48.27
2010	6.56	67.35	120.05	128.58	268.55	16.1	65.07	275.29	164.58	2.58	27.09	41.57
2011	34.46	5.45	85.15	35.28	247.75	157.2	273.37	443.99	227.38	-1.52	60.29	5.07
2012	6.06	0.25	43.55	172.98	23.25	253.4	172.27	150.49	122.68	-0.52	2.39	16.67
2013	16.76	7.15	141.25	130.38	449.45	105.9	370.87	283.39	17.98	82.58	49.79	7.57
2014	13.76	65.15	90.75	110.28	81.45	22.5	58.07	54.49	12.78	39.48	2.39	2.57
2015	2.46	35.05	62.45	32.78	32.45	91.3	216.27	169.79	73.88	32.48	2.39	4.07
Average	12.70	11.30	49.80	75.60	80.70	88.10	155.60	179.40	76.30	34.50	22.50	16.30

Appendix A-7 Yearly average climatic data

Months	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Min temp	10.47	11.68	12.97	15.17	15.99	14.41	13.99	12.97	14.73	12.65	10.59	9.63	12.94
Max temp	24.46	26.23	27.46	28.53	29.96	30.98	29.30	29.04	29.47	27.17	25.33	24.73	27.72
Precipitation (mm)	12.7	11.3	49.8	75.6	80.7	88.1	155.6	179.4	76.3	34.50	22.5	16.3	66.90
Sunshine hour	6.58	8.05	7.71	8.12	8.93	7.41	6.44	6.41	6.65	8.42	9.14	7.74	7.63
RH (%)	56.81	48.81	50.38	47.14	36.76	30.19	45.19	49.29	42.19	43.33	48.10	52.81	45.92
Wind speed (km/day)	170.21	180.53	174.12	175.52	189.41	191.52	170.58	163.87	171.94	182.88	176.34	170.08	176.42

Appendix A-8 Soil textural analysis using Hydrometer

Canal Reach	Field number	Soil depth (cm)	Hydrometer reading after 40 sec. (g/l)	Temperature reading after 40 sec.(^{0}c)	Hydrometer Reading after 2 hr. (g/l)	Temperature reading after 2 hr. (^{0}C)	% Sand	%Clay	% Silt	Textural class
Head	1	0-30	22.5	19	16	21	20	58	22	Clay
		30-60	21.5	19	14.5	21	24	52	24	Clay
	2	0-30	22.5	19	16	21	20	58	22	Clay
		30-60	21.5	19	16	21	24	58	18	Clay
	3	0-30	23.5	19	16.5	21	16	60	24	Clay
		30-60	21.5	19	15	21	24	54	22	Clay
Middle	1	0-30	22.9	19	15.5	21	18	56	26	Clay
		30-60	22.0	19	16.0	21	22	58	20	Clay
	2	0-30	22.5	19	16.0	21	20	58	22	Clay
		30-60	23.0	19	16.0	21	18	58	24	Clay

	3	0-30	21.5	19	15.5	21	24	56	20	Clay
		30-60	23.0	19	16.0	21	18	58	24	Clay
Tail	1	0-30	22.0	19	16.0	21	22	58	20	Clay
		30-60	23.0	19	16.0	21	18	58	24	Clay
	2	0-30	23.0	19	16.0	21	18	58	24	Clay
		30-60	22.0	19	15.5	21	22	56	22	Clay
	3	0-30	23.0	19	16.0	21	18	58	24	Clay
		30-60	22.0	19	15.5	21	22	56	22	Clay

Appendix A-9 Estimated total available moisture (TAM)

Canal Reach	Field code	Soil depth (cm)	FC* (%)	PWP* (%)	TAM* (%)	TAM (mm m^{-1})
Head	1	0-30	39.5	20.5	19	190
		30-60	37.2	21.8	15.4	154
Average						172
Middle	2	0-30	38.22	21	17.22	172.2
		30-60	36.6	19.5	17.1	171
Average						171.6
Tail	3	0-25	41	24	17	170
		25-50	38.5	21	17.5	175
		50-75	36.4	20.2	16.2	162
		75- 100	36	18	18	180
Average						171.75

FC* and PWP* = Moisture content at field capacity and permanent wilting point respectively.

TAM* = Total available moisture

Appendix A-10 Estimated soil infiltration rates for Robit irrigation scheme

Cumulative time(min)	Elapsed time(min)	Reading before filling(cm)	Reading after filling(cm)	Incremental infiltration (cm)	Infiltration rate (cm min^{-1})	Infiltration rate (cm hr^{-1})	Cumulative infiltration (cm)	Cumulative infiltration rate in mm day^{-1}
0	0	0	10	0			0	0
0.5	0.5	7	7	3	6.0	360	3	86400
1	0.5	4.5	4.5	2.5	5.0	300	5.5	72000
2	1	2.5	10	2	2.0	120	7.5	28800
5	3	8.5	8.5	1.5	0.5	30	9	7200
10	5	7.4	7.4	1.1	0.22	13.2	10.1	3168
20	10	6.6	6.6	0.8	0.08	4.8	10.9	1152
40	20	6.0	6.0	0.6	0.03	1.8	11.5	432
60	20	5.5	5.5	0.5	0.03	1.5	12	360
90	30	5.1	10	0.4	0.013	0.8	12.4	192
120	30	9.62	9.62	0.38	0.013	0.76	12.78	182.4
150	30	9.26	9.26	0.36	0.012	0.72	13.14	172.8
180	30	8.91	8.91	0.35	0.012	**0.7**	13.49	168
210	30	8.56		0.35	0.012	**0.7**	13.84	168

Appendix A-11 Area coverage, arranged irrigation schedule by WUAs and crops grown in each offtake structure

Tertiary Offtake Name	Reach category	Location of offtake structures (m)	Area coverage(ha)	Type of Crop Grown in each field and irrigation schedule arranged by WUAs
TO1 (L1)	Head	100-300	1.5	Onion (1)
TO2 (L2)		300-500	9	Mung bean (1)
TO3 (L3)		500- 750	17	Maize (1)
TO4*		750-900	13	Onion and maize (2)
TO5 (L4)	Middle	900-1100	22	Mung bean (2)
TO 6*		1100-1300	15	Onion and maize (3)
TO7 (L5)		1300 -1500	12.5	Onion (3)
TO 8*		1500-1700	23	Onion and maize (4)
TO 9 (L6)		1700 - 1900	10.5	Onion (4&5)
TO10 (L7)	Tail	1900- 2100	12.5	Maize (5)
TO 11*		2100- 2300	13	Onion & mung bean (6)
TO12 (L8)		2500- 2500	10	Onion (6&7)
TO13 (L9)		2500-2750	15.5	Mung bean (7)

* = Tertiary offtakes not selected for measurements in the present study, 1, 2, 3, 4, 5, 6 and 7 = irrigation fields arranged to irrigate on Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday respectively.

Appendix A-12 CROPWAT estimated reference crop evapotranspiration (ET_O) and effective rainfall values

Country: ETHIOPIA Station: SHEWA ROBIT

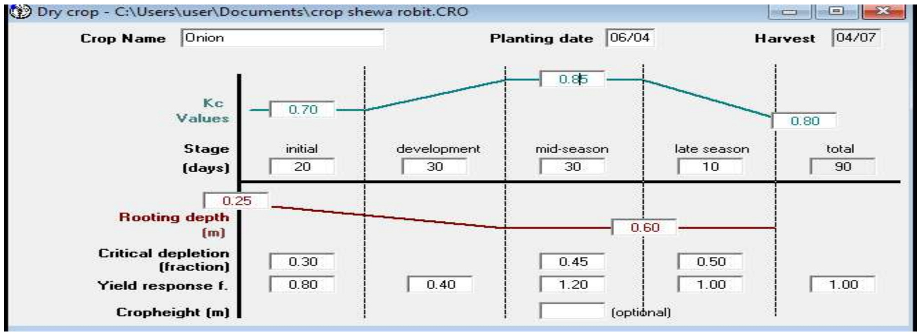
Altitude: 1417 m. Latitude: 9.83 °N Longitude: 39.98 °E

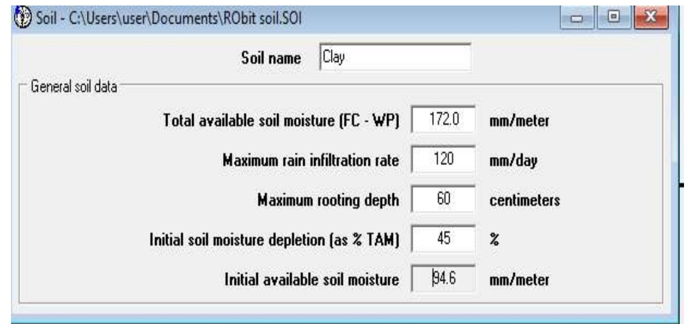
Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	10.5	24.5	57	170	6.6	17.2	3.77
February	11.7	26.2	49	180	8.1	20.5	4.63
March	13.0	27.5	50	174	7.7	21.1	4.89
April	15.2	28.5	47	175	8.1	22.0	5.27
May	16.0	30.0	37	189	8.9	22.8	5.91
June	14.4	31.0	30	191	7.4	20.1	5.90
July	14.0	29.3	45	171	6.4	18.7	5.01
August	13.0	29.0	49	164	6.4	19.1	4.83
September	14.7	29.5	42	172	6.7	19.5	5.20
October	12.6	27.2	43	183	8.4	21.2	5.13
November	11.0	25.3	48	176	9.1	20.9	4.55
December	9.6	24.7	53	170	7.7	18.3	3.96
Average	13.0	27.7	46	176	7.6	20.1	4.92

Station: Shewa robit Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	12.7	12.5
February	11.3	11.1
March	49.8	45.8
April	75.6	66.5
May	80.7	70.3
June	88.1	75.7
July	155.6	116.9
August	179.4	127.9
September	76.3	67.0
October	34.5	32.6
November	22.5	21.7
December	16.3	15.9
Total	802.8	663.7

Appendix A-13 CROPWAT estimated soil and crop data for onion crop





Appendix A-14: CROPWAT estimated crop water requirement (ET_C) and irrigation requirement (IR) for onion crop

Month	Decade	Stage	Kc Coefficient	ETc mm/day	ETc mm/decade	Ref mm/decade	NIR. mm/decade
Apr	1	Init	0.7	3.6	18	10.2	7.8
Apr	2	Init	0.7	3.69	36.9	22.9	14
Apr	3	Deve	0.71	3.89	38.9	23.1	15.8
May	1	Deve	0.76	4.33	43.3	23	20.3
May	2	Deve	0.82	4.82	48.2	23.4	24.8
May	3	Mid	0.86	5.1	56.1	24	32.1
Jun	1	Mid	0.87	5.13	51.3	23.5	27.8
Jun	2	Mid	0.87	5.13	51.3	23.6	27.7
Jun	3	Late	0.86	4.8	48	28.7	19.3
Jul	1	Late	0.82	4.37	17.5	14.1	0
Total					**409.5**	**216.4**	**189.7**

Appendix A-15 CROPWAT estimated irrigation schedule and duty for onion crop

Date	Day	Stage	Rain mm	Ks Fraction	ETa %	Depl. %	NIR mm	Deficit mm	Loss mm	GIR mm	Flow duty (D) $ls^{-1}ha^{-1}$	Monthly average flow duty $ls^{-1}ha^{-1}$	Growth stage average flow duty $ls^{-1}ha^{-1}$
9-Apr	4	Init	0	1	100	26	10.8	0	0	24	0.7	0.58	0.58
13-Apr	8	Init	13.1	1	100	8	3.7	0	0	8.2	0.24		
17-Apr	12	Init	13.1	1	100	7	3.7	0	0	8.2	0.24		
21-Apr	16	Init	0	1	100	28	15	0	0	33.3	0.96		
25-Apr	20	Init	0	1	100	20	11.7	0	0	25.9	0.75		
3-May	28	Dev	13.2	1	100	23	15.4	0	0	34.2	0.49	0.64	0.64
11-May	36	Dev	0	1	100	29	22.1	0	0	49.2	0.71		
19-May	44	Dev	0	1	100	24	20.3	0	0	45.2	0.65		
25-May	50	Dev	0	1	100	18	16.5	0	0	36.7	0.71		
4-Jun	60	Mid	0	1	100	36	32.7	0	0	72.7	0.84	0.71	0.71
14-Jun	70	Mid	0	1	100	31	27.7	0	0	61.6	0.71		
24-Jun	80	Mid	0	1	100	25	22.2	0	0	49.4	0.57		
4-Jul	End	End	0	1	0	11							

Appendix A-16 CROPWAT estimated crop water requirement (ETc) and irrigation requirement (IR) for mung bean crop

Month	Decade	Stage	Kc Coefficient	ETc mm/day	ETc mm/decade	Ref mm/decade	NIR mm/decade
Apr	1	Init	0.4	2.06	6.2	6.1	0.1
Apr	2	Init	0.4	2.11	21.1	22.9	1.8
Apr	3	Deve	0.67	3.7	37	23.1	13.9
May	1	Mid	1.15	6.57	65.7	23	42.8
May	2	Mid	1.16	6.86	68.6	23.4	45.3
May	3	Mid	1.16	6.86	75.4	24	51.5
Jun	1	Late	0.97	5.73	57.3	23.5	33.8
Jun	2	Late	0.63	3.73	22.4	14.1	10.6
Total					**353.7**	**160.1**	**203.9**

Appendix A-17 CROPWAT estimated irrigation schedule and flow duty for mung bean crop

Date	Day	Stage	Rain mm	Ks fraction	ETa %	Depl. %	NIR. mm	Deficit mm	Loss mm	GIR mm	Flow duty l/s/ha	Monthly average flow duty $ls^{-1}ha^{-1}$	Growth stage average flow duty $ls^{-1}ha^{-1}$
12-Apr	5	Init	0	1	100	17	10.4	0	0	23.1	0.53	0.45	0.45
17-Apr	10	Init	13.1	1	100	3	2.1	0	0	4.7	0.11		
22-Apr	15	Init	0	1	100	17	13.7	0	0	30.5	0.71		
2-May	25	Dev	0	1	100	29	29.5	0	0	65.6	0.76	1.03	0.76
14-May	37	Mid	0	1	100	52	53.5	0	0	118.8	1.15		1.165
26-May	49	Mid	0	1	100	53	55.1	0	0	122.4	1.18		
7-Jun	61	End	13.3	1	100	46	47.7	0	0	106	1.02	1.02	1.02
16-Jun	End	End	0	1	0	22							

Appendix A-18 CROPWAT estimated crop water requirement (ETc) and irrigation requirement for maize crop

Month	Decade	Stage	Kc Coefficient	ETc mm/day	ETc mm/decade	Ref mm/decade	NIR mm/decade
Mar	3	Init	0.3	1.51	7.5	8.2	0
Apr	1	Init	0.3	1.54	15.4	20.4	0
Apr	2	Deve	0.34	1.79	17.9	22.9	0
Apr	3	Deve	0.58	3.18	31.8	23.1	8.7
May	1	Deve	0.85	4.82	48.2	23	25.2
May	2	Deve	1.11	6.57	65.7	23.4	42.4
May	3	Mid	1.23	7.28	80	24	56
Jun	1	Mid	1.23	7.27	72.7	23.5	49.2
Jun	2	Mid	1.23	7.26	72.6	23.6	49.1
Jun	3	Late	1.23	6.88	68.8	28.7	40.1
Jul	1	Late	1.04	5.51	55.1	35.3	19.8
Jul	2	Late	0.75	3.73	37.3	40.4	0
Jul	3	Late	0.47	2.31	20.8	33.6	0
Total					**594.1**	**330**	**290.5**

Appendix A-19 Estimated irrigation schedule and flow duty for maize crop

Date	Day	Stage	Rain mm	Ks Fraction.	ETa %	Depl. %	NIR mm	Deficit mm	Loss mm	GIR mm	Flow duty $ls^{-1}ha^{-1}$	Growth stage average flow duty $ls^{-1}ha^{-1}$	Monthly average flow duty $ls^{-1}ha^{-1}$
1-Apr	6	Init	0	1	100	16	9.1	0	0	20.2	0.39		
7-Apr	12	Init	11.5	1	100	2	1.5	0	0	3.4	0.07		
13-Apr	18	Init	13.1	1	100	3	1.8	0	0	4	0.08	0.19	
19-Apr	24	Dev	0	1	100	7	5.4	0	0	12	0.23		0.19
28-Apr	33	Dev	0	1	100	8	6.4	0	0	14.1	0.18		
7-May	42	Dev	13.2	1	100	15	13.8	0	0	30.7	0.39		
16-May	51	Dev	0	1	100	41	40.5	0	0	90	1.16		
25-May	60	Mid	0	1	100	47	48.8	0	0	108.5	1.4	0.49	
4-Jun	70	Mid	0	1	100	51	52.1	0	0	115.8	1.34		0.98
14-Jun	80	Mid	0	1	100	45	46.1	0	0	102.4	1.18		
24-Jun	90	Mid	0	1	100	39	40.3	0	0	89.6	1.04		1.19
4-Jul	100	End	0	1	100	26	26.7	0	0	59.3	0.69	1.24	

18-Jul	114	End	0	1	100	7	7.5	0	0	16.6	0.14	
29-Jul	End	End	0	1	0	4						0.415

Appendix A-20 CROPWAT estimated average required flow (Q_R)

Reach location		Head			Middle			Tail			
Offtake code		L 1	L 2	L 3	L 4	L 5	L 6	L 7	L 8	L 9	Spatial mean values
Crop type		Onion	Mung bean	Maize	Mung bean	Onion	Onion	Maize	Onion	Mung bean	
Area coverage (ha)		1.5	9	17	22	12.5	10.5	12.5	10	15.5	
Monthly average flow duty (l/s/ha)	April	0.58	0.45	0.19	0.45	0.58	0.58	0.19	0.58	0.45	0.45
	May	0.64	1.03	0.98	1.03	0.64	0.64	0.98	0.64	1.03	0.85
	June	0.71	1.02	1.19	1.02	0.71	0.71	1.19	0.71	1.02	0.92
Monthly required flow(l/s)	April	0.87	4.05	3.23	9.9	7.23	6.07	2.38	5.78	6.98	5.16
	May	0.96	9.27	16.66	22.66	8	6.72	12.25	6.4	15.97	10.99
	June	1.07	9.18	20.23	22.44	8.88	7.46	14.88	7.1	15.81	11.89
Temporal mean required flow (l/s)		0.96	7.5	13.37	18.33	8.03	6.75	9.83	6.43	12.92	9.35

Appendix A-21: Measured flow depths and corresponding observed discharge

Location	Date of irrigation	Area ha	Crop type	April Water depth from flume, cm	Discharge observed from standard tables (l/s)	May Date of irrigation	Water depth from flume, cm	Discharge observed from standard tables (l/s)	June Date of irrigation	Water depth from flume, cm	Discharge (l/s), observed from standard table	Temporal Mean values l/s
L1	9-Apr	1.5	Onion	5	1.206	3-May	3	1.206	7-Jun	5	1.206	**1.14**
	13-Apr			4	1.206	11-May	3	1.206	17-Jun	6	1.705	
	17-Apr			4	1.206	19-May	3	0.772				
	21-Apr			4	1.206	27-May	3	0.772				
	Mean				**1.206**			**0.77**			**1.455**	
L2	12-Apr	9.0		10	4.991	2-May	14	8.408	8-Jun	18	12.413	**8.531**
	17-Apr		Mung	11	5.786	14-May	13	7.496				

	22-Apr		bean	9	4.239	26-May	14	8.408				
	Mean				**5.01**			**8.104**			**11.413**	
	1-Apr			9	4.239	7-May	20	14.616	4-Jun	31	28.829	
L3	7-Apr	17.0	Maize	9	4.239	16-May	19	13.499	18-Jun	30	28.829	**15.59**
	13-Apr			9	4.239	25-May	19	13.499				
	19-Apr			8	3.532							
	Mean				**4.49**			**13.871**			**28.829**	
	13-Apr			19	13.499	3-May	24	19.389	9-Jun	23	30.283	
L4	18-Apr	22.0	Mung bean	18	12.413	15-May	23	18.151				**20.49**
	23-Apr			17	11.361	27-May						
	Mean				**12.424**			**18.77**			**30.283**	

L5	9-Apr	12.5	Onion	12	6.621	3-May	11	5.786	7-Jun	16	10.342	
	13-Apr			11	5.786	11-May	12	6.621	17-Jun	16	10.342	
	17-Apr			12	6.621	19-May	11	5.786				
	21-Apr			12	6.621	27-May	13	7.496				
	Mean				**6.412**			**6.422**			**10.342**	**7.726**
L6	10-Apr	10.5	Onion	11	5.786	4-May	10	4.991	8-Jun	12	6.621	
	11-Apr			11	5.786	12-May	12	6.621	18-Jun	11	5.786	
	18-Apr			10	4.991	20-May	11	5.786				
	22-Apr			10	4.991	28-May	11	5.786				
	Mean				**5.521**			**5.799**			**7.06**	**6.081**
L7	2-Apr	12.5	Maize	6	2.261	8-May	15	9.358	5-Jun	19	13.499	**8.095**
	8-Apr			6	2.261	17-May	14	8.408	19-Jun	20	14.616	
	14-Apr			5	1.705	26-May	13	7.496				

	20-Apr			4	1.206							
	Mean				**1.858**			**8.42**			**14.01**	
	12-Apr			10	4.991	6-May	10	4.991	5-Jun	12	6.621	
	13-Apr			10	4.991	14-May	10	4.991	19-Jun	12	6.621	
	20-Apr			9	4.239	22-May	9	4.239				
L8	24-Apr	10	Onion	10	4.991	30-May	9	4.239				
	Mean				**4.803**			**4.615**			**6.621**	**5.346**
	2-Apr			11	5.786	8-May	16	10.342	5-Jun	18	12.413	
	8-Apr			10	4.991	17-May	16	10.342	19-Jun	19	13.499	
L9	14-Apr	15.5	Mung bean	11	5.786	26-May	16	10.342				**9.453**
	20-Apr			10	4.991							
	Mean				**5.389**			**10.01**			**12.956**	

Appendix A -22 Design flow rate and currently delivered flow of tertiary offtake structures (Q_D)

Locations	L1	L2	L3	L4	L5	L6	L7	L8	L9
Design flow rate (ls^{-1})	2.85	17.1	23.94	31.92	21.09	18.81	22.23	21.66	30.21
Average delivered flow(ls^{-1})	0.96	7.50	13.37	18.33	8.03	6.75	9.83	6.43	12.92

Appendix A-23 Parameter estimates of binary Logit Model for head reach users

```
      name:  <unnamed>
       log:  C:\Users\dbu\Desktop\Head reach final.smcl
  log type:  smcl
 opened on:   6 Aug 2017, 23:52:22

. logit satisfaction avilabilityofadequatewater wareravailabilityintime farmlocationfromcanalhead landsize schoolingyears

Iteration 0:   log likelihood = -51.176455
Iteration 1:   log likelihood = -31.017486
Iteration 2:   log likelihood =  -30.17892
Iteration 3:   log likelihood = -30.165453
Iteration 4:   log likelihood = -30.165431
Iteration 5:   log likelihood = -30.165431

Logistic regression                               Number of obs   =         75
                                                  LR chi2(5)      =      42.02
                                                  Prob > chi2     =     0.0000
Log likelihood = -30.165431                       Pseudo R2       =     0.4106
```

satisfaction	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
avilabilityofadequatewater	3.723094	.852367	4.37	0.000	2.052485	5.393702
wareravailabilityintime	.9809384	.6912815	1.42	0.156	-.3739486	2.335825
farmlocationfromcanalhead	-.9203278	.6633131	-1.39	0.165	-2.220397	.379742
landsize	-1.434978	2.506253	-0.57	0.567	-6.347143	3.477187
schoolingyears	.1082727	.0887823	1.22	0.223	-.0657373	.2822828
_cons	-1.047379	.9329732	-1.12	0.262	-2.875973	.7812145

```
. proportion satisfaction

Proportion estimation             Number of obs    =      75
```

	Proportion	Std. Err.	[95% Conf.	Interval]
satisfaction				
0	.4266667	.0574953	.3121048	.5412285
1	.5733333	.0574953	.4587715	.6878952

```
. exit, clear
```

Appendix A-24 Parameter estimates of Logit Model in middle reach users

```
      name:  <unnamed>
       log:  C:\Users\dbu\Desktop\middle reach perfect.smcl
  log type:  smcl
 opened on:   6 Aug 2017, 21:29:16

. logit satisfaction avilabilityofadequacywater availabilityofwaterintime farmlocation farmsize schoolingyears

Iteration 0:   log likelihood = -51.926023
Iteration 1:   log likelihood = -40.733823
Iteration 2:   log likelihood = -40.610975
Iteration 3:   log likelihood = -40.610661
Iteration 4:   log likelihood = -40.610661

Logistic regression                               Number of obs   =         75
                                                  LR chi2(5)      =      22.63
                                                  Prob > chi2     =     0.0004
Log likelihood = -40.610661                       Pseudo R2       =     0.2179
```

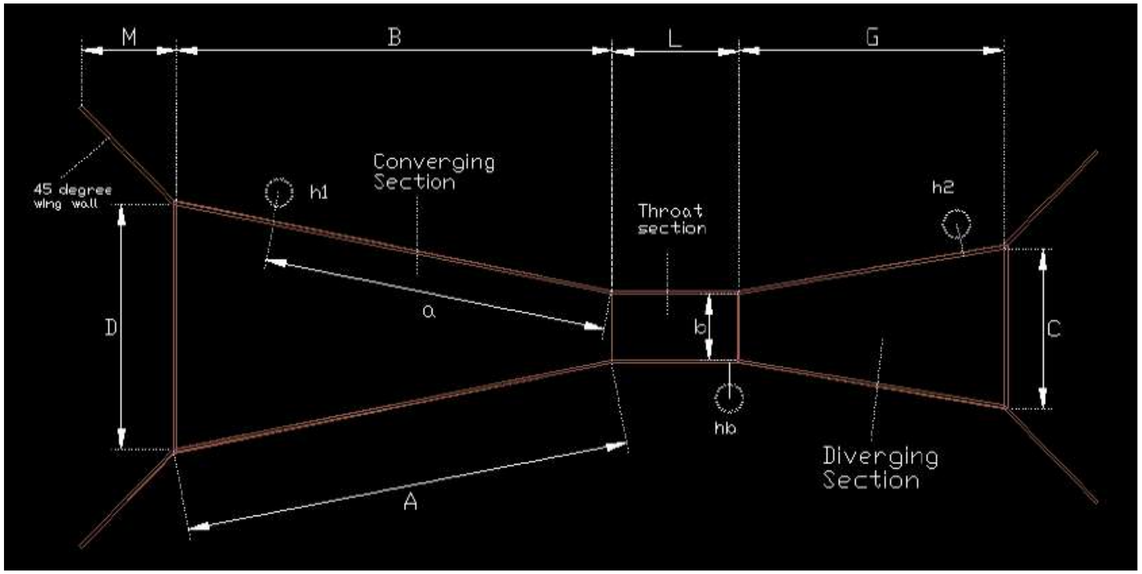
satisfaction	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
avilabilityofadequacywater	.9089303	.5628771	1.61	0.106	-.1942884	2.012149
availabilityofwaterintime	1.897666	.5615509	3.38	0.001	.797046	2.998285
farmlocation	-1.053541	.5590874	-1.88	0.060	-2.149332	.0422497
farmsize	-3.295042	2.236622	-1.47	0.141	-7.67874	1.088656
schoolingyears	.083213	.0723388	1.15	0.250	-.0585684	.2249944
_cons	-.7332032	.8051474	-0.91	0.362	-2.311263	.8448567

```
. exit, clear
```

Appendix B: Figures Showing the Existing Condition of the Scheme

Appendix B-1 Installation of Current meter instrument and figure showing Malfunctioned flow regulator

Appendix B-2 Flow diverting by the farmer to the Mung bean crop



Appendix B-3 Dimensions of 3-inch Parshall flume

Appendix C: Questionnaire Prepared Concerning Users Satisfaction

Arba Minch University

School of graduate studies

Institute of Technology

Department of Water Resource and Irrigation Engineering

Dear respondents

My name is Abrha Ybeyn Gebremedhn from Arba Minch University, Ethiopia. I am conducting a study on the water delivery performance and level of users' satisfaction in Robit small-scale irrigation scheme. Therefore, I am kindly requesting you to give a response as much as you can. The main objective of the questionnaire is to evaluate the level of users satisfaction from the irrigation service received, and to identify the causes for the dissatisfaction of users and recommend improvement options. All the questionnaire targets on the head, middle and tail reaches of the scheme and collected from 225 irrigation users' 75 each reach.

Date_______________

Keble________________________

Name of the interviewee ____________________________

Sex [ ] Male [ ] Female

Block (Location) [ ] Head [ ] Middle [ ] Tail

Educational level _____________________

Prepared Questions

1. Is there water users' associations (WUAs) and water committee in your scheme? [ ] Yes [ ] No
2. If your answer is yes what looks like the strength of the WUAs and water committee in managing the scheme?

   [ ] Strong **[ ]** Medium **[ ]** Weak
3. If the management is weak, what is the major management problems related to water distribution in the irrigation system?

   [ ] Sanction not imposed against illegal water users' [ ] Poor coordination of water distribution by WUAs of water committee

[ ] Rotation does not accomplish equality [ ] Rotation is not strictly implemented

4. Is there any established bylaw in Robit irrigation scheme? [ ] Yes [ ] No
5. Is there any fee that could be collected from the irrigation users? [ ] Yes [ ] No
6. Who is the responsible body for the operation and maintenance of the scheme? [ ] Farmers [ ] government [ ] water committee
7. What is your landholding size ________________________________?
8. Location of your farm plot from canal head [ ] near [ ] far
9. Is the available irrigation water adequate for your farm land? [ ] Yes [ ] No
10. If no, what are the possible reasons for inadequate water supply of the canals?
    [ ] Poor scheduling of available water supply [ ] sedimentation problem
    [ ] Over-abstraction by upstream water user [ ] poor control by O&M staff
    [ ] poor motivated O&M staff [ ] Inadequate supply of water a water source
    [ ] Damaged control structures (at intake) [ ] Inadequate canal capacity
    [ ] others
11. In general, what do you feel about the adequacy of irrigation water in the scheme?
    [ ] Satisfied [ ] dissatisfied
12. Does the supplied water reliable and delivered at the scheduled time? [ ] Yes [ ] No
13. If no, what are the possible reasons?
    [ ] water scarcity [ ] unequal water distribution [ ] unfortunate Irrigation scheduling
    [ ] over abstraction of water by upstream users [ ] others
14. What do you feel about the reliability of Debalkew irrigation scheme? [ ] Satisfied not satisfied [ ]
15. Is there equitable distribution of irrigation water among all beneficiaries? [ ] Yes [ ] No
16. If no, what are the causes for the unequal water distribution?
    [ ] water scarcity [ ] unequal water distribution [ ] unfortunate Irrigation scheduling
    [ ] over abstraction of water by upstream users [ ] others
17. How do you feel about the water distribution in general? [ ] Satisfied [ ] Not satisfied
18. Generally, are you satisfied with the irrigation service received? [ ] yes [ ] no