

HYDRAULIC PERFORMANCE EVALUATION OF WATER CONVEYANCE SYSTEM
OF WONJI SHOA IRRIGATION SCHEME IN ETHIOPIA



ASCHENAKI MEKONNEN SEIFE

A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCES
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PRESENTED IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE
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OFFICE OF GRADUATE STUDIES
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DECLARATION

I declare that this thesis entitled “**Hydraulic Performance Evaluation of Water Conveyance System of Wonji Shoa Irrigation Scheme in Ethiopia**” is my own work and has not been submitted to any university for similar purpose. The references used in this thesis are duly recognized by proper citations.

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I, the major advisor of this research thesis, hereby certify that I have closely advised the student while developing this thesis and read the draft thesis, thesis entitled **“Hydraulic Performance Evaluation of Water Conveyance System of Wonji Shoa Irrigation Scheme in Ethiopia”** prepared under my guidance by Aschenaki Mekonnen. Therefore, I recommend the submission of the thesis to the department for further review and evaluation.

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APPROVAL PAGE OF THE THESIS

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Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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TABLE OF CONTENT

DECLARATION.....	i
RECOMMENDATION OF ADVISOR.....	ii
APPROVAL PAGE OF THE THESIS	iii
ACKNOWLEDGMENT	iv
TABLE OF CONTENT	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
ACRONOMYS.....	x
ABSTRACT	xi
CHAPTER ONE.....	1
1. INTRODUCTION	1
1.1 Background	1
1.2 Statements of the Problem	4
1.3 Objectives	5
1.3.1 General objective.....	5
1.3.2 Specific objectives.....	5
1.4 Research Questions	5
1.1 Significance of the Study	5
1.2 Scope of the Study	6
1.3 Limitations of Study	6
1.4 Thesis Organization	7
CHAPTER TWO.....	8
2. LITERATURE REVIEW	8
2.1 Irrigation practices in Ethiopia	8
2.2 Irrigation Efficiency.....	8
2.3 Importance of Irrigated Agriculture.....	9
2.4 Irrigation System Management.....	9
2.5 Conveyance Efficiency	10
2.5.1 Factors Affecting Conveyance Efficiency	12
2.6 Crop Water Requirements and Effective Rainfall	15
2.7 Irrigation System Performance	16

CHAPTER THREE	18
3. MATERIALS AND METHODS	18
3.1 Description of Study Area	18
3.1.1 Location and topography of the study area	18
3.1.2 Climate of study area.....	19
3.1.3 Soil of Wonji Shoa irrigation scheme	19
3.1.4 Irrigation infrastructure	20
3.2 Materials and Software Used	22
3.3 Data Collection and Preparation	23
3.3.1 Primary data collection	23
3.3.2 Secondary data collection.....	26
3.4 Hydraulic and Hydrologic Factors on Conveyance Efficiency	28
3.4.1 Canal conveyance efficiency.....	28
3.4.2 Canal conveyance losses	28
3.5 Hydraulic Factors on Conveyance Efficiency	29
3.6 Hydrologic Factors on Conveyance Efficiency	29
3.7 Comparison and Evaluation of Hydraulic and Hydrologic Factors on Water Conveyance Efficiency.....	32
3.8 Data Analysis	33
CHAPTER FOUR	36
4. RESULTS AND DISCUSSIONS	36
4.1 Pumps and Irrigation Canals.....	36
4.2 Canal Conveyance Efficiency.....	36
4.2.1 Main canal conveyance efficiency	36
4.2.2 Secondary canal right branch conveyance efficiency	38
4.2.3 Secondary canal left branch conveyance efficiency	39
4.2.4 Performance of conveyance efficiency in tertiary canals.....	41
4.3 Hydraulic Factors Influences Conveyance Efficiency.....	45
4.4 Hydrologic Factors Influences on Conveyance Efficiency	49
4.4.1 Inflow-outflow (Field observation) method of seepage loss.....	50
4.4.2 Indirect measurement of seepage loss or using empirical equation	50
4.5 Evaporation Loss	55
4.6 Comparison and Evaluation of Hydraulic and Hydrologic Factors.....	56

5. CONCLUSION AND RECOMMENDATION	59
5.1 Conclusion	59
5.2 Recommendations.....	60
REFERENCES	61
APPENDIX-A	73
APPENDIX-B	78

LIST OF TABLES

Table	Page
Table 2.1 Empirical formulas for estimating seepage loss	14
Table 3.1 Mean monthly values of meteorological data from (2010–2021).....	27
Table 4.1 Average conveyance efficiency of main canal	37
Table 4.2 Average conveyance efficiency of the right branch of the secondary canal	38
Table 4.3 Conveyance Efficiency of the Left Branch of the Secondary Canal.....	40
Table 4.4 Conveyance Efficiency of Tertiary Canals.....	42
Table 4.5 Calculation of manning's roughness 'n' for Wonji-Shoa irrigation scheme	45
Table 4.6 Model summary for roughness coefficient.....	46
Table 4.7 Analysis of variance (ANOVA) table of roughness coefficient.....	46
Table 4.8 Water availability at Koka dam.....	49
Table 4.9 Crop and irrigation water requirement	47
Table 4.10 General details characteristics of different sections and seepage loss	50
Table 4.11 Field observation and empirical formulas for estimating seepage loss.....	51
Table 4.12 Calculated values of seepage loss for the lined canal using different methods.....	52
Table 4.13 Calculated values of seepage loss for the un-lined canal using different methods.	53
Table 4.14 Evaporation loss using aerodynamic equation	55
Table 4.15 Model summary canal geometry versus seepage loss	56
Table 4.16 Analysis of variance (ANOVA) Table	57

LIST OF FIGURES

Figure	Page
Figure 3.1 Location map of the study area	19
Figure 3.2 Main pump station of Wonji Shoa Sugar Factory.....	21
Figure 3.3 Discharge measuring cippoletti weir and water level gauge.....	22
Figure 3.4 Main canal dimension and discharge measurement by float-area methods.....	24
Figure 3.5 Layout of Wonji Shoa Irrigation Scheme main system and offtakes	25
Figure 3.6 Discharge and secondary canal dimension measurement	25
Figure 3.7 Layout of secondary canal and reservoir location.....	26
Figure 3.8 Mean monthly values of meteorological data (2010–2021).	27
Figure 3.9 Mass balance for the inflow-outflow method	30
Figure 3.10 Conceptual framework of research methodology for the study	35
Figure 4.1 Average conveyance efficiency of main canal.....	38
Figure 4.2 Average conveyance efficiency of the right branch of the secondary canal	39
Figure 4.3 Conveyance Efficiency of the Left Branch of the Secondary Canal	41
Figure 4.4 Tertiary canal conveyance efficiency.....	43
Figure 4.5 Water efficiency and loss in the lined and un-lined Wonji Shoa canal	44
Figure 4.6 Water availability at Koka dam	49
Figure 4.7 Crop and irrigation water requirement.....	48
Figure 4.8 Mean monthly rainfall, effective rainfall and ETo values	49
Figure 4.9 Comparison seepage loss by field observation and empirical formula.....	52
Figure 4.10 Seepage loss of lined Wonji Shoa irrigation scheme.	53
Figure 4.11 Seepage loss of un-lined Wonji Shoa irrigation scheme.....	54
Figure 4.12 Scatterplot for hydraulic parameter correlation with seepage loss	58

ACRONOMYS

CE	Conveyance Efficiency
CWR	Crop Water Requirement
Ea	Application Efficiency
E _p	Potential Evaporation
Em	Main canal conveyance efficiency
Es	Secondary canal conveyance efficiency
Et	Tertiary canal conveyance efficiency
ET	Evapotranspiration
ETc	Crop evapotranspiration
ETo	Reference evapotranspiration
FAO	Food and Agricultural Organization
ENMA	Ethiopia national metereological agency
HVA	Handles Vereniging Amsterdam
IWUAs	Irrigation Water Use Associations
IWR	Irrigation water requirement
Kc	Crop coffiecient
NSR	Night storage reservoir
Mc	Main canal
Reff	Effective rain fall
Qout	Discharge out flow from the given canal
Qin	Discharge inflow to the given canal
Sc	Secondary canal
SCRB	Secondary canal right branch
SCLB	Secondary canal left branch
Sl	Seepage loss
Tc	Tertiary canal
WSSF	Wonji Shoa Sugar Factory

ABSTRACT

Water is a crucial global resource, used by living things for survival and in various industrial processes. The water losses in canals have a significant and diverse effect on the efficient water supply to fields as it is a basic element of irrigation systems. A complex web of interconnected hydrologic and hydraulic barriers limits the Wonji Shoa irrigation scheme's conveyance efficiency. The serious problem in the domain/field of irrigation systems is addressing water conveyance inefficient and minimizing canal water loss. One of the major challenges in the Wonji Shoa irrigation scheme is bridging the accelerated gap between the required and available water and pinpoint areas that need management intervention to increase the conveyance system's efficiency. The aim of this research is to evaluate hydraulic and hydrologic parameters in irrigation conveyance systems, thereby enhancing transportation efficiency and aiding the identification of areas of water loss. The various methods used to assess the impact of hydraulic and hydrologic parameters on conveyance efficiency in irrigation canals, include field measurements, the velocity area method, Minitab software for statistical analysis, CROPWAT 8.0 for estimation of evaporation loss and inflow-outflow, and empirical methods to calculate seepage loss. In this study, the overall conveyance efficiency is 40.29% and 31.59% in the right and left branches of the whole conveyance system, respectively, and on average 35.94%. Most of the canals are earthen; considerable water is lost due to seepage, except in the lined main canal, where there is minimum loss. Among the hydraulic parameters analyzed, water depth (WD) and wetted perimeter (Pw) emerge as the predominant factors. The comparison of empirical formulas with field observations (inflow-outflow) for the purpose of quantifying seepage loss within hydrologic factors yields significant insights regarding the precision and reliability of various estimation techniques. The results obtained from the inflow-outflow method emphasize the crucial relevance of in-situ measurements and real time data capture for more accurate evaluations, even though empirical formulas provide a quick and easily accessible route to estimation. The overall seepage loss was 25.7%, and for lined main canals it was 0.016%/100 m, and the unlined (earthen) result was 1.16%/100 m, and evaporation loss is quite low implies neglected,. Overall, optimizing canal designs to minimize wetted perimeter and controlling water depth has been crucial for reducing seepage loss and enhancing conveyance efficiency. Seepage loss is the prime factor in water loss in most of the earthen (unlined) canals.

Keywords: Conveyance efficiency, hydraulic parameter, hydrologic parameter, seepage loss, and Water scarcity.

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Water is the most important resource of the world, necessarily utilized by living things for survival and also has a lot of uses in different industrial processes (Khan, 2019). The water losses in canals has significant diverse effect on the efficient water supply to fields as it is a basic element of irrigation system so there is a need to be aware of water losses and take necessary precautions to overcome losses. Heavy water losses are detected in irrigation systems which are providing water to agriculture fields. Agricultural water consumes almost 70% of the total freshwater used worldwide, and this percentage can be higher in developing countries (DOUNGMANEE, 2016). Effective management of water in an irrigation system requires knowledge of the quantity of water flowing in the canal in order to send the right quantity of water to every user at the right time, avoid unnecessary losses, and avoid physical and environmental damages. Seepage out flow from canals affects the efficient operation of the canal system as this water leaves the canal, moving downhill and through the soil strata, and may no longer be directly available to the water users. Also, seepage affects the effective water management criteria because it sometimes produces erosion and piping damage at control structures (Molina, 2008).

The rising population increases the water and food demands, leading to further water stress. Hence, the scarcity or mismanagement of water resources poses a substantial and escalating threat to life and sustainable development (Rajput and Gautam, 2023). As we delve into the land of irrigated agriculture, numerous complex challenges arise. Especially, one of the prominent concerns revolves around the poor efficiency associated with the misuse of water resources in irrigation practices (Ahmadi et al., 2021). To address this issue and ensure the economic and environmental sustainability of irrigation projects, it becomes imperative for water users to enhance agricultural productivity. This requirement demands a comprehensive transformation in their institutional structures, water use management systems and policies, service delivery systems, and the implementation of proper farmland management strategies (Teklay and Ayana, 2014).

For a lot of nations, especially those that rely profoundly on agriculture, water is economically vital. The success of agriculture is largely dependent on its availability in the right quantities, qualities, and times, all of which improve food security, job creation, and poverty reduction (Eshetu and Alamirew, 2018). The success of irrigation system mainly depends upon the water delivery performance of irrigation canal, canals continue to be a primary method of water conveyance for agriculture. However, water losses during transportation are frequently very high (Ghazaw, 2011). Water escaping from canals causes problems like waterlogging, groundwater contamination, salinization, and health risks. Understanding canal water losses from an engineering standpoint is also crucial, since it can aid in evaluating the infrastructure's or hydraulic performance and pointing out flaws in construction and design that need to be fixed in succeeding requirements (Karad et al., 2013).

The water losses that transpire between farm offtakes and canal headworks are referred to as canal water losses. The primary elements that influence canal water losses include the canal lining materials, the cross-sectional profile and water level, the soil hydraulic characteristics and their spatial changes, the position of the ground-water table, and the quantity of silt inside the canal (Yao et al., 2012). Irrigation efficiencies may be viewed as having a matrix of meanings and values in response to the need for integrated water frameworks. The percentage of water applied to the field that is used for beneficial purposes is generally correlated with irrigation efficiency. When thinking about seasonal water use or allocation, these definitions are more relevant (Sadoff et al., 2020). The inflow–outflow method is applied to calculate channel seepage loss by measuring the discharge between the cross sections of the channel in upstream and downstream. The privilege of this method over the others is that, in this method, seepage loss can be measured under the normal conditions of the channel (Hosseinzadeh Asl et al., 2020a).

Evaporation, transpiration, and absorption are three additional significant water losses from canals that light in comparison to seepage and leakage. In hot, dry weather, these two forms of water loss can be substantial (Contor and Taylor, 2013). In heavily vegetated canals, transpiration losses are typically high in addition to high temperatures, winds, and low humidity. Similar to seepage, absorption is another relatively small loss in which water seeps into the canal bed and sides but does not spread to the nearby soils. The types and amounts of

water loss differ between and within canals, but their inconsistency and the major factors of influence are still not clear, especially at a global scale. Such understanding would be very important for water scientists, engineers and role players involved in allocating resources to operate and maintain water conveyance infrastructure (Ishani, 2014). The causes of ground water rise, seepage from canals and excessive irrigation water applications are two major factors that are connected to sub-parameter water management techniques (Kedir, 2015).

As one of the biggest irrigation systems in the region, the Wonji Shoa Sugar Factory (WSSF) in Ethiopia is essential to the region sugarcane production and sugar industry as a whole. In 1954 Wonji sugar factory was officially inaugurated and has been in operation for almost 70 years, during that time it has undergone several modifications. For the factories and sugarcane plantation, water is pumped from Awash River and distributed through gravity system and furrow irrigation is the predominant irrigation technique used at this area (Dametie et al., 2009).

Awash River is known for its best quality for irrigation at Wonji Shoa and the river does not have any salinity or toxicity problem for irrigation purposes and all water quality parameters are below the FAO, guidelines for water quality restriction limit (Taddese, 2019). Water from main pump station is distributed through canal networks among sections which are proportionally divided. During daytime, sugarcane fields are directly irrigated either from the source or from reservoirs. At night water is stored into reservoirs which are constructed throughout the scheme. Except main canal, all canals and reservoirs are not covered with lining materials.

The previous studies focus basically on hydraulic performance evaluation of the canal for estimating the canal conveyance systems. Thus, the present study aim to evaluate the hydraulic and hydrologic parameters that influence irrigation water conveyance systems. In order to better understand and emphasize the main aspects of control, this study examined canal geometry, flow velocity and mannings roughness coefficient with seepage and evaporation loss. This approach ensures that the systems can deliver water efficiently and sustainably, addressing the growing challenges of water scarcity and irrigation water demands.

1.2 Statements of the Problem

The current situation in the area was characterized by a complex water distribution system pertaining to or affecting the efficient utilization of irrigation water and the need to minimize water loss in the context of expanding irrigation systems. In the domain of irrigation systems, water scarcity and demand present critical challenges to irrigation system efficiency (Velasco-Muñoz et al., 2019). Water becoming increasingly scarce in the Awash basin, the Wonji Shoa irrigation schemes were charged with diverting excess water, engaging in inefficient water usage, and ineffective irrigation water management. To meet increasing demand and supply scarcity, it was being prominent to decrease water loss to make irrigation systems more and more efficient. A large amount of water diverted for irrigation purposes is being lost due to seepage, evaporation, and inefficient practices. This scenario not only impacts irrigation water distribution but also imposes an additional strain in the Awash basin, which has been further reduced by outdated canal infrastructure and inadequate drainage systems. With the increasing scarcity of water and the growing demand for this vital resource, water conservation is of paramount importance. The most optimal approach for irrigation systems involves using the minimum amount of water with minimum loss necessary to consistently or reliably meet the irrigation needs of the fields. However, the problem arises from the misallocation of water within the conveyance system, which disrupts the maintenance and operation of the canals. Pinpoint areas that require management intervention to improve the conveyance system and bridging the accelerated gap between the required irrigation water and the available pose a big challenge in the Wonji Shoa irrigation scheme. Moreover, the task of meeting the ever-increasing demand for food and agricultural production further makes the challenges faced worse. Therefore, in order to effectively address these issues, it becomes imperative to evaluate the performance of canal conveyance efficiency and determine the percentage of canal water loss that occurs during the conveyance process.

1.3 Objectives

1.3.1 General objective

The main objective of the study was to evaluate hydraulic performance of water conveyance system of Wonji Shoa irrigation scheme.

1.3.2 Specific objectives

- To identify the key hydraulic factors that impact conveyance efficiency.
- To investigate the hydrologic factors influencing water loss and conveyance efficiency.
- To evaluate the combined effect of hydraulic and hydrologic factors on the overall conveyance efficiency.
- To propose recommendations for improving conveyance efficiency based on the findings.

1.4 Research Questions

- How are hydraulic factors affecting conveyance efficiency?
- Which hydrologic factors influence water loss and efficiency of conveyance?
- Which cause of conveyance inefficiency (hydrologic or hydraulic) has seen dominant in the Wonji Shoa irrigation schemes?
- How to propose recommendations for improving conveyance efficiency.

1.1 Significance of the Study

Water losses in canals impact irrigation system efficiency, impacting agricultural productivity and food demand. Irrigation technology can improve household income and rural lifestyles. Evaluating hydraulic and hydrologic factors affecting water conveyance efficiency is crucial for financial savings, resource preservation, water management, and mitigating climate change effects. Improving water management techniques requires identifying and resolving primary hydraulic and hydrologic factors that affect effectiveness.

1.2 Scope of the Study

The study was concentrate on a particular irrigation system (surface irrigation method only), taking into account its separate structures and difficulties. From hydrologic parameter seepage and evaporation of the canal conveyance system being studied, and hydraulic parameters such as, canal geometry, roughness coefficient and flow rate over the entire irrigation system also analyzed to survey the significant loss in the conveyance system. In order to achieve the focused and significant investigation of the hydraulic and hydrologic parameters impacting conveyance efficiency, precisely define the scope and link it with the research goals. It was impossible to quantify the whole impact of a water scarcity, the region has to declare a strategic policy and develop a program for managing its water resources. The goal was to identify area of water loss in irrigation systems and their underlying causes in order to maximize the amount of water that is readily available and minimize the amount of water loss.

1.3 Limitations of Study

There was lack of specific measuring structure and tools availability or accessibility at the designated research site for the quantification of flow rate, seepage and evaporation losses. Due to these, seepage loss were assessed utilizing the principle of inflow-outflow discharge balance and indirect methods (empirical formulas) for more accuracy, becuae Inflow-outflow methods of seepage measurement could have some errors due to instrument restrictions or measurement staff. The canal's cross-section exhibits non-uniformity along its entire length, leading to inconsistencies in flow velocity across different segments. Leakage losses of the overall canal system and flow measurement at several offtake structures was not considered in this study due to malfunctioning of measurement facilities. In distributaries, historic water tables and water quality data were not available for a limited period. Due to the fact that unavailability of pan in the study area, the Penman-Monteith formula was utilized to assisting in the calculation of evaporation losses from the canal waterway, because it consider all weather parameter. In certain distributaries, historic water tables and water quality data were not available or available for a limited period.

1.4 Thesis Organization

The study was organized into five chapters. The first chapter was the introduction, which consists of the background, statement of the problems, objectives of the study, research questions, significance of the study, scope, and limitations of the study. Chapter two was literature review, review previous studies on hydraulic and hydrologic factors affecting performance of conveyance system. Chapter three incorporated, the materials and methods, the description of the study area, its climate characteristics, topography, and water availability were highlighted. Materials and data analysis, and the step-by-step methodologies applied to address the objectives of the study. Chapter four describes the results and discussions of the study that addresses the objectives of the research described in chapter one. Finally,chapter five provides a conclusion and recommendations, references,and appendix were provided.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Irrigation practices in Ethiopia

Irrigation is defined as the artificial application of water to crops for farming purposes in arid regions and as a means of reducing the impacts of drought in semi-arid regions. Irrigation is essential even in areas where the average yearly total of seasonal rainfall is not uniformly distributed and fluctuates annually. When conventional rain-fed farming is an extremely risky undertaking, irrigation can help guarantee consistent agricultural yield (Kedir, 2012).

According to Awulachew (2010), in Ethiopia's ambitious objective for irrigation development is 1.8 million hectares. Increasing the efficiency of existing installed irrigation and bridging the gap between irrigation project design and implementation are two of the challenges. Irrigation expansion is a crucial instrument to stimulate economic expansion and rural progress, and it is regarded as a foundation of food safety and alleviation of poverty in Ethiopia (Bekele et al., 2005; Mosisa and Adeba, 2023). Currently, the government has undertaken the development of several new irrigation projects to improve food coverage. But there is less focus on improving the performance of existing systems (Dejen et al., 2012).

2.2 Irrigation Efficiency

According to Mdemu et al. (2004), irrigation water may not always be used for evapotranspiration (ET); it may also be employed for other uses. Further beneficial uses of water include evaporative cooling during periods of intense heat or frost protection, salt removal (leaching requirement), seedbed preparation, germination of seeds, softening of a soil crust for seedling emergence, and ET from plants that are beneficial to the crop (windbreaks or cover crops for orchards). The definition of irrigation efficiency is the ratio of the volume of water that is beneficially used to the volume of irrigation water applied. Efficiency in irrigation systems can be broken down into various forms, including:

Conveyance efficiency; was how well water is transported from the source to the field, **Distribution efficiency;** was how evenly water is applied across the field, and

Application efficiency; was how much of the applied water effectively contributes to crop growth. High efficiency levels minimize water losses due to evaporation, runoff, or deep percolation, which can significantly enhance water use efficiency. For example, studies have shown that irrigation systems with high conveyance and distribution efficiencies can achieve overall irrigation efficiencies above 90%, leading to better water management and reduced costs for farmers (Parra et al., 2020). Since the primary purpose of most irrigation systems is to provide water for agricultural ET, irrigation efficiency (E_i) and water application efficiency (E_a) can be used interchangeably (Akkuzu et al., 2007).

2.3 Importance of Irrigated Agriculture

Rainfall in Ethiopia is distributed unevenly both in terms of time and space. The challenges with agricultural productivity are impaired by the country's unequal distribution of rainfall in terms of both space and time (Haile, 2015). Irrigation development is crucial for Ethiopia's economic expansion and consistent agricultural growth. Construction of small, medium, and large-scale irrigation infrastructure is necessary for food security and generating excess for export, bringing foreign exchange and providing local companies with necessary raw resources (Makombe et al., 2011).

2.4 Irrigation System Management

Water is a limited resource in many countries where agriculture plays a major role in ensuring food security, fostering economic growth, and reducing poverty. Globally, agriculture accounts for 70–90% of water use (Dhaval et al., 2015). Irrigation plays a major role in food security, so most agricultural water consumption is for irrigation. Despite the fact that only 20% of agricultural land is irrigated globally, irrigation produces about 39% of the world's food supply (Morison et al., 2008).

According to Velasco-Muñoz et al. (2019), one of the largest difficulties to agricultural water management in the twenty-first century is increasing agricultural productivity. While there is a limited supply of water to meet the growing demand for food. Providing irrigation services entails collective actions, which are the results of effective communication and coordination among users and service providers.

According to Hailelassie et al. (2016), tertiary-level management is commonly carried out by irrigation water users' associations (IWUAs). However, such organizations are not well established and lack technical and financial capacities to properly discharge their duties of irrigation management. The performance of different irrigation schemes in Ethiopia and observed that the performance of the existing irrigation schemes are low due to poor operation and maintenance services, problems related to improper planning and design, and lack of incentive for proper management of water in state-run projects (Awulachew and Ayana, 2011).

According to Gupta et al. (2022), efficient operation and management in irrigation scheme plays an important role in the sustainability of irrigated agriculture. However, traditional irrigation management problems include water distribution systems with less capacity than the peak demand, irregular delivery rates, and low irrigation efficiency and uniformity, absence of frequent maintenance are the main constraints to achieve high performance. The major reason for the low performance of irrigation systems is an inaccurate water distribution due to the lack of a good monitoring system for water delivery. Therefore, it is necessary to reduce water conveyance losses, increase the water application efficiency and prepare water distribution plans (Korkmaz et al., 2009).

According to Hamdy (2007), the performance of irrigated system is unsatisfactory due to underutilization of irrigation services and poor system management. The gap between the government and the beneficiaries is often too distant to enable efficient and responsive management and inadequate maintenance of infrastructure. Some corrective measures to improve the low performance are efficient water management, all activities in the irrigation network should be monitored and checked, technical requirements should be met, training and extension should be enhanced, evaluations should be performed on a daily and seasonal basis and the results should be delivered to the relevant individual and institutions with an efficient monitoring and evaluation system (Gomo, 2012).

2.5 Conveyance Efficiency

Conveyance efficiency refers to the ability of a hydraulic system, such as channels or canals, pipelines, to transport water from one point to another with minimal losses. It is a crucial

aspect of water resource management, as inefficient conveyance can result in water shortages, increased energy consumption, infrastructure damage, and environmental impacts (El-Molla, 2021). Water losses during conveyance were assumed to account for 20–70% of global canal flows (Lund et al., 2021).

According to Tefera (2013), the designed conveyance efficiency of 95% was not achieved in either scheme, with fentale having 34.4% and tibila 89%. Hydraulic factors like changes in roughness coefficient and hydraulic radius were identified as causes, as well as hydrologic factors like variation in hydraulic radius leading to increased water depth, seepage and evaporation.

Additionally, Mohammed and Tefera (2017), investigated the impact of using reference conveyance parameters on the real-time performance of the canal. They found that variations in hydraulic parameters, particularly manning's roughness coefficient and canal slope, were the major contributors to decreased efficiency. This highlighted the need for site-specific evaluations and adaptations in designing and managing irrigation systems.

According to Mohammadi et al. (2019), the study highlighted the importance of considering both hydraulic and hydrologic factors for optimizing channel design and management practices. They found that vegetation growth and evaporation significantly reduced efficiency, while proper channel management could mitigate these losses. This pivotal metric, often overlooked, establishes the foundation for the overall efficiency of the irrigation system primarily hinges on factors such as the length of the canals, the type of soil, the permeability of the canal banks, and the condition of the canals. In the context of large-scale irrigation projects, the amount of water lost tends to exceed that of smaller schemes due to the presence of an elongated canal system. When water is transported via pipes, the main determinant is pipe leakage, which is typically close to 100% for newly implemented systems.

According to Alemneh et al. (2019), the study emphasized the importance of incorporating climate change considerations into water management plans and designing resilient irrigation infrastructure. Typically, the transportation of irrigation water from a water source to a farm or field is facilitated through pipelines, earthen or lined canals, or natural drainage systems. Owing to transmission losses within many conveyance systems, the quantity of water delivered to the farm or field is typically less than the amount of water diverted from the

source. The water losses within the conveyance system are primarily attributed to pipeline leaks, seepage, spills, and evaporation from canals (Irmak et al., 2011; Irmak et al., 2016). Atmospheric parameters such as precipitation, temperature, humidity, and wind speed can affect the hydrological cycle, including the amount of water that is available for irrigation and the rate of evaporation from the canals (Zhao et al., 2020).

2.5.1 Factors Affecting Conveyance Efficiency

In the face of growing water scarcity, optimizing water delivery systems in agriculture becomes ever more crucial. One key measure in this regard is conveyance efficiency, which measures the percentage of diverted water reaching its intended destination with minimum loss (Mutema, 2022). Hydraulic factors like increased roughness coefficient and irregular geometry reduce conveyance efficiency, while hydrologic factors like seepage and evaporation losses reduce the amount of water actually delivered. Proper maintenance, lining, and management are needed to optimize canal conveyance efficiency. Both hydraulic and hydrologic influence efficiency, impacting crop yields, water management, economy and the sustainability of agricultural practices (Owino et al., 2023).

▪ Hydraulic Factors

Hydraulic factors play a crucial role in determining the efficiency of water conveyance systems, impacting how much water reaches its intended destination with minimal loss. The key hydraulic factors and their influence:

Canal geometry: the importance of channel dimensions (width, depth, slope), cross-section shape (rectangular, trapezoidal), and overall design significantly impact flow velocity and water losses. Optimal design minimizes friction and maximizes flow efficiency, leading to higher conveyance efficiency. Rectangular and trapezoidal sections generally offer higher efficiency compared to circular sections due to reduced wet perimeter and increased flow velocity (Chakraborty et al., 2017).

Roughness coefficient: The influence of surface roughness on efficiency is well documented. Demonstrated how vegetation, sediment buildup, and channel deterioration increase roughness, reducing efficiency. advocate for regular maintenance and channel lining techniques like concrete or plastic to minimize this impact and improve efficiency (Sajid et al.,

2022). According to Mohammed (2017), manning's roughness coefficient displayed higher observed values in comparison to the designed values, ranging from 0.026 to 0.073 as opposed to 0.017 to 0.03 during the design phase. Deviations from the design values have a direct impact on conveyance efficiency. The anticipated conveyance efficiency for the primary canal of the Fentale irrigation scheme was 77%, whereas the operational efficiency stood at 17% due to differences in hydraulic parameters such as manning's roughness coefficient and canal slope.

Hydraulic radius: Maximizing the hydraulic radius, the ratio of flow area to wet perimeter is crucial. Point out that larger hydraulic radii lead to higher flow velocities and efficiency (Aliza, 2018).

Hydraulic structures: Poorly designed or operated structures like gates, siphons, and pumps can significantly impact efficiency. Highlights how these structures can lead to energy losses and flow disruptions, reducing efficiency (Sajid et al., 2022).

▪ **Hydrologic Factors**

Several climatic elements, such as temperature, humidity, wind speed, and precipitation, have an impact on the hydrological cycle, which determines how much water is available for irrigation and how quickly water evaporates from the canals. By establishing a connection between meteorological data and the hydraulic efficiency of lined canals, managers may also identify the particular circumstances that are most likely to result in decreased efficiency and develop tailored management strategies to address these issues (Bekele et al., 2010).

Water availability: The seasonal changes in flow or operating requirements can cause sedimentation, erosion, and operational issues that ultimately impact efficiency. Surge tanks and other storage facilities are examples of structures that may regulate flow and help mitigate these effects (Alemneh et al., 2019).

Seepage loss: Seepage loss is one of the major components of water loss from canals. Seepage is affected by various factors such as water depth, canal lining quality, canal dimensions, bed slope, sediment volume, age of canal, flow volume, flow velocity and quality of implementation and operation of canals (Mohammadi et al., 2019).

Table 2.1 Empirical formulas for estimating seepage loss (Gad et al., 2023)

S. No	Empirical Formulas	Equation	Description
1	Nazeer Ahmed((Mowafy, 2011).	$S = \frac{0.04 \times Q^{0.68}}{56.81}$	S is the seepage over 1 km (m ³ /s), Q is discharge in m ³ /s
2	Davis- Wilson((Akkuzu, 2012a).	$S = 0.45 \times C \times d^{\frac{1}{3}} \frac{(P \times L)}{4 \times 10^6 + 3650 \times \sqrt{v}}$	S is seepage from the channel along the channel length (m ³ /s), C is numerical coefficient is 3.5, v is velocity flow in the canal in m/s, d is water depth in m
3	Moritz A((Shah et al., 2020).	$S = 0.2 \times C \times \left(\frac{Q}{V}\right)^{0.50}$	S is the seepage rate over 1 km (m ³ /s), Q is discharge in m ³ /s, V is velocity in m/s, C is depend on soil material, 0.34 and 2.2 clay and sand respectively (Leigh, 2014).
4	Pakistani((Ahmad, 2019).	$S = \frac{(5 \times Q^{0.0652} \times P \times L)}{10^6}$	S is seepage loss in m ³ /s, Q is discharges, m ³ /s, p is wetted perimeter in m, L is length in m
5	Molesworth and Yennidunia (Hosseinzadeh Asl et al., 2020b).	$S = C \times L \times P \times \sqrt{R}$	S is seepage loss (m ³ /s); R is hydraulic radius (m); L is length in km, C is coefficient (0.0015 and 0.003 for clay and Sand soils, respectively) depends on hydraulic parameters,

Canal seepage primarily depends upon the soil permeability, water depth in the canal, length of wetted perimeter, location of groundwater table, velocity of the flowing water, shear stress (force of moving water on bed), slope between surface of water in canal and beneath groundwater surface of an aquifer, constraints on groundwater flow e.g., drains, rivers and streams (Birara and Halefom, 2017). More than 0.55% per 100m length of usable water is get lost in lined canal and 0.84% per 100m length water is loss in unlined canal on average in irrigation canals of Tendaho Sugar Factory, Ethiopia (Eshetu and Alamirew, 2018). According to Ahmad (2016), the results predict average 13.38% water losses with respect to the total discharge of the canal which has an average amount of 196 cumecs. According to (Kulkarni and Nagarajan, 2018), the results of computed seepage loss by empirical formulae, Davis and Wilson Formula predicts least seepage loss and Moritz, Molesworth formula predicts most seepage loss. According to Abuzeid (2021), the results obtained using the Molesworth formula

were most consistent with the measured seeping quantities of water using the field ponding method. The measured seeping quantities from the Al Maanna canal were around 1.563 million m³/month, while the calculated quantities using the Moleth–Worth equation were 1.617 million m³/month.

Seepage loss causes depletion in freshwater resources, water logging, salinization, and ground water contamination (Ishani, 2014). Seepage loss from earthen irrigation channels depend on a number of factors and vary from (30 to 50) percent of the discharge available at the head of an irrigation system (Arshad et al., 2009).

Evaporation loss: It is the transfer of the water from the liquid to vapor stage. As the canal water is exposed to the atmosphere at the surface, loss due to evaporation is obvious. The evaporation losses are very small as compared to the seepage loss. It is of course true that in most of the cases evaporation loss is not significant (Akkuzu, 2012).

According to Ahmad (2016), the average contribution of evaporation losses is 1.22% of total losses in canal. It is range from 0.25 to 1 % of the total canal discharge (McJannet et al., 2008; Liu et al., 2016). The evaporation from canals was estimated by using a simple empirical relationship between evaporation rate and water surface area (Wang et al., 1989). Among the hydrological cycle, evaporation is perhaps the most difficult to estimate due to complex interactions among the components of land-plant-atmosphere system.

The most common and important factors affecting evaporation are solar radiation, temperature, relative humidity, vapour pressure deficit, atmospheric pressure, and wind. Evaporation losses should be considered in the design of various water resources and irrigation systems (Shu et al., 2011). It was along the canal remain unquantified, they are expected to exceed the designed values. Other influencing factors include the size of the irrigation area, rotation schedule, types of crops cultivated, and management practices (Mohammed, 2017).

2.6 Crop Water Requirements and Effective Rainfall

I. Crop water requirements

Crop water requirement means the total quantity and the way in which a crop requires water from the time it is sown to the time it is harvested (Pereira et al., 2021). Different crops will have different water requirement and some crop may have different water requirement for different soil condition; depending upon the climate, type of soil, method of cultivation and useful rainfall etc. Frequency and depth of irrigation is very dependent on the water holding capacity of the soil and the root depth. The effects of weather conditions are captured in the ETo estimate. Therefore, as ETo represents a factor of climatic demand, crop coefficient (Kc) varies mainly with the specific crop characteristics (Abuzeid and Sabery, 2021).

According to Dejen et al. (2015), assesses irrigation water demand and actual supply of Metahara large-scale scheme. The existing operational rule in the scheme is not adequate and actual irrigation water supply is poorly matched with crop water demand, then average annual irrigation supply is in excess of demand. An attempt has been made to compute the crop water requirements using CROPWAT 8.0 model of FAO and comparing the same with the available water resources of the district. The utilizable water resources of the district are less than requirement i.e. the available water resources cannot achieve crop water demand, this create a deficit scenario. This deficit indicates that, the total area brought under irrigation would be deficit years, therefore during such period deficit irrigation or reduction in command area may have to be adopted (Sun and Yong, 2019).

II. Effective rainfall

Rainfall may be separated into components: runoff, infiltration, interception, and evapotranspiration (ET). The effective rainfall is useful directly and/or indirectly for crop production at the site where it falls. A method for estimating effective rainfall should therefore account for crop characteristics, crop ET, water storage change in the crop root zone, and surface storage capacity (Mubarak, 2017).

2.7 Irrigation System Performance

The performance of a system can be defined as its efficiency, understood as the relation between actual results (inputs) versus the expected results (outputs) of the system. In the case of this study, the expected result of the system was the improvement of canal system and pinpoint the area need through water conveyance system. The purpose of performance

assessments is to achieve an efficient and effective use of resources by providing relevant feedback to the scheme management at all levels (Legesse and Tadesse, 2021).

According to Tebebal and Ayana (2015), make an assessment of hydraulic performance evaluation of hare community managed irrigation scheme. They found that water delivery performance, water utility and maintenance activities of the system were found to be poor. After reviewing significant work, researches suggest that capacity building of farmers, adequate operation and maintenances of the system, improving diversion capacity of the scheme is required to improve the existing low system performance.

According to Molden and Gates (1990), there exist three categories of performance measures: process measures, output measures and impact measures. The first category refers to the system's internal operations, such as policies, organizational and communicative processes. The second one, output measures, is used to evaluate irrigation services delivered to farmers, of essential importance given its impact on agricultural production and therefore on farmers' revenue (system's final output). Last category brings up the evaluation of the effects of system's outputs in a larger scale, in the social, economic and environmental dimensions. Nevertheless, the concept of 'Irrigation system performance' is in continuous evolution.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of Study Area

The study was conducted at Wonji Shoa Sugar Factory located in the Oromia Region State, Ethiopia. It is approximately 110 km away from Addis Ababa, the capital city of Ethiopia. Additionally, it is located 12 km downstream of the Koka dam, which manages the flow of the Awash river, and 10 km to the southwest of Adama town. Wonji Shoa Sugar Factory (WSSF) was established in, 1954 by the dutch company known as Handles Vereniging Amsterdam (HVA), stands as the initial large-scale irrigation scheme in Ethiopia (Bekele, 2007). At Wonji Shoa, 5800 ha of land are irrigated by the main pumping station near the WSSF headquarter at Wonji.

3.1.1 Location and topography of the study area

The Wonji Shoa Sugar Factory is situated at Latitude 8°22' to 8°27'N and at Longitude 39°12' to 39°17'E, at an altitude of 1540 m. It is characterized by very gentle and regular topography that makes it most suitable for irrigation. The water source for irrigation is lifted from the awash river, by pump to the main canal and delivered, by gravity to the field which has been a carrying capacity of 5160 l/s (Wakjira, 2023). The main irrigated land lies south west of Awash river. It has very flat slopes ranging from 0.05% to 0.1% on south and south east direction, with flood deposited (Kedir, 2015). The surrounding topography is steep on all sides toward the plantation area (Berhanu,1996).

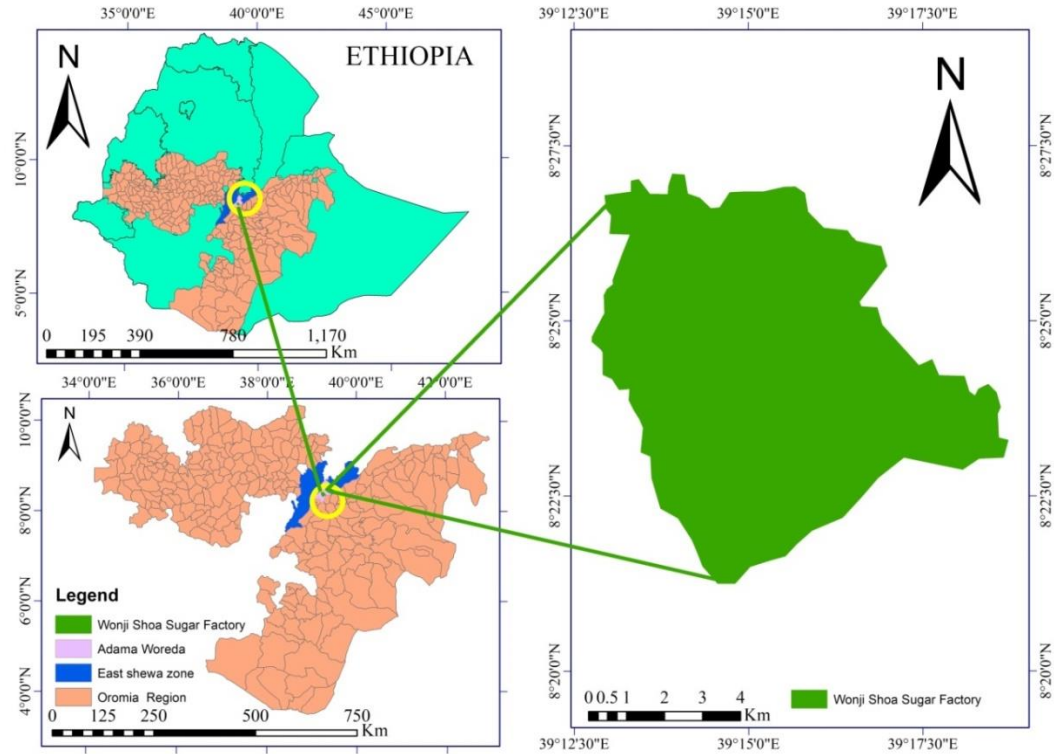


Figure 3.1 Location map of the study area

3.1.2 Climate of study area

The Wonji Shoa Suagar Factory experiences a semi-arid climate characterized by a bimodal rainfall pattern. The main rainy season stretches from June to September, while a smaller one occurs from March to April. Despite receiving an average annual rainfall of 830 mm, the erratic nature necessitates extensive irrigation for sustainable sugarcane cultivation. Temperatures are generally warm, with an average maximum of 28.6°C and a minimum of 15.8°C. This warm climate, coupled with the extended rainy season, provides ideal conditions for sugarcane growth (Yadeta et al., 2021).

3.1.3 Soil of Wonji Shoa irrigation scheme

Soil types across the factory vary, ranging from sandy loam to heavy clay, with vertisols (black clay soil) being the dominant type, which present inherent challenges. Vertisols are fertile but prone to cracking during dry periods, demanding careful irrigation and land management practices (Dinka and Ndambuki, 2014). Salinization and erosion pose potential

threats due to the semi-arid climate and intensive agricultural practices. Soils of the whole canals system is categorized as vertic nature clay soils or fine textured constructed.

3.1.4 Irrigation infrastructure

Irrigation water is conveyed starting from the main pump station to the entire cane field using different kind and types of irrigation infrastructures(i.e., pump,canals, offtakes). The main components of the irrigation infrastructure developed within the factory are the followings.

I. Water resource and abstraction

The primary water source for the entire command area of the project is derived from the Awash river. Regulation of the flow of the Awash river is managed through the koka power dam, with the volume of flow predominantly influenced by the electrical power needs. The process involves pumping irrigation water from the Awash river at the project's headwork, allowing it to flow by gravity through a 480 m lined main canal passed through a silting basin. The diversion of water for irrigation purposes from the awash river is facilitated by power-driven pumps, which then discharge it into the main canal for subsequent distribution by gravity into secondary left and right branches and ultimately, into night storage reservoirs. Field irrigation is implemented through furrows, and the methodology employed to calculate irrigation needs is based on field observed data.

II. Pumps

The main pump station, located at Wonji, contains eight centrifugal pumps designed to serve around 5800 ha of the area including both factories and nearby farmers' fields. The station is constructed to facilitate the discharge of an aggregate discharge of 5.16 m³/s of water through the utilization of eight electric pumps. Six vertical shaft pumps have design capacity of 730 l/s each while two horizontal shaft pumps have capacity of 390 l/s each. The capacities of pumps at main station are not constant and mainly depend on; level of awash river and condition of pumps. The river flow is regulated based on electric supply from Koka station.



Figure 3.2 Main pump station of Wonji Shoa Sugar Factory

The pumps that are used to lift irrigation water from awash river is installed 70 years ago with a total design discharge capacity of 5160 l/s for both vertical and horizontal shaft pumps. During this research period, the main pump station's present discharge capacity of 3650 l/s is being utilized.

III. Settling basin

A settling basin, also known as a sedimentation basin, is used in water and wastewater treatment to remove suspended particles from water. The main function of a settling basin is to allow heavier particles, such as sand, silt, and other sediments, to settle to the bottom due to gravity, separating them from the water. There are two well designed settling basin in Wonji-Shoa irrigation scheme which were designated as, silt basin A and silt basin B. Silt basin A is the one located next to the main road or at the right side viewed in the direction of water flow.

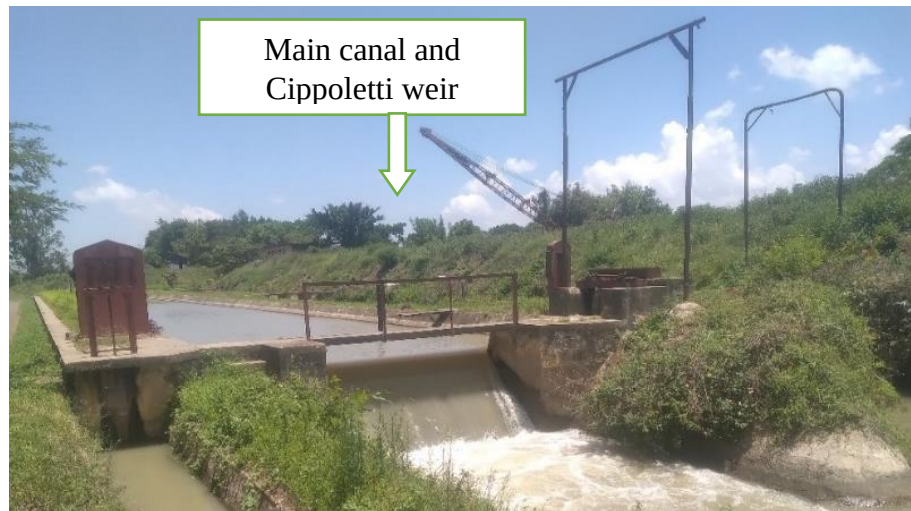


Figure 3.3 Discharge measuring cippoletti weir and water gauge staff

Water from pump station were proportionally divided into the basins later after leaving the basins to join into the main supply canal shown (Figure 3.3). Water from five pumps passes through silt basin A. While water from three pumps was passes through silt basin B. Both basins are served by separately operated metal sluice gates to remove the deposited silt and after weir join together.

3.2 Materials and Software Used

Materials and softwares used during this study, smartphone camera: to take photos of the the over view of structure, stopwatch: to know the time taken by a floating object (double plastic cup) to reach the second marked point, floating object: this is used to determine the flow water velocity in the canals, levelling instrument: to estimate longitudinal slopes, reading staff (levelling staff): used to measure the water depth and tape meter to measure width and length of canal structures, Wonji Shoa irrigation scheme document was used to collect required data relating to design canal capacity and dimension, Arc GIS10.3: was used to a delineate location map of the study area, and CROPWAT 8.0 had been used to estimate crop water requirement and by inputting weather data. and excel software: used to estimate of mathematical calculations, Minitab software: for statistical analysis (regression and correlation).

3.3 Data Collection and Preparation

The field work was conducted and the data collections were started in march, 2024. Data was collected from the two sources, which are primary and secondary sources. The field observation was used to measure the hydraulic parameters and formulas used like; the manning's equation, float-area method, and hydrologic parameters i.e the seepage loss and evaporation losses from the canal was assessed.

3.3.1 Primary data collection

The primary data were collected through field measurements and observations. described as follows: Measurement of the actual dimensions of the canal conveyance system, interview of technical experts and assistances, frequent field observation, field measurement related to hydraulic (canal dimension) and hydrologic (water availability, evaporation and seepage) parameters and using float-area method (continuity equation), amount of irrigation water that was discharged using main pump station, amount of water that was conveyed through the selected main, secondary, and tertiary canals were assessed.

A. Discharge measurement method

The methodology of distance traveling to time was utilized to measure the flow velocity of water in the primary canal and its distribution in the secondary and tertiary sections. Subsequently, the discharge was determined by applying the float-area(continuity equation) method. The double plastic cup was used as the floating object, starting from the upper limit of the canal segment and timing its passing to a set point within the same canal. The purpose of this floating object is to establish the flow velocity of water in the canal. The experiment was repeated three times to calculate the average time needed to compute discharges. Moreover, the cross-sectional area of the canal was determined through the examination of the average water depth using a reading staff and the canal width using a tape measurement at multiple points. The passage of double plastic cup through each segment was monitored using a stopwatch.

$$A = \left(\frac{B+Tw}{2} \right) \times D \quad (3.1)$$

Where, A is the area of the wetted canal (m^2), B is the bottom wetted width of the canal (m), Tw is the top wetted width of the canal (m), and D is the depth of water in the canal (m). The surface flow velocity, V_s (m/s) was calculated as:

$$V_s = \frac{L}{T} \quad (3.2)$$

Where, L is the length of the canal, but it must be straight and laminar flow and T is the time taken for the floating material to reach the end section. Since the measurement was taken at the surface due to the external factors that affect the floating object like wind and back flow (wave action), Because surface velocities are typically higher than mean or average velocities is the product of surface velocity and correction factor(k) was taken for safety factors, ranges from 0.6 for rough beds to 0.8 for smooth beds (0.77 is a commonly used value) and finally, the flow rate in (m^3/s) canals was calculated by using Equation 3.3 (Belay, 2020).

$$Q = 0.77 \times V \times A \quad (3.3)$$



Figure 3.4 Main canal dimension and discharge measurement by float-area methods

The water surface depth in the canals bottom was determined through the use of a reading staff and distance using tape meter at average 30 m intervals. The first assessment was conducted at the main pump station, involving 8 (eight) measuring stations which were further divided into two segments. The total length of the main canal for this assessment was 480 m. Subsequently,

the next round of measurements for water surface elevation data was carried out at 42 measuring stations, divided into three segments at interval of 30 m, along the left branch secondary canal covering 3750 m.

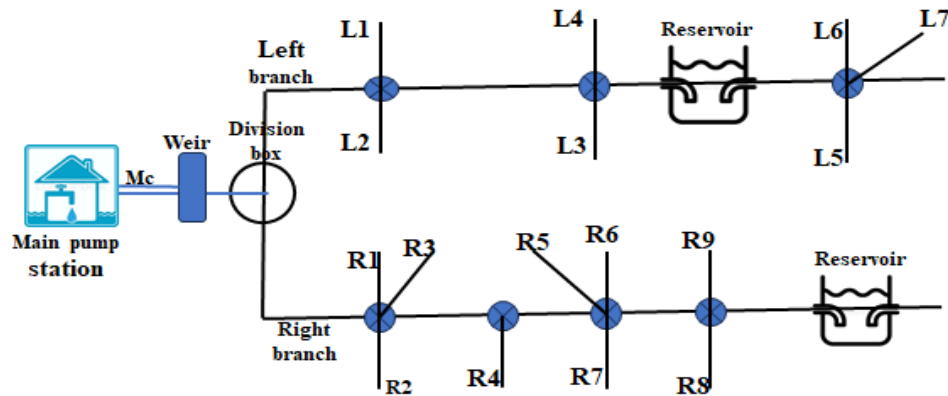


Figure 3.5 Layout of Wonji Shoa Irrigation Scheme main system and offtakes

The right branch canal was assessed at 25 measuring stations, also divided into three segments, covering a length of 2200 m with 30 m intervals. Generally, discharge data were collected from 8, 42, and 25 review stations situated along the main, left and right secondary canals respectively.



Figure 3.6 Discharge and secondary canal dimension measurement

3.3.2 Secondary data collection

Secondary data that used for this research was collected as much as possible from responsible bodies and officials.

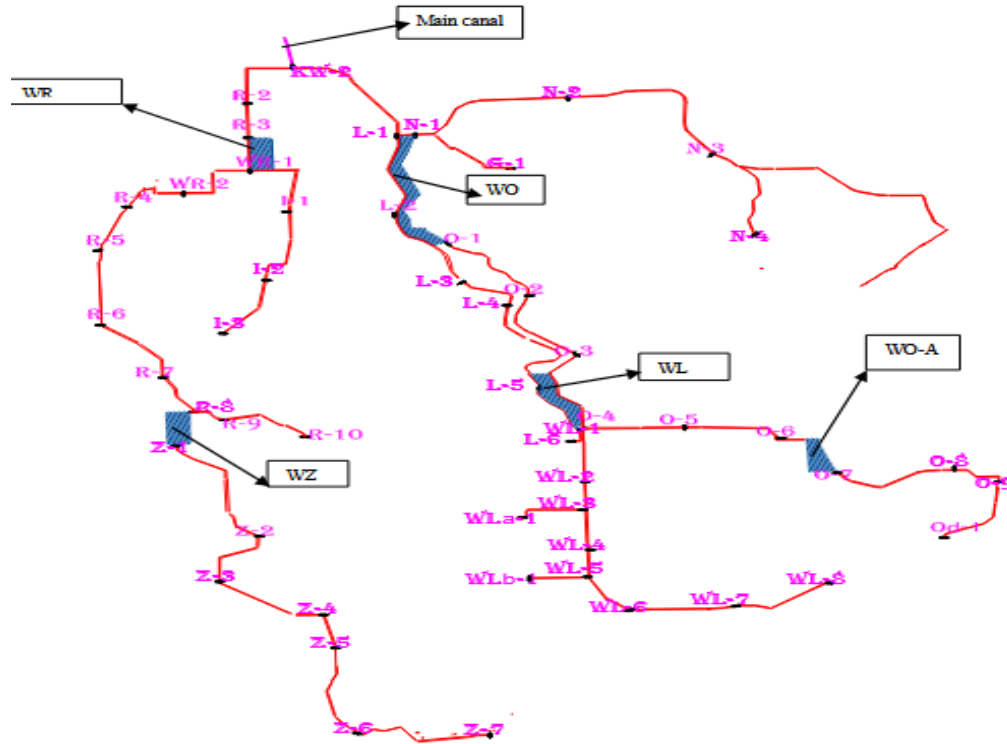


Figure 3.7 Layout of secondary canal and reservoir location

Source: (Kedir, 2015; Ratha and Samantara, 2018).

▪ Meteorological and hydrological data

Meteorological data was an important input for estimating cropwater requirement, the irrigation water demand and evaporation calculated with empirical method using Penman-Monteith approach. By taking 12 years, monthly meteorological data (2010-2021GC) was collected from the Ethiopian National Meteorological Agency (ENMA).

Table 3.1 Mean monthly values of meteorological data from (2010–2021).

Months	Min Temp (°C)	Max temp (°C)	Humidity (%)	Wind speed (km/day)	Sunshine (hour)	Precipitation (mm)
Jan	13.6	27.3	39.4	2.4	9.4	5.16
Feb	15.3	29.3	39.8	2.5	9.4	16.95
Mar	16.7	30.6	39.6	2.3	9.4	44.10
Apr	17.1	30.8	40.9	2.0	9.4	52.15
May	17.2	30.6	43.3	1.7	9.4	71.88
Jun	17.9	30.3	45.7	2.3	7.8	69.16
Jul	16.4	27.3	60.2	2.4	6.5	292.39
Aug	16.6	26.7	62.2	2.0	6.4	194.96
Sep	15.9	27.7	55.6	1.3	7.1	146.06
Oct	15.0	28.3	40.1	1.9	9.2	18.15
Nov	14.7	27.6	42.5	2.2	9.0	25.45
Dec	13.3	26.4	41.7	2.4	9.6	3.74
Average	15.8	28.6	45.9	2.1	8.5	78.35

The collected data includes monthly maximum and minimum temperature ,monthly windspeed, monthly humidity, monthly precipitation and monthly sunshine hour. The missing data value filled with arthimatic mean methods, since the percentage of missing data was less than 10%, which is accebtale (Chow et al., 1988).

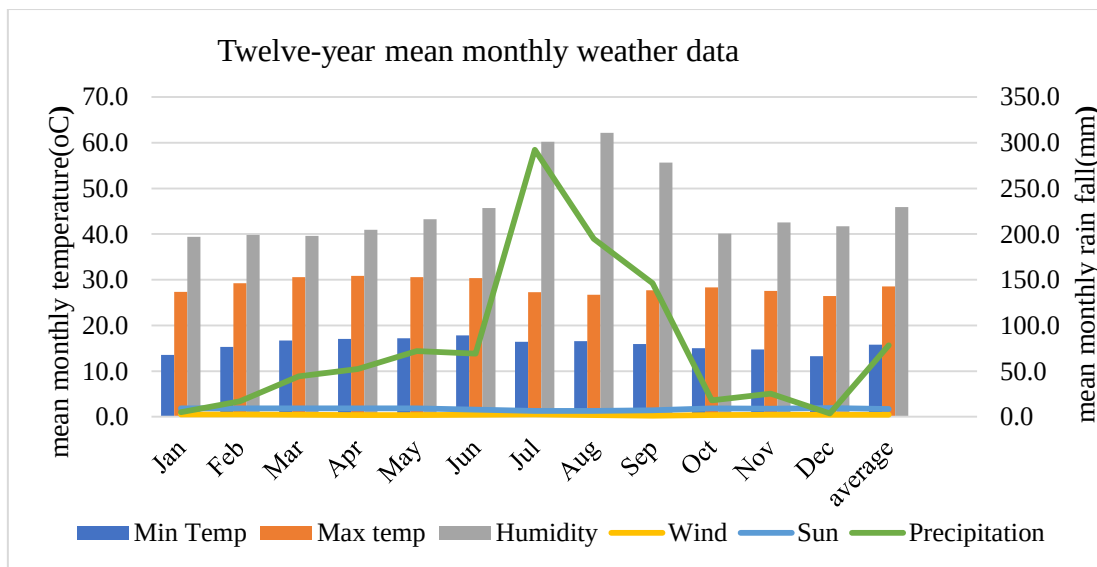


Figure 3.8 Mean monthly values of meteorological data (2010–2021).

3.4 Hydraulic and Hydrologic Factors on Conveyance Efficiency

3.4.1 Canal conveyance efficiency

Water is transported through the canal network, watercourses and channels from the sources such as reservoirs, canal to the field for the crop use. For the determination of conveyance efficiency in the main, secondary and tertiary canal velocity area method was used to compute discharge. Conveyance efficiency is assessed by measuring the inflow and outflow of selected canal reaches (Legesse and Tadesse, 2021).

$$\text{Conveyance efficiency: } CE = \left(\frac{Q_{out}}{Q_{in}} \right) \times 100 \quad (3.4)$$

Where; CE is the conveyance efficiency expressed as a percentage (%), Q_{in} is the total water flowing into a specific section of the canal (m^3/s), and Q_{out} is the total water flowing out of a specific section of the canal (m^3/s), and the conveyance efficiency of the scheme as whole was calculated by (Bos, 1997;Abdi,1995).

$$CE \% = E_m \times E_s \times E_t \quad (3.5)$$

where, E_m is the conveyance efficiency of main canal (%), E_s is the conveyance efficiency of secondary canal (%), E_t is the conveyance efficiency of tertiary canal (%).

3.4.2 Canal conveyance losses

The loss of water from the canal due to seepage and evaporation is a substantial part of the usable water. Losses of irrigation water occur during convey of water from the head of the canal to the tail reach among different chain age of the canal. In open canals, such losses take place primarily due to evaporation and seepage. About 10 to 15% of the water admitted in to a canal can get lost in this way (Mazumder, 2019). It measures the efficiency of the canal system to convey water and shows the water loss over a given travel distance. A water conveyance loss ratio can be calculated for each section of the main, secondary, and tertiary canals using Equation 3.6 (Ucar et al., 2010).

$$\text{Conveyance loss \%: } CL = \frac{Q_{in} - Q_{out}}{Q_{in}} \times 100 \quad (3.6)$$

Where, CL is the water conveyance loss expressed as a percentage (%), and Q_{in} and Q_{out} is the total water flowing into and out of a specific section of the canal (m^3/s) respectively.

3.5 Hydraulic Factors on Conveyance Efficiency

Hydraulic parameters

Focuses on the movement of water through the canal system. Hydraulic concerns primarily deal with the physical properties of the water flow inside the conveyance system. In open channel hydraulics, Manning's equation is frequently used to calculate a flow rate of canals. The effectiveness of a canal in carrying flow is represented by the conveyance efficiency, also referred to as the conveyance factor. The flow in the open channels is determined by Manning's formula (Ye et al., 2018).

$$Q = \frac{1}{n} \times A \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \quad (3.7)$$

Where, flow rate (Q) is the volume of water passing through a canal cross-section per unit time (m^3/s). cross sectional area(A) in m^2 : hydraulic radius (R) in m , is the ratio of cross sectional area to wetted perimeter in m : hydraulic gradient or bed slope (S): The slope of the water surface along the canal (m/m). Manning's roughness coefficient (n): factor representing the resistance of the canal walls to flow (dimensionless).

3.6 Hydrologic Factors on Conveyance Efficiency

Hydrologic parameters

Hydrologic parameters focuses on the interaction between the canal system and the surrounding. The key parameters (water availability and seepage and evaporation) primarily address how water functions in its natural environment and interacts with the conveyance system (Quan et al., 2022).

❖ **Methods of seepage loss measurement**

A. Direct measurement of seepage loss (Inflow-outflow Method)

The inflow-outflow method was a water balance approach that consists in the direct measurement of the flow rate flowing into and out of a reach of the canal (Rosenberry and

Menheer, 2006). Inflow-outflow technique gives the loss occurring throughout water passage in the open canals without hindering or obstructing the regular irrigation process of the certain canal, at the similar time allow precise calculations. Seepage loss from an irrigation canal were usually measured by inflow -outflow method (Karataş and Akkuzu, 2007).

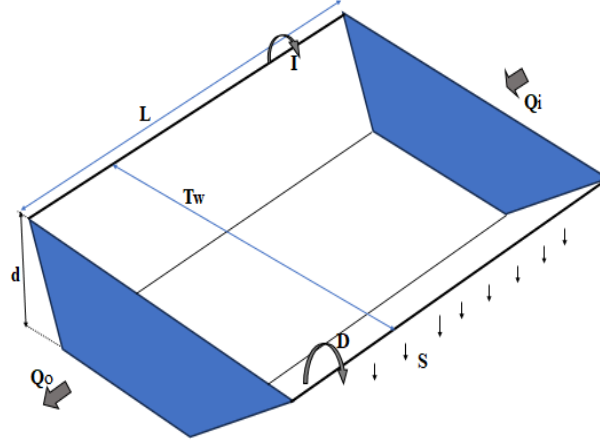


Figure 3.9 Mass balance for the inflow-outflow method

$$Sl = Qi - Qo - D + I \quad (3.8)$$

Where, Sl is seepage loss through the segment (l/s); Q_i is inflow to the segment (l/s); Q_o is outflow from the segment (l/s); D is water delivered from the segment (l/s); and I is inflow to the segment from other sources (l/s). During the measurement of inflow-outflow; normal operating condition of the canal, no change in water level during measurement, no water flow either from outside into the segment or from the segment to the outside (i.e., $D=0$ and $I=0$), nothing to prevent the flow, and sufficient length of segment for measurement of conveyance loss were critically considered. using this method, it is necessary assume steady flow conditions and take long canal reaches to obtain a measurable loss (Molina, 2008; Kilic and Tuylu, 2011).

$$\text{Seepage loss rate in \% /length (m): } Sl = 100 \times \frac{Q_{in}-Q_{out}}{Q_{in} \times L} \quad (3.9)$$

$$Sl = \frac{Q_{in}-Q_{out}}{WP_{avg} \times L} \quad (3.10)$$

Where, Sl is seepage loss in $m^3/s/m^2$; Q_{in} is inflow rate (m^3/s); Q_{out} is outflow rate (m^3/s); L is canal length (m); and, WP_{avg} is average wetted perimeter (m).

B. Indirect measurement of seepage loss or Using empirical equation

Empirical formulas were adapted where straight dimensions of canals were not reachable or useful (Ahmad, 2019). As represented in Table 2.1 in literature review the seepage was calculated by using Davis and Wilson formula, Molesworth and yennidunia empirical, Pakistani formula, Nazir ahmad formula and Mortiz formula, which were compared with field observation results. These formulas were established on affiliations (relationships) observed between water losses and the hydraulic situations (Mohamed and Waleed, 2023).

Crop water requirement and irrigation water requirement

The irrigation requirements for crops in the chosen minor's command were determined utilizing CROPWAT 8.0 windows model (Julaia, 2009). Thus, the meteorological data from the preceding Table 3.4 were entered into the CROPWAT 8.0 model, and the program calculates reference evapotranspiration using the Penman-Monteith equation (FAO, 1992). Crop coefficient data were taken from the FAO 56 crop evapotranspiration manual.

$$ET_c = ETo \times K_c \quad (3.11)$$

Where, ET_c is crop evapotranspiration (mm/day); ETo is reference crop evapotranspiration (mm/day); K_c is crop coefficient.

The irrigation water needed for each stage of irrigated crop in the command area was computed by subtracting effective rainfall from ET_c (Allen et al., 2000). According to Equation 3.12, the irrigation requirement (IR) indicates the difference between the Evapotranspiration of the crop under ideal conditions (ET_c) and the effective rainfall ($Reff$) contributions during the same time period (Aksara and Pasin, 2015).

$$IR = ET_c - Reff \quad (3.12)$$

Calculation of evaporation losses

The evaporation for canal water have been calculated using the Penman-Monteith combination model on the assumption that this was an accurate representation of the evaporation. The Penman-Monteith equation to calculate evaporation (not evapotranspiration), will modify the equation by omitting the term related to transpiration (Allen et al., 1998; Droogers and Allen, 2002). The modified equation focuses solely on estimating the potential evaporation rate. Developed by Howard Penman in 1948, this equation requires daily mean temperature, wind speed, air pressure, and solar radiation to predict evaporation accurately using CROPWAT8.0

software (Anderson and French, 2019). Here's the simplified form of the Penman-Monteith equation for evaporation (Pereira et al., 2015).

$$E_p = \frac{0.408\Delta(R_n - G) + \frac{\gamma(900)}{(T + 273)}u_2(e_a - e_s)}{(\Delta + \gamma(1 + 0.34u_2))} \quad (3.13)$$

Where, E_p is the potential evaporation rate in (mm/day), Δ is the slope of the saturation vapor pressure-temperature curve (kPa/°C), R_n is the net radiation at the surface (MJ/m²/day), G is ground heat flux in KJ/kg, γ is the psychrometric constant (kPa/°C), T is the air temperature (°C), u_2 is the wind speed at 2 meters above the surface (m/s), e_a is the actual vapor pressure (kPa), e_s is the saturation vapor pressure (kPa), then canal evaporation becomes:

$$R = \frac{E_p \times A_s \times k_w}{Q} \quad (3.14)$$

A_s is surface area exposed for evaporation (m²) is the product of top width of canal (W) in (m) and length of canal (L) in (m)

Where, R is evaporation loss of irrigation water in transport (%), but evaporation losses from canals are normally lower depend on canal size and adjusted by of 0.6 to 0.8 (Leigh, 2014). k_w is coefficient (correction factors) of open water (0.7), The evaporation loss of irrigation water in transport varies directly with the rate of potential evaporation E_p , the top width of water surface in the canal W , and the distance of canal L , and varies inversely with the discharge Q in (m³/s). The accuracy of this method is influenced by factors like water flow velocity, width of the water surface, and the precision of measuring water temperature, making it suitable for determining cumulative evaporation over longer time periods (Liu et al., 2016).

3.7 Comparison and Evaluation of Hydraulic and Hydrologic Factors on Water Conveyance Efficiency.

Comparing the performance assessments of water conveyance systems under various conditions can help identify specific areas with low efficiency. By pinpointing inefficient locations, targeted interventions can be made to improve overall system performance. Such assessments are crucial for optimizing water delivery and minimizing losses within irrigation schemes, especially in areas with limited water resources.

The primary causes of reduced conveyance efficiency in canals stem from both hydraulic and hydrologic factors. Hydraulic parameters, such as canal geometry and flow conditions, directly impact how effectively water is conveyed. Hydrologic factors, including losses from evaporation and seepage, also play a major role, often resulting in substantial water loss over time. Together, these factors determine the amount of water reaching the intended destinations versus what is lost during conveyance.

Hydrologic parameters like seepage and evaporation are particularly influential in affecting water availability in the conveyance system. Seepage losses, influenced by soil permeability and maintenance practices, can lead to significant reductions in water supply, especially in poorly maintained or vegetated canals. Although evaporation is generally less impactful than seepage, it can still contribute to cumulative water loss, particularly in hot, arid climates where open canal systems are exposed to high temperatures.

On the hydraulic side, canal geometry and flow characteristics are critical. Parameters such as water depth, width, wetted perimeter, hydraulic radius, and canal slope affect the volume and speed of water flow, while Manning's roughness coefficient indicates the resistance encountered by the water, often due to the canal's surface condition or vegetation. Flow velocity, in turn, determines how quickly water is delivered. Variations in these parameters directly influence conveyance efficiency, as higher resistance or suboptimal canal geometry can slow down water flow, increase seepage, and reduce the effectiveness of the irrigation system.

3.8 Data Analysis

In this study, conveyance efficiency performance evaluation and factors affecting conveyance efficiency (hydraulic and hydrologic) was presented. Analyze the collected primary and secondary data to evaluate hydraulic and hydrologic factors, and conveyance efficiency. The missing rainfall data was filled using arithmetic mean method, effective rainfall and irrigation requirement was calculated using CROPWAT 8.0 software from weather data and field observation to measure hydraulic parameters. Comparison between water balance (inflow-outflow) method and empirical formula was used to analysis seepage loss and the potential evaporation losses computed by Penman-Monteith equation.

The statistical analysis was done using Minitab software, to identify correlations, and multiple regression between the hydraulic and hydrologic factors. The scatterplots to confirm the correlation, measure direction and the strength of the linear relationship between two variable. Visualize the data using graph, ANOVA table and chart to represent the result clearly and effectively. The evaluation criteria has been root mean squared error (RMSE) and R-squared(R^2), thus the lower RMSE indicator and the higher the R^2 value, the more accurate the method. In Minitab software the standard error is equivalent to the root mean square error (RMSE) in the model.

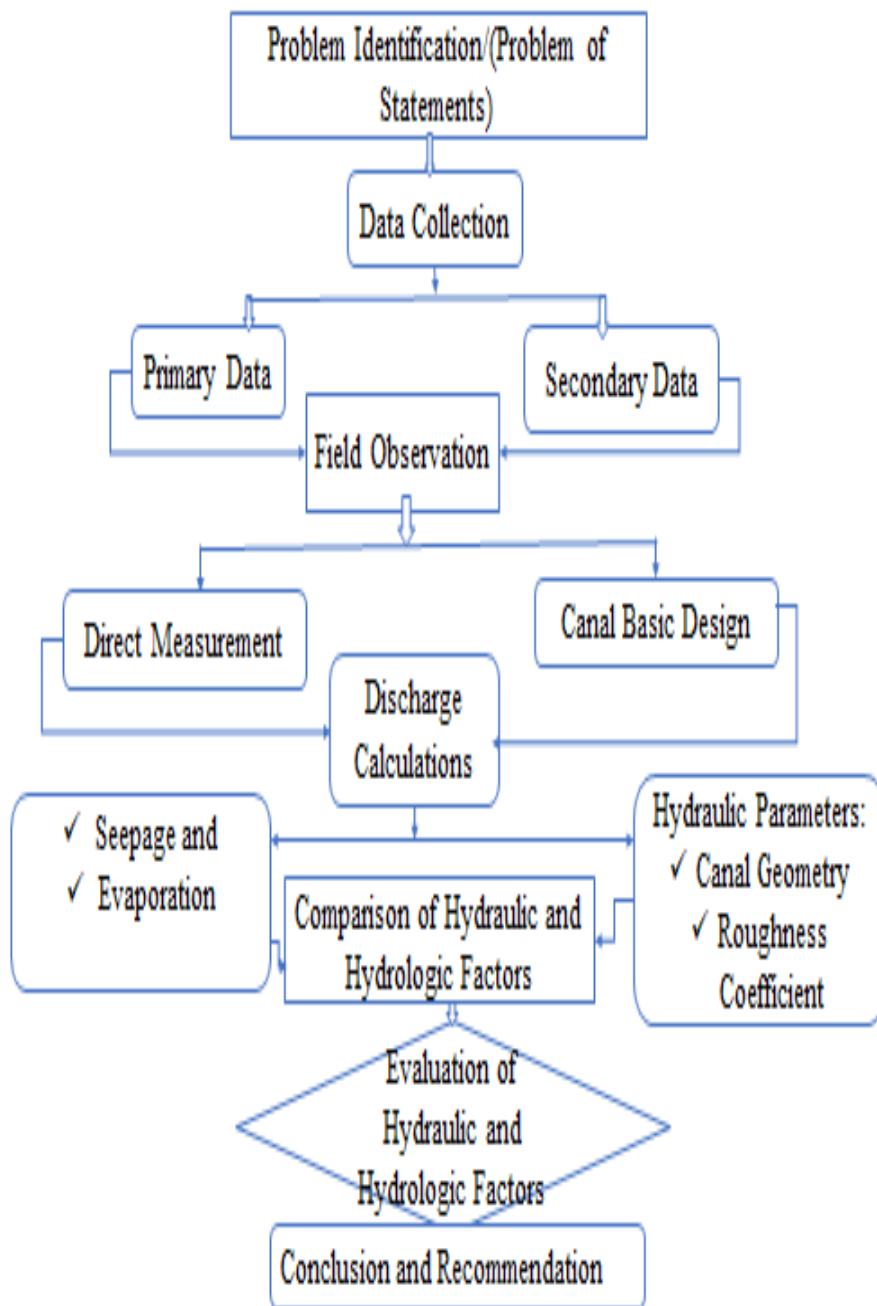


Figure 3.10 Conceptual framework of research methodology for the study

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 Pumps and Irrigation Canals

The Wonji Shoa irrigation schemes face challenges in classifying distributaries canal shapes as trapezoidal, due to deterioration from inadequate upkeep and repeated silt and vegetation removal. Variability in cross-sectional profiles is observed, and some canal banks and beds are overgrown with vegetation. The majority of pumps at the main pumping station operate continuously, except during rainy seasons. Malfunctioning of horizontal and vertical pump types is attributed to not functional motor parts, and reduced discharge capacities due to sediment accumulation and the lowering elevation of the Awash river bed near the pumping station.

Currently, only six pumps are operational in the study area, irrigating approximately 70% of the overall irrigable area. Monitoring of irrigation activities is inadequate, with water distribution often left to field irrigators for 9 hours and 15 hours. Factors such as weed growth, debris, sediment deposition, and poor maintenance contribute to inefficient practices. The mean reference evapotranspiration and crop evapotranspiration for the Wonji Shoa irrigation scheme are estimated to be 3.57 mm/day and 4.11 mm/day, respectively. The capacities of pumps at the main station are not constant and depend on the level of the Awash River and pump condition.

4.2 Canal Conveyance Efficiency

4.2.1 Main canal conveyance efficiency

The estimated average value of inflow, outflow, and water conveyance efficiency for various segments of the primary canal demonstrates prominent disparities. The conveyance efficiency (CE) displays an average value in main canal (95.14%) and this implies enhanced structural reliability and hydraulic performance. The canal exhibit relatively low mean velocities (0.155 m/s), which suggests a design approach focused on erosion mitigation and conveyance efficiency maximization. The low velocity of 0.155 m/s is likely due to the canal's low gradient slope, which limits the flow speed naturally, making higher velocities difficult to

achieve. This slower flow helps minimize sedimentation issues by allowing fine particles to settle, and supports operational practices focused on erosion control and reducing the need for frequent maintenance.

Table 4.1 Average conveyance efficiency of main canal

Distance	m	80	280	480
Inflow	l/s	3650	2819	2768
Outflow	l/s	3560	2692	2557
CE	%	97.53	95.49	92.38
Aveg. CE	%			95.14
overall CE	%			90.70

The designation main canal denotes the canal section situated after trapezoidal weir to the downstream from the primary segment. This specific area features a diminished cross-sectional area accompanied by reduced water depth 1.6 m and narrower bottom and top width. Nevertheless, the mean velocity within this segment registers a higher value 0.42 m/s, possibly attributable to water flow restriction illustrated in appendix-A. The overall conveyance efficiency of 90.7%, indicating good water delivery performance of the canal system. This performance is achieved with minimal losses across different sections due to the presence of a lined canal section as indicated in Table 4.1. The prescribed conveyance efficiency for lined canals of any extent stands at 95% according to (USBR, 1976). Conveyance efficiency of the system amounts 90% design stage.

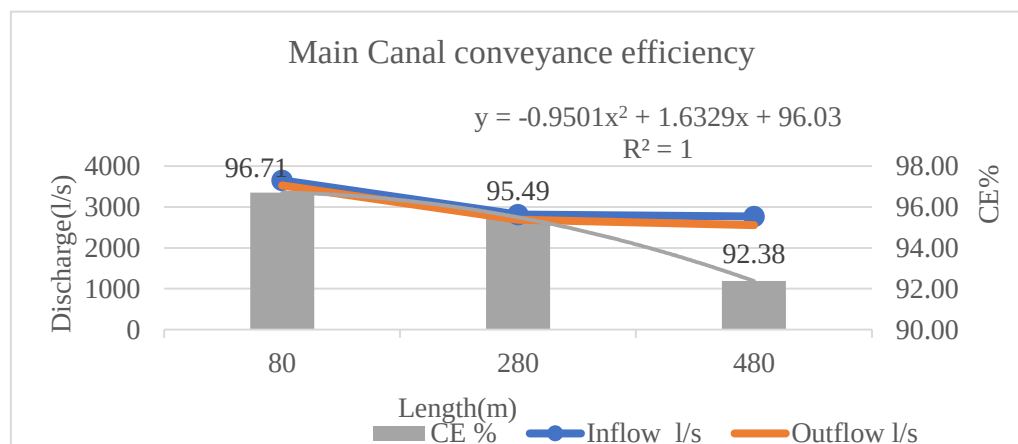


Figure 4.1 Average conveyance efficiency of main canal

The line graphs show the variations in inflow and outflow rates, both exhibiting a decline with increasing distance, indicating a reduction in flow rate along the canal. The polynomial regression analysis for efficiency (with $R^2=1$, signifying a perfect fit) implies a quadratic correlation, demonstrating an initial rise in efficiency followed by a decline towards the end of the canal. Inadequate operational management of silt and debris in canal flows, changes in water demand or utilization patterns along the canal capacity fluctuations, and infrastructure issues like conveyance characteristics and silt deposition resulting in water seepage loss could all be contributing factors to the decline in conveyance efficiency.

4.2.2 Secondary canal right branch conveyance efficiency

Due to the longer service life without maintenance, extensive length of the canal, the presence of silt and debris, the characteristics of the canal, and the growth of vegetation along the section, the segment that was intended to give 4 m³/s diverted water at 2.2 km of the secondary canal had a decreased capacity of 1.79 m³/s. The right branch's secondary canal was evaluated at average 30 m intervals using average values, with 400 m estimated differences.

Table 4.2 Average conveyance efficiency of the right branch of the secondary canal

Distance(m)	200	600	1000	1400	1800	2200
Qi(m ³ /s)	2.56	2.55	2.45	2.35	2.30	2.20
Qo(m ³ /s)	2.45	2.15	1.95	1.86	1.80	1.72
CE %	95.70	84.30	79.60	79.20	78.26	78.18
Aveg. CE%						82.54
Overall CE%						67

The performance of canal conveyance efficiency within each segment yielded progressive results; however, the overall conveyance efficiency was only 67%. This indicates that longer distances create greater opportunities for losses and inefficiencies. The recommended conveyance efficiency for lined canals of any length is 95%. For earthen canals with clay soil could be 80%, 85%, and 90% for canal lengths of > 2000 m, 200–2000 m, and < 200 m, respectively (FAO, Brouwer et al., 2001).

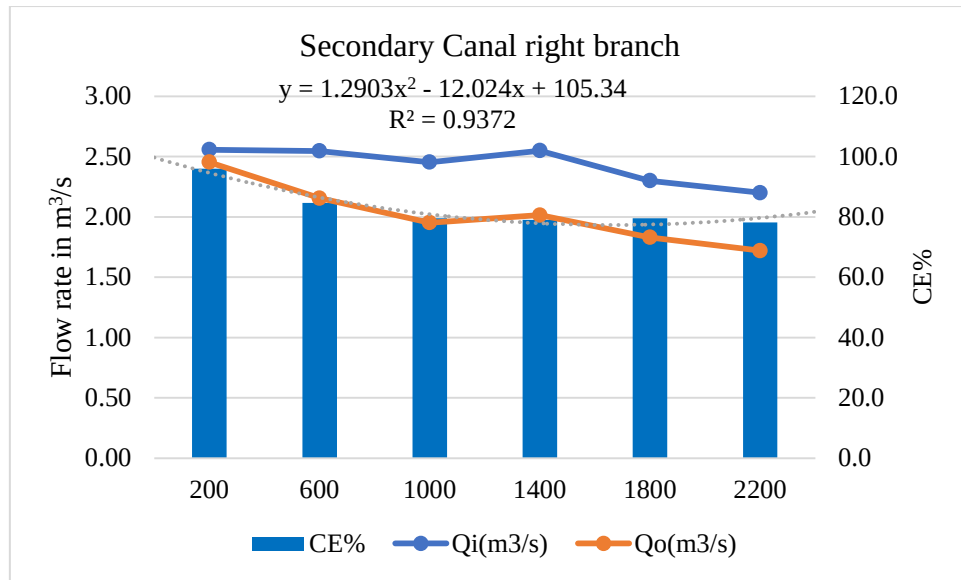


Figure 4.2 Average conveyance efficiency of the right branch of the secondary canal

As illustrated in Figure 4.2, the conveyance efficiency (CE%), flow rates (inflow and outflow) for the right branch of the secondary canal were described at intervals of 200 m, 600 m, 1000 m, 1400 m, 1800 m, and 2200 m. The conveyance efficiency exhibits a decline from approximately 95.7% at 200 m to a lowest point of around 78.26% at 1800 m, before reach to roughly 78.18% at 2200 m, thus indicating outstanding inefficiency at each interval. The polynomial trend line for conveyance efficiency show cases a nonlinear reduction in efficiency, with $R^2 = 0.94$, denoting a highest degree of fit. These findings underscore substantial fluctuations in conveyance efficiency, implying variability in the canal performance along its length, inflow and outflow rates with specific inefficiencies observed near the 1400 m point. At 1800 m the conveyance efficiency was 78.26%, because there was minimum hydraulic factor (such as, canal geometry, roughness coefficient and canal velocity) and hydrologic factors (seepage) was in good performance.

4.2.3 Secondary canal left branch conveyance efficiency

In the Table 4.3 illustrates that conveyance efficiency initiates at relatively high levels for shorter lengths (91.24% at 250m) and progressively fluctuated as the length increases, reaching a minimum at 1000 m (79.02%). Subsequent to this point, minor fluctuations were observed. This suggests a diminishing ability of the system to effectively convey water with increasing cross-section (hydraulic parameters) such as; water depth, wetted perimeter,

roughness coefficient and minimum velocity of water and possibly influenced by factors such as, debris, silt deposit, vegetation growth through the bank and bed of canal, led seepage (hydrologic parameter).

Table 4.3 Conveyance Efficiency of the Left Branch of the Secondary Canal

Discharges before reservoir								After reservoir	
Reach	250	500	750	1000	1250	1500	1750	2750	3750
Length(m)									
Qin (m ³ /s)	2.56	2.24	2.20	1.71	1.35	1.27	1.25	1.67	1.57
Qout (m ³ /s)	2.33	1.98	1.81	1.35	1.08	1.01	0.99	1.53	1.35
CE%	91.24	88.48	82.54	79.02	80.17	79.24	79.2	91.12	86.37
Avg. CE%									85.29
Overall CE%									52.95

The overall conveyance efficiency of 52.95% implies that, almost 47.05% of water was lost in this canal system from the beginning to the end, indicating significant losses or inefficiencies within the system.

A clear inverse correlation exists between length and conveyance efficiency, where an increase in length corresponds to a decrease in efficiency, with exception at average length 1750 m the conveyance efficiency becomes high, due to the reduction of flow limitation factors (hydraulic and hydrologic parameters). This phenomenon may be attributed to longer distances, canal shape fail, heavily silt deposit offering more opportunities for losses and inefficiencies to increase. The outflow (Qout) consistently registers lower values than the inflow (Qin), suggesting that water is either lost or not completely conveyed throughout the system. Local efficiencies (CE% at different lengths) exhibit a higher average value in comparison to the overall efficiency shown in appendix-A. This observation implies point towards localized efficiencies that are not continued across the entire length of the system.

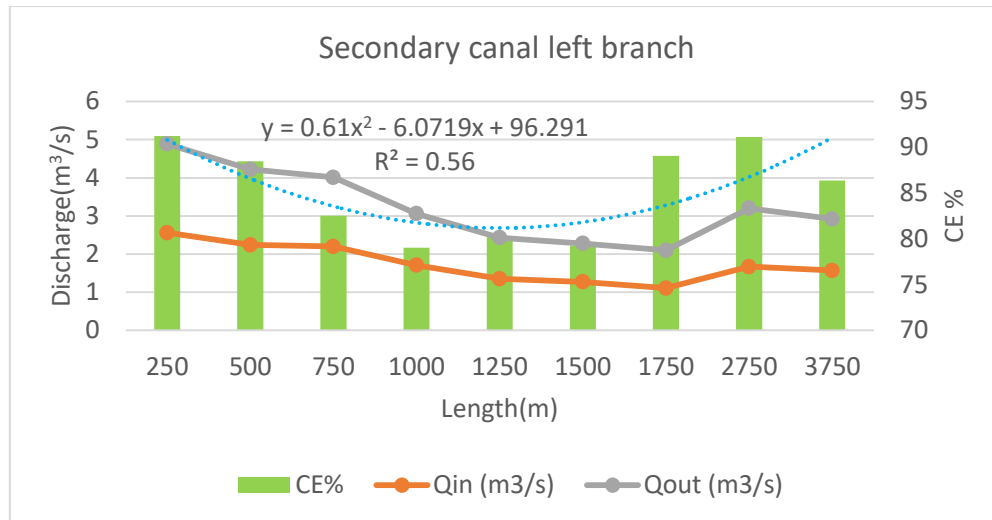


Figure 4.3 Conveyance Efficiency of the Left Branch of the Secondary Canal

The graph representing the secondary canal left branch displays a clear connection between the inflow (Q_{in}) and outflow (Q_{out}) discharges, as well as the conveyance efficiency (CE%) at different distances. Both the inflow (Q_{in}) and outflow (Q_{out}) diminish with increasing distance, before 1250 m indicating a reduction in water within the system and after that their was fluctuation in conveyance efficiency. This trend aligns with the decrease in CE% from 91.24% at 250 m to a minimum of 79.02% at 1000 m, with minor variations thereafter. The presence of a quadratic trendline for CE% ($R^2 = 0.56$) emphasizes a significant inverse relationship between the length of the system and its efficiency, highlighting the fluctuation of longer distances on efficiency.

4.2.4 Performance of conveyance efficiency in tertiary canals

The tertiary canal receives water from the left and right branches of the secondary canal; there are sixteen number of tertiary canal assessed and each of them discharges 70-75 l/s within nine hours irrigation time. In this section, conveyance efficiency was declined due to the wedding of canal bed and bank, clogging offtaking canal with debris, and the silt deposition on bed mainly in the left branch canal.

Table 4.4 Conveyance Efficiency of Tertiary Canals

Canal types	Reach Length(m)	Depth of water(m)	Mean velocity(m/s)	wetted perimeter(m)	Qin (l/s)	Qout (l/s)	CE%
TC-1	500	0.5	0.53	1.19	75	51.5	68.67
TC-2	512	0.6	0.49	1.2	74.8	52	69.52
TC-3	520	0.68	0.48	1.42	75	45	60.00
TC-4	500	0.69	0.62	1.17	72.5	51.5	71.03
TC-5	515	0.72	0.38	1.2	72.5	43	59.31
TC-6	525	0.55	0.42	1.24	75	50	66.67
TC-7	450	0.58	0.41	1.18	73.5	48	65.31
Average CE for tertiary canal left branch							65.79
TC-1	470	0.56	0.54	1.32	72	44	61.11
TC-2	510	0.62	0.62	1.1	72.5	52	71.72
TC-3	490	0.66	0.55	1.3	75	50	66.67
TC-4	535	0.58	0.42	1.26	73.00	48	65.75
TC-5	522	0.51	0.36	1.17	71.52	42	58.72
TC-6	540	0.58	0.38	1.42	75	52	69.33
TC-7	505	0.62	0.28	1.17	74.5	41.5	55.70
TC-8	485	0.76	0.40	1.2	72.5	43.5	60.00
TC-9	600	0.63	0.41	1.34	74	46	62.16
Average CE for tertiary canal right branch							63.46
Average CE for tertiary canal							64.63

Across all reaches combined, the average conveyance efficiency (CE) of the tertiary canals was 64.63%. This indicates that 35.28% of water is lost due to factors such as seepage and evaporation. The left branch (TC-4) and the right branch (TC-2) demonstrated the lowest loss percentages, with CE values of 71.03% and 71.72%, respectively. In contrast, the right branch (TC-7) exhibited a significantly lower CE of only 55.70%, indicating greater losses compared to other reaches. CE values below 70% were observed in reaches 1, 2, 3, 5, 6, and 7 of the left branch, as well as in reaches 1, 3, 4, 5, 6, 8, and 9 of the right branch, suggesting comparatively larger losses in these areas. The relationship between reach length and CE% does not appear to be clearly defined. Throughout all tertiary canals, the average velocity was measured at 0.46 m/s. Higher CE% values were found in reaches TC-4 and TC-2 (left and right branches), which had mean velocities of 0.62 m/s. Conversely, lower CE% values were observed in reach TC-7 (right branch), with a mean velocity of only 0.28 m/s.

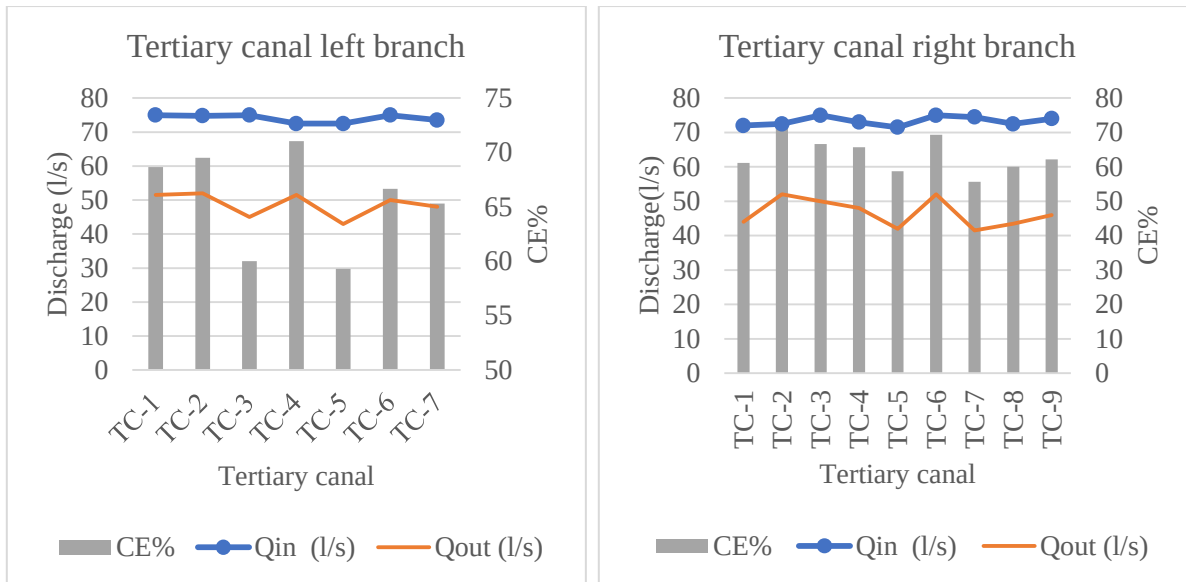


Figure 4.4 Tertiary canal conveyance efficiency

In general, the conveyance efficiency of the main canal was 90.7% at a distance of 480 m from the main pump station. The right branch secondary canal was a conveyance efficiency of 67%, while the left branch secondary canal shows a conveyance efficiency of 52.95%. The right and left branch tertiary canals exhibit efficiencies of 63.46% and 65.79%, respectively. The decline in efficiency, particularly in the left and right branches leading to the tertiary canals, can be attributed to significant silt deposition and the growth of vegetation, which has completely shaded the bed and side of the canals.

In this study, the overall conveyance efficiency, as determined by Equation 3.5, was 40.29% for the right branch and 31.59% for the left branch of the entire system and in Wonji Shoa irrigation scheme, observed that the conveyance efficiency established during the design stages was 90%, the average overall canal conveyance efficiency (field survey value) was 35.94%, which implies inefficient water distribution within the system, this significant inconsistency can be attributed to the fact that inappropriate hydraulic parameters (increasing the roughness coefficient, wetted perimeter, and water depth) and hydrologic parameter (seepage), due to deterioration of canal shape at the time of maintenance, vegetation growth in the bank and bed of canal, and poor management practices.

While Mohammed and Tefera (2017), in their investigation of the Fentale irrigation scheme, observed that the conveyance efficiency established during the design phase was 80%, a figure

that aligns with the recommendations set forth by the Food and Agriculture Organization of the United Nations; the value derived from the field survey was 17%. This significant discrepancy can be attributed to the fact that the poor performance of designated conveyance parameters (including the roughness coefficient, hydraulic radius, and bed slope).

These values are notably below the standard benchmark of 95% documented by Brouwer and Prins (1989) and the USBR (1976) for lined canals. The Food and Agriculture Organization of the United Nations (FAO, 1992) specifies that the benchmark for conveyance efficiency is 65%, a standard usually observed in both major projects (>10,000 ha) and minor projects (<1,000 ha) that face challenges related to communication and management effectiveness. Therefore, the total irrigation efficiency of the conveyance system is improved from the current levels of 33% to 40% to at least 60% to 70%, otherwise the sustainability of the Wonji Shoa irrigation scheme was in jeopardy (Kedir, 2012).

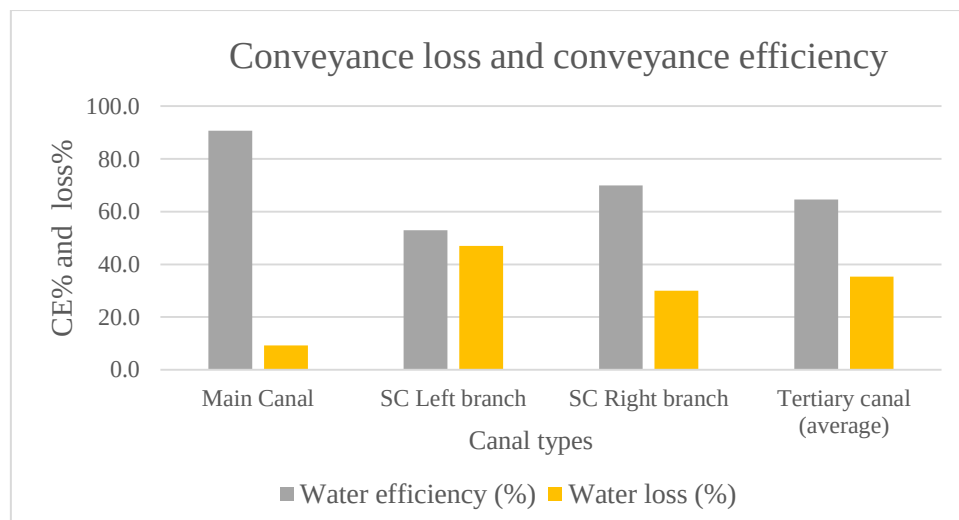


Figure 4.5 Water efficiency and loss in the lined and un-lined Wonji Shoa canal

In several canal sections, such as the main canal, the secondary canal left and right branches, and the tertiary canal, the water conveyance efficiency and water loss percentages were displayed in the Figure 4.5, between 9.28% and 47.05% of water is lost, the maximum loss occur in secondary canal left branch.

4.3 Hydraulic Factors Influences Conveyance Efficiency

By using manning's formula in Equation 3.7, hydraulic parameter changes have a great effect on the conveyance efficiency of the canals. In this study, the hydraulic effect on conveyance efficiency change (decrease) was manipulated by the change in manning's roughness coefficient (n). The values of the calculated 'n' for different sections on the main canal were between 0.018 and 0.02. Manning's 'n' value of 0.016 should be used in concrete-lined channels for optimum cross-section and for better hydraulic performance of the channel (Zakir-hassan et al., 2023). The Table 4.5 illustrates the relationship between various hydraulic parameters and manning's roughness coefficient across different canal sections, including lined main canal (Mc) and unlined segments of secondary canal left (SCL) and secondary canal right (SCR). Manning's roughness coefficient (n), indicated remains around 0.018 to 0.026 across all sections. However, the standard values range from 0.012 to 0.018 for the canal on which 'n' was calculated (Arora et al., 2002). An increase in the value affects the amount of discharge (which was made to decrease), due to the change in the canal shape and materials. The lined sections have good cross-section, lower bed slopes, and greater inflow rates, reflecting their higher conveyance efficiency. Unlined sections display greater roughness, leading to reduced inflow and hydraulic performance. The relationship highlights the significant impact of lining on reducing resistance and enhancing the flow of water through the canals.

Table 4.5 Calculation of manning's roughness 'n' for Wonji-Shoa irrigation scheme

Canal Section	Aw (wetted area)(m ²)	So (bed slope) (m/m)	R (hydraulic radius)(m)	Qin(m ³ /s)	n (manning's roughness)
Mc lined	5.14	0.00024	0.642	2.819	0.018
Mc lined	4.45	0.00024	0.733	2.692	0.021
SCL unlined	4.15	0.00025	0.705	2.557	0.022
SCL unlined	4.32	0.00016	0.759	2.025	0.023
SCL unlined	4.45	0.0001	0.762	1.916	0.019
SCL unlined	4.45	0.00011	0.802	1.786	0.023
SCR unlined	6.3	0.00012	0.917	2.557	0.025
SCR unlined	5.7	0.0001	0.901	2.16	0.027
SCR unlined	5.22	0.00012	0.86	2.01	0.026

The stastical data analysis (multiple regression analysis) using Minitab software: "n" versus "Aw" wetted area(m²), "R" hydraulic radius(m), "So" bed slope(m/m), Qin (m³/s).

Regression Equation $n = -0.00169 + 0.003811 A_w + 0.02133 R + 65.76 S_o - 0.00957 Q_i$

Table 4.6 Model summary for roughness coefficient

S	R ²	R ² (adj)
0.0005	97.67%	95.80%

Table 4.7 Analysis of variance (ANOVA) table of roughness coefficient

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.000057	0.000014	52.38	0.000
Aw wetted area(m ²)	1	0.000020	0.000020	75.15	0.000
R hydraulic radius(m)	1	0.000015	0.000015	54.06	0.001
So bed slope(m/m)	1	0.000014	0.000014	50.66	0.001
Qinflow(m ³ /s)	1	0.000015	0.000015	56.54	0.001
Error	5	0.000001	0.00000027		
Total	9	0.000058			

The regression analysis illustrate highly significant relationship between manning's roughness coefficient (n) and the independent variables: wetted area (Aw), hydraulic radius (R), bed slope (So), and flow rate (Qi). The regression equation, indicates that as the wetted area, hydraulic radius, and bed slope increase, manning's coefficient also increases, suggesting rougher flow conditions. Conversely, an increase in flow rate is associated with a decrease in manning's coefficient, indicating smoother flow conditions. wetted area has the highest individual F-value (75.15), indicating it is the most influential predictor.

The model explains a substantial portion of the variance in 'n' coefficient of determination (R² = 0.98), indicating that 98% its effectiveness in predicting manning's coefficient based on the given variables. The coefficients for Aw, R, So, and Qi are all statistically significant (p < 0.001), with low standard errors (S or RMSE = 0.0005), suggesting the reliability of the model's estimates. According to Gad and Waleed (2023), the value of the determination coefficient was 0.98, and the RMSE was 0.0017 for lined canals and the value of determination coefficient was 1, and the RMSE was 0.0003 for un-lined canals and which has been tolerable difference with this study. Overall, this analysis provides valuable

understandings into the factors influencing manning's roughness coefficient in hydraulic systems.

Crop water requirement and irrigation water requirement

The basic and preliminary inputs for any irrigation network design is finding out of the requirements of irrigation water for the entire growth of crop on the specified climate. Hence for characterization of irrigation structures, crop water requirement was calculated based on climate data (2010-2022) using the CROPWAT 8.0 software. Thus by using excel sheet and the average sugar cane kc value 1.15 from FAO, recommendation.

Table 4.8 Crop and irrigation water requirement

Month	Pe _{eff} (mm/month)	ET _o (mm/month)	ET _o (mm/day)	ET _c (mm/day)	IWR(mm/day)
January	4.2	99.8	3.22	3.70	3.56
February	13.5	99.0	3.54	4.07	3.62
March	35.3	121.4	3.91	4.50	3.32
April	41.7	116.1	3.87	4.45	3.06
May	57.5	117.3	3.78	4.35	2.43
June	55.4	112.7	3.76	4.32	2.48
July	233.9	108.1	3.49	4.01	0.00
August	156.0	108.6	3.50	4.03	0.00
September	116.9	108.6	3.62	4.16	0.27
October	14.5	114.4	3.69	4.24	3.76
November	20.3	98.8	3.29	3.78	3.11
December	3.0	99.5	3.21	3.69	3.59
Average	62.7	108.7	3.57	4.11	2.02

Peak crop water requirement of 4.5mm/day in the month of March and minimum of 3.69 mm/day in the month of December was obtained in consideration of effective rainfall. The values in Table 4.9 is different from previous reports (Kedir, 2012), crop water requirement is 4.6 mm/day, slightly similarity of the way, the seasonal variation.

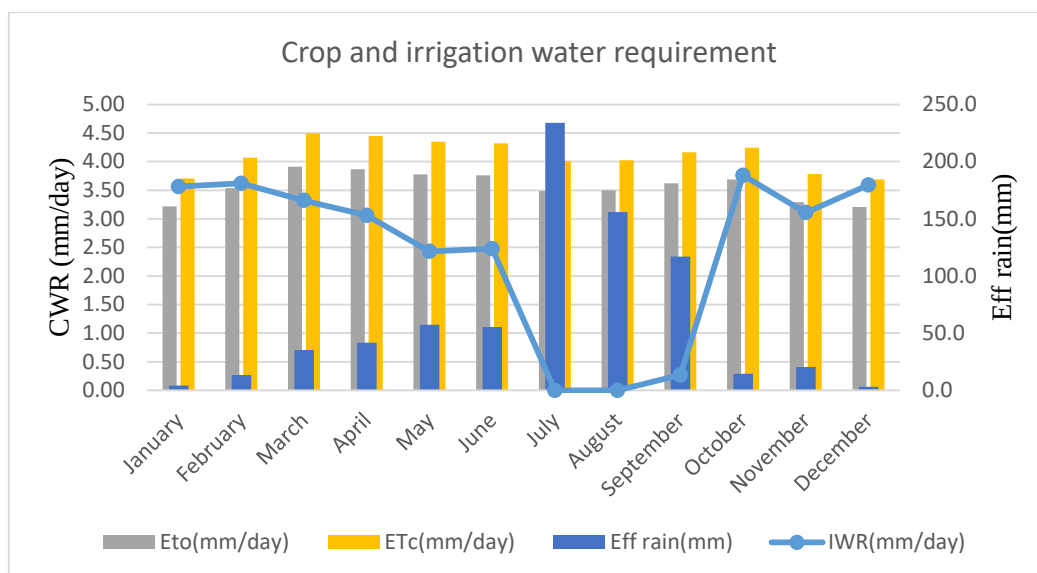


Figure 4.6 Crop and irrigation water requirement

For estimating water demand of the scheme and irrigating of a specific field the corresponding value for mean demand 4.11 mm/day, which is duty of 0.476 l/s/ha has been considered, but from Wonji Shoa Sugar Factory irrigation department report 0.53 l/s/ha should be considered currently. On the other hand, for design purposes of canals and structures the corresponding values for peak demand (5.3 mm/day), which is 0.62 l/s/ha should be considered. The maximum irrigation water was required in this study is the month of October to end of May and minimum in month of June to end of September, but actual observation and long year water abstraction data revealed that maximum irrigation water was required in the month of November to end of May and minimum in month of June to October which were slightly similar to the study period calculated values.

Rainfall data analysis

In Wonji Shoa irrigation scheme the mean minimum and maximum rainfall amount occurred in months of December (3.7 mm) and July (292.4 mm), respectively. It has an average total annual rainfall of 940.1 mm. The mean total annual effective rainfall amount of the study area was 752.1 mm. Hence this effective rainfall contributed to support the crop water demand in the irrigation seasons. The effective rainfall is determined with the 'USDA SCS' method by the CROPWAT 8.0 software. based on the mean monthly rainfall data from the Nazerth meteorological station near by station to Wonji Shoa irrigation schemes.

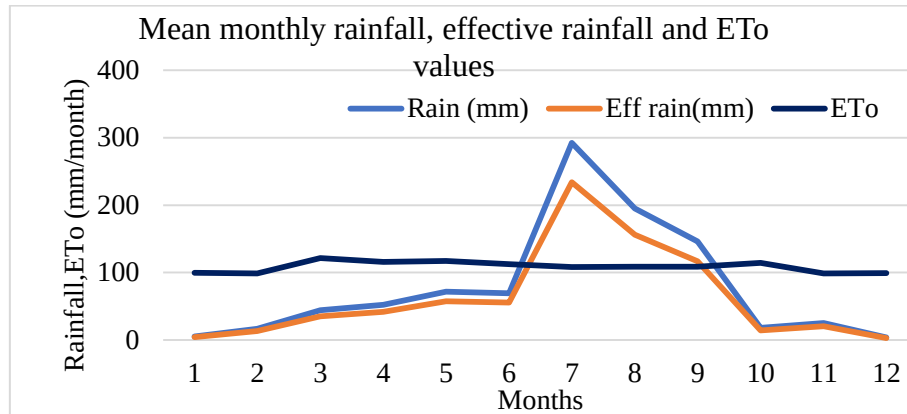


Figure 4.7 Mean monthly rainfall, effective rainfall and ETo values

4.4 Hydrologic Factors Influences on Conveyance Efficiency

Water availability: Water availability directly impact the conveyance efficiency of canal. The amount of water available deliver from Koka dam (2007-2016) years was contribute for downstream side.

Table 4.9 Water availability at Koka dam

Years	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
flow(Mm ³)	106.26	105.55	106.20	107.91	135.44	136.68	107.30	107.34	63.30	54.57

In Table 4.8 shows the progressive decreases Awash river stream flow discharge year to year mainly 2015 and 2016.

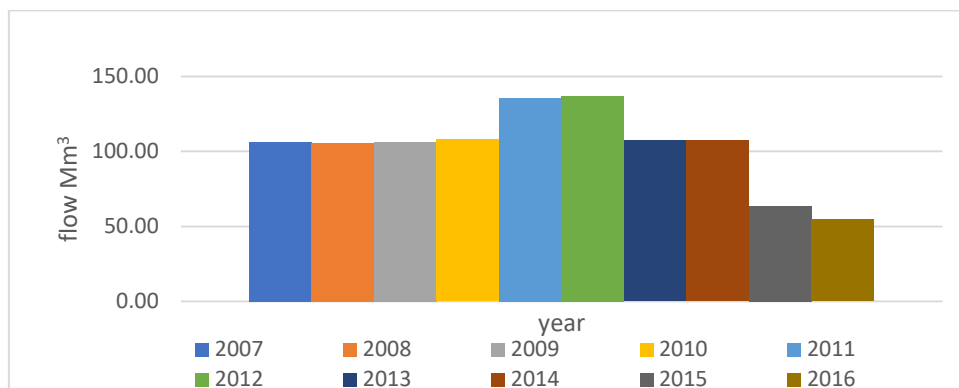


Figure 4.8 Water availability at Koka dam

As illustrated in Figure 4.6 the fluctuation in water availability significantly affected the conveyance efficiency of the canal over the years. In year with higher water availability the canal operated at optimal efficiency allowing for increased flow rates and reduce losses. Conversely, during the dry season, diminished water level led to decrease in flow velocity of water resulting in sedimentation and increase roughness. The fluctuation caused the canal to operate inefficiently, often leading to water shortage in the downstream agricultural areas. Consequently, this study demonstrated that maintaining consistent water availability is crucial for optimizing the canal performance and ensuring reliable irrigation.

4.4.1 Inflow-outflow (Field observation) method of seepage loss

Estimation of seepage loss using Equation 3.9, the field observation (inflow-outflow) from Wonji Shoa irrigation scheme and the findings underscore the importance of on-site measurements and real-time data collection for more precise assessments.

Table 4.10 General details characteristics of different sections and seepage loss

Canal Name	Length(m)	Tw(m)	Vm(m/s)	Pw(m)	Aw(m ²)	R(m)	Qin(m ³ /s)	Qout(m ³ /s)	SL(m ³ /s)	SL%/100 m
MC	280	5.23	0.15	6.93	4.45	0.96	2.819	2.692	0.127	0.0161
	480	4.8	0.418	6.4	5.72	0.92	2.768	2.557	0.211	0.0159
SCR	200	4.8	0.35	8.3	6.9	0.84	2.56	2.45	0.103	2.0148
	600	4.8	0.36	6.12	6.1	0.99	2.55	2.16	0.390	1.057
	1000	4.3	0.37	6.38	5.8	0.91	2.45	1.95	0.502	2.0456
	1400	4.7	0.36	6.28	5.6	0.90	2.45	2.01	0.440	1.281
	1800	4.3	0.36	6.1	5.2	0.86	2.21	1.83	0.388	0.9749
	2200	4.3	0.36	5.91	5.0	0.84	2.18	1.80	0.379	0.7916
SCL	250	4.8	0.37	6.65	6.1	0.92	2.56	2.44	0.116	1.8249
	1250	4.3	0.42	5.7	4.6	0.80	2.44	2.03	0.414	1.3595
	1750	4.7	0.36	6.16	5.3	0.86	2.17	1.94	0.236	0.6218
	3000	4.8	0.40	5.8	4.4	0.75	1.94	1.79	0.150	0.2591
	3750	4.42	0.41	5.56	4.2	0.75	1.79	1.68	0.108	0.1614
	4500	4.09	0.39	5.01	4.4	0.88	1.68	1.59	0.091	0.1208
Avg									0.277	1.1677
Total									4.038	14.160

4.4.2 Indirect measurement of seepage loss or using empirical equation

✚ Performance analysis of the empirical equations and field observation

In addition to inflow-outflow methods the mentioned in Table 4.9, the seepage loss from the lined and unlined cross sections of the canal and its branches were calculated using the empirical formulas shown in Table 4.10, while empirical formulas provide a quick and accessible means of estimation, the findings from field observation underscore the importance of on-site measurements and real-time data collection for more precise assessments.

Table 4.11 Field observation and empirical formulas for estimating seepage loss.

S.No	Length(m)	Canal types	Nazer ahmed(m ³ /s)	Davis-Wilson(m ³ /s)	field observation(m ³ /s)	Moritz (m ³ /s)	Pakistani(m ³ /s)	Molesworth (m ³ /s)
1	78	Mc Lined canal	0.0013	0.0004	0.2000	0.2758	0.0039	0.1243
2	280		0.0014	0.0009	0.1270	0.2919	0.0104	0.1270
3	480		0.0014	0.0014	0.2110	0.1750	0.0164	0.1243
4	200	SCRB Unlined canal	0.0013	0.0008	0.1030	0.1828	0.0088	0.1185
5	600		0.0013	0.0017	0.3905	0.1810	0.0195	0.1290
6	1000		0.0013	0.0030	0.5020	0.1761	0.0338	0.1236
7	1400		0.0013	0.0041	0.4401	0.1783	0.0466	0.1229
8	1800	SCLB Unlined canal	0.0012	0.0050	0.3884	0.1697	0.0578	0.1199
9	2200		0.0012	0.0059	0.3793	0.1670	0.0684	0.1190
10	250		0.0013	0.0008	0.1166	0.1797	0.0088	0.1241
11	1250		0.0013	0.0031	0.4147	0.1637	0.0378	0.1158
12	1750		0.0012	0.0049	0.2364	0.1674	0.0567	0.1203
13	3000		0.0011	0.0073	0.1505	0.1488	0.0908	0.1124
14	3750		0.0010	0.0089	0.1081	0.1416	0.1083	0.1123
15	4500		0.0010	0.0098	0.0912	0.1419	0.1166	0.1218
Total			0.0188	0.0580	3.8589	2.7406	0.6847	1.8150
Average			0.0013	0.0039	0.2573	0.1827	0.0456	0.1210

Where, Mc is Main canal, SCLB is Secondary canal left branch, SCRB is Secondary canal right branches

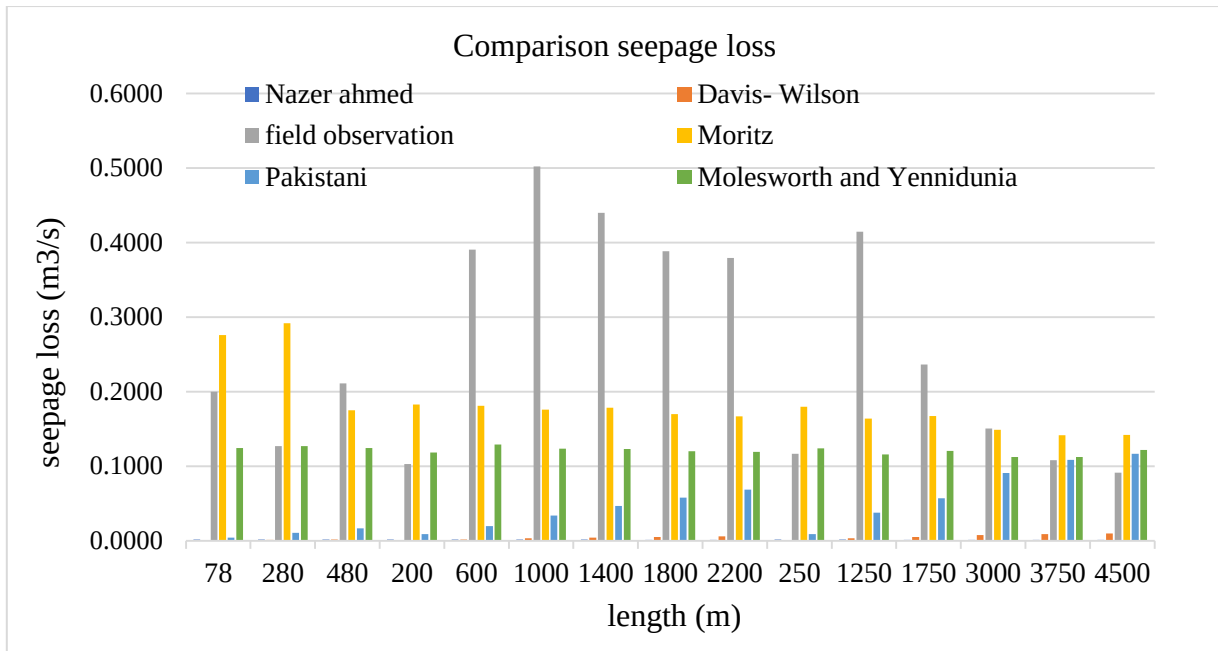


Figure 4.9 Comparison seepage loss by field observation and empirical formula

As Figure 4.9 demonstrates that lined and unlined branches in the field observation was 0.257 m³/s (26%) on average and in lined canal the Moritz empirical formula reach good seepage loss estimation, while the lined and unlined branches in the empirical Moritz and Molesworth methods were compatible with field observation for calculating seepage loss using all equation listed in literature review Table 2.1.

Table 4.12 Calculated values of seepage loss for the lined canal using different methods.

Canal types	Length(m)	Nazer ahmed(m ³ /s)	Davis- Wilson(m ³ /s)	field observation(m ³ /s)	Moritz (m ³ /s)	Pakistani(m ³ /s)	Molesworth (m ³ /s)
Lined canal	78	0.0013	0.0004	0.2000	0.2758	0.0039	0.1243
	280	0.0014	0.0010	0.1270	0.2919	0.0106	0.1270
	480	0.0014	0.0014	0.2110	0.1750	0.0164	0.1243

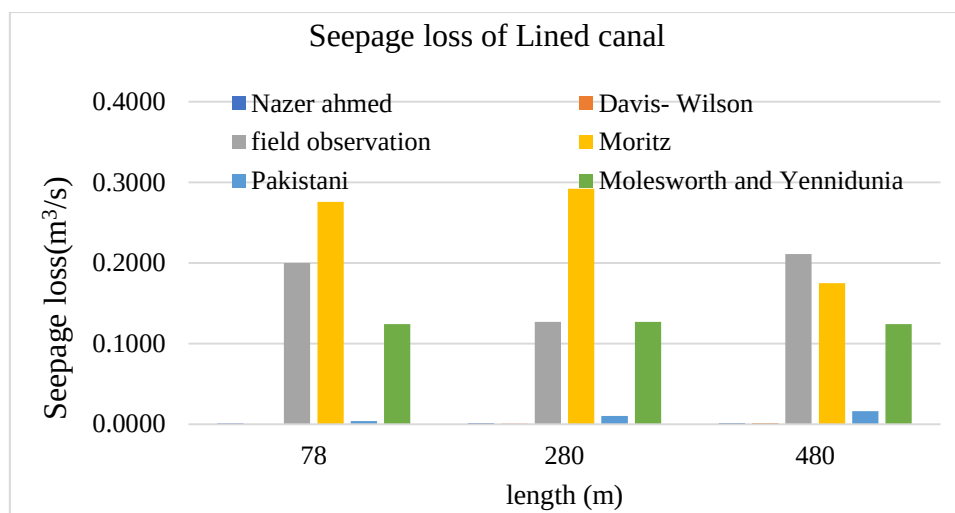


Figure 4.10 Seepage loss of lined Wonji Shoa irrigation scheme.

The seepage loss in the lined main canal were calculated using various empirical formulas and field observation methods. As illustrated in Figure 4.10, the results indicate that the Moritz formula yields higher estimates than the Molesworth formula, while also demonstrating good agreement with field measurements.

Table 4.13 Calculated values of seepage loss for the un-lined canal using different methods.

Canal types	Nazer ahmed(m ³ /s)	Davis- Wilson(m ³ /s)	field observation(m ³ /s)	Moritz (m ³ /s)	Pakistani (m ³ /s)	Molesworth (m ³ /s)
SCR	0.0013	0.0008	0.1030	0.1828	0.0088	0.1185
Unlined canal	0.0013	0.0017	0.3905	0.1810	0.0195	0.1290
	0.0013	0.0030	0.5020	0.1761	0.0338	0.1236
	0.0013	0.0041	0.4401	0.1783	0.0466	0.1229
	0.0012	0.0050	0.3884	0.1697	0.0578	0.1199
	0.0012	0.0059	0.3793	0.1670	0.0684	0.1190
SCL	0.0013	0.0008	0.1166	0.1797	0.0088	0.1241
Unlined canal	0.0013	0.0031	0.4147	0.1637	0.0378	0.1158
	0.0012	0.0049	0.2364	0.1674	0.0567	0.1203
	0.0011	0.0073	0.1505	0.1488	0.0908	0.1124
	0.0010	0.0089	0.1081	0.1416	0.1083	0.1123
	0.0010	0.0098	0.0912	0.1419	0.1166	0.1218
Total	0.0188	0.0580	3.8589	2.7406	0.6847	1.8150
Average	0.0013	0.0039	0.2573	0.1827	0.0456	0.1210

The result of unlined secondary canal the seepage loss are computed by using various empirical and field observation (inflow-outflow) method, from Figure 4.11 the results is seen that Moritz and Molesworth empirical had good agreement with field measurements, due to the involved hydraulic parameters. So, they can be used safely in calculating the expected seeped quantities of water through irrigation open canal networks with reasonable and accurate results. Estimated losses by Davis and Wilson and Nazer ahmed quations are much lower than the measured values, the use of these empirical equations in the estimation of seepage loss is not possible. relied upon estimation seepage loss in lined concrete and unlined canals. It is advisable to use field observation method, Moritz and Molesworth empirical formula for computing seepage loss in Wonji-Shoa irrigation scheme. Considering on average 0.257 m³/s (0.67 Mm³/month) or 25.7% and 0.016 % per100 m for line canal, 1.167 % per 100 m for unlined canal has been observed, this much seepage lost jeopardy the canal performance of the system or inefficient conveyance water .

It is advised to provide all canal lining in order to cover whole command area for irrigation. According to (Kedir, 2012), it was found that mean conveyance losses through seepage 12.36%,. More than 0.55%per 100m length of usable water is get lost in lined canal and 0.84%per 100m length water is lossed in unlined canal on average in irrigation canals of Tendaho Sugar Factory, Ethiopia (Eshetu and Alamirew, 2018). According to Ahmad (2016), the results predict average 13.38% water losses with respect to the total discharge of the canal which has an average amount of 196 cumecs.

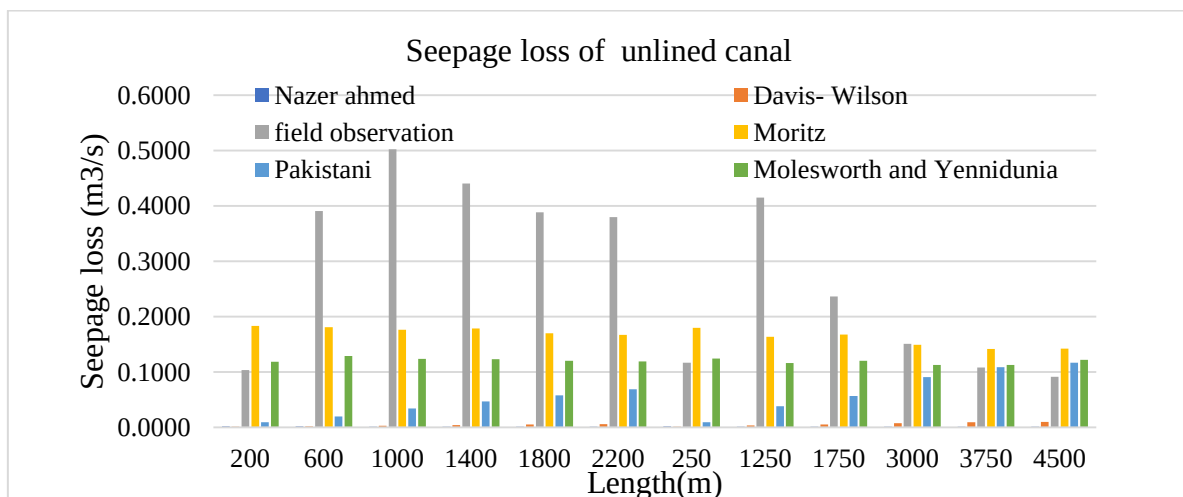


Figure 4.11 Seepage loss of un-lined Wonji Shoa irrigation scheme

4.5 Evaporation Loss

The substantial efforts have been performed to estimate the evaporation loss from agricultural irrigation canals. The evaporation from canals was estimated by using a simple empirical relationship between evaporation rate and water surface area (Wang, 1987). Using the meteorological data in Table 3.5 and using Equation 3.15 the evaporation loss were calculated (Liu SuHua et al., 2016).

Table 4.14 Evaporation loss using aerodynamic equation

Canal Name	Length(m)	WD(m)	Tw(m)	Vmean(m/s)	Pw(m)	Qin(m ³ /s)	Ep (mm/day)	(R)(%)
MC	78	2.19	6.84	0.155	9.418	3.650	3.57	0.0006
	280	1.63	5.23	0.153	6.929	2.819	3.57	0.0015
	480	1.60	4.80	0.418	6.400	2.768	3.57	0.0024
SCR	200	1.85	4.80	0.354	8.300	2.557	3.57	0.0011
	600	1.65	4.80	0.359	6.120	2.546	3.57	0.0033
	1000	1.74	4.30	0.366	6.380	2.454	3.57	0.0051
	1400	1.63	4.70	0.357	6.280	2.454	3.57	0.0078
	1800	1.54	4.30	0.355	6.100	2.213	3.57	0.0101
	2200	1.53	4.30	0.361	5.910	2.178	3.57	0.0126
SCL	250	1.51	4.80	0.366	6.650	2.557	3.57	0.0014
	1250	1.40	4.30	0.421	5.700	2.440	3.57	0.0064
	1750	1.53	4.70	0.359	6.160	2.173	3.57	0.0109
	3000	1.23	4.80	0.404	5.800	1.936	3.57	0.0215
	3750	1.28	4.42	0.412	5.560	1.786	3.57	0.0268
	4500	1.35	4.09	0.385	5.010	1.678	3.57	0.0317
Avg								0.0095

The evaporation loss (R) of irrigation water in transport varies directly with the rate of evaporation E_p , the width of water surface in the canal W , and the distance from the intake to the fields L , and varies inversely with the discharge Q . The rate of evaporation changes with time of day and is almost zero or negative at night, so the evaporation loss can be reduced by making a rational irrigation schedule. In this study, the calculation of evaporation loss was of the order of average 0.0095% at most, and it is minimum compared to the seepage loss and should be neglected.

4.6 Comparison and Evaluation of Hydraulic and Hydrologic Factors

Both hydraulic and hydrologic factors significantly influence the efficiency of water conveyance systems. Hydraulic factors primarily govern the physical behavior of water flow within the system, whereas hydrologic factors influence the availability and variability of water inputs.

In general, hydrologic parameters (seepage and evaporation loss) due to silt deposition and growing of vegetation in the bank and bed of the canal, caused hydraulic parameters (a decrease in canal conveyance characteristics), and in turn hydraulic parameters such as an increase in Manning's roughness coefficient, depth of water, and wetted perimeter caused hydrologic effects such as evaporation and seepage loss. Discharge in conveyance system lost due to evaporation and seepage resulted in the water scarcity in command areas, leading to crop water stress and lower yields.

- **Trend analysis:** Canal geometry versus seepage loss

The relationships between the canal geometric properties and the seepage loss rates were evaluated using regression analysis in the Minitab software program.

Table 4.15 Model summary canal geometry versus seepage loss

S	R ²	R ² (adj)
0.0719	87.76%	75.51%

The decrease from R² (87.76%) to the adjusted R²(75.51%) indicates that, while the model accounts for a significant portion of the variance, some predictors may not contribute meaningfully. The adjusted measure may also be impacted by the sample size in relation to the number of predictors. Even while R² indicates a good match, adjusted R² provides a more realistic view, suggesting that some predictors might not be contributing much. The observed values deviate from the anticipated values by an average of 0.0719 units, according to the standard error of the estimate "S," which is roughly 0.0719. This demonstrates how well the regression model predicted outcomes. With a low S suggesting accurate predictions and a high R² indicating great explanatory power, the regression model performs well overall. Given the complex nature of the model, the adjusted R² somewhat disagrees with this conclusion.

Table 4.16 Analysis of variance (ANOVA) Table

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	7	0.259395	0.037056	7.17	0.009
R (m)	1	0.041853	0.041853	8.10	0.025
Aw (m ²)	1	0.000213	0.000213	0.04	0.845
Pw (m)	1	0.160777	0.160777	31.10	0.001
Vmean (m/s)	1	0.002074	0.002074	0.40	0.547
WD (m)	1	0.182289	0.182289	35.26	0.001
Length (m)	1	0.025497	0.025497	4.93	0.062
Qin (m ³ /s)	1	0.005232	0.005232	1.01	0.348
Error	7	0.036187	0.005170		
Total	14	0.295582			

The analysis of variance (ANOVA) Table 4.16 provides detailed insights into the influence of various hydraulic parameters on seepage loss (SL) in canal geometry. The overall regression model, with a P-value of 0.009 and an F-value of 7.17, is statistically significant, indicating that it effectively explains a significant portion of the variance in seepage loss. Among the parameters analyzed, water depth (WD) and wetted perimeter (Pw) emerge as the predominant factors. The water depth (WD), with an F-value of 35.26 and a very low P-value of 0.001, shows a strong positive correlation with seepage loss, suggesting that deeper channels significantly increase the hydrostatic pressure, thereby driving more water through the canal boundaries into the surrounding ground. Similarly, the wetted perimeter (Pw), with an F-value of 31.10 and a P-value of 0.001, indicates that an increase in the perimeter leads to a higher surface area for water interaction, resulting in elevated seepage rates. Other parameters such as hydraulic radius (R), also contribute to seepage but to a lesser extent, with (P-value = 0.025, F-value = 8.10). Conversely, parameters like wetted area (Aw), mean water flow velocity (Vmean), flow rate (Qin), and length show minimal and non-significant impact on seepage loss, as indicated by their higher P-values and lower F-values.

By going through these calculation steps, each value in the ANOVA Table 4.16 is derived and how it contributes to the understanding of the influence of hydraulic parameters on hydrologic parameters (seepage loss).

Based on the comparison the correlation has been shown as:

- ✚ Wetted perimeter (m) versus seepage loss (m³/s)
- ✚ Increased hydraulic radius (m) of the canals versus seepage loss (m³/s)
- ✚ Cross-sectional Area (m²) versus seepage loss (m³/s)

✚ Depth of water (m) versus seepage loss (m^3/s)

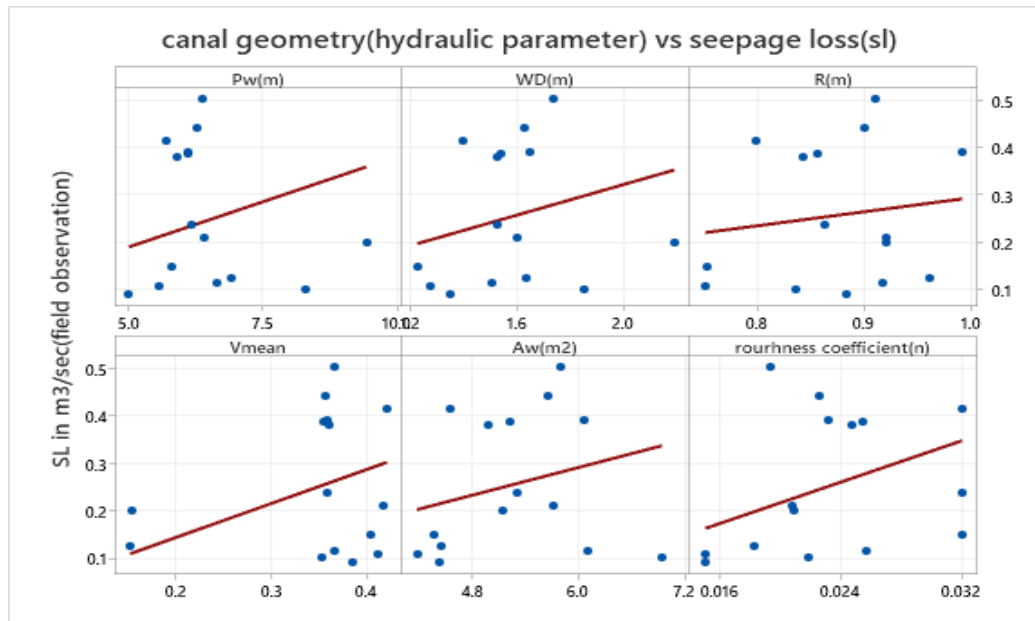


Figure 4.12 Scatterplot for hydraulic parameter correlation with seepage loss

The scatter plot in Figure 4.12 revealed that water depth (WD) and wetted perimeter (Pw) were the primary factors influencing seepage loss (SL) from the canal. According to Hosseinzadeh Asl et al., (2020), the wetted perimeter has been distinguished as an effective parameter in the seepage from the channels, yet the channels side slope has a low impact on the seepage. According to Gad and Waleed (2023), the investigation of the hydraulic parameters showed that the seepage and flow features, such as roughness coefficients, Froude number, and water depth, have significant connections. This shows compatible to the study period and the wetted perimeter (Pw), which indicates the overall length of the canal's boundary in touch with water, exhibits a strong positive relationship with seepage loss. This suggests that with an increase in perimeter, a larger surface area becomes available for water interaction with the canal boundaries, resulting in elevated seepage rates due to the expanded interface facilitating water movement into the adjacent soil. Enhanced water depth(WD) elevates the hydraulic head, promoting more water infiltration into the soil through the canal walls and bed. This heightened pressure gradient significantly boosts the seepage potential. Both these factors are crucial as they directly impact the volume and pressure of water in contact with the canal's boundaries, thereby playing a pivotal role in determining the seepage loss rate in hydraulic systems.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The Wonji Shoa irrigation scheme faces significant challenges in its water conveyance system, with significant losses occurring before it reaches the intended destinations. Field observations reveal that the conveyance efficiency of calculated values is much lower, with a longer service life without maintenance and an extensive length of distributary canal, which makes conveyance efficiency more important than other efficiencies in affecting the overall irrigation performance. The overall conveyance efficiency was 40.29% and 31.59% in the right and left branches of the whole conveyance system, respectively, and on average 35.94% obtained during the study period and the design stage 90%. To improve overall conveyance efficiency, modern technologies should be implemented to monitor water flow and quality, alongside optimized procedures to reduce seepage and runoff. Regular maintenance and infrastructure rehabilitation are also essential to prevent losses from seepage and other inefficiencies. The substantial variation in conveyance efficiency has been attributed to changes in hydraulic parameters (such as the roughness coefficient, wetted perimeter, and water depth), as well as hydrologic factors (seepage and evaporation). Furthermore, this study aided the Wonji irrigation scheme to pinpoint the critical sections of the canal and to carry rehabilitation work on a priority basis. In conclusion, hydraulic parameters were the predominant factors in the Wonji Shoa irrigation scheme's water conveyance inefficiencies and water losses. The investigation of the hydraulic parameters such as wetted perimeter and water depth has been distinguished as an effective parameter in the seepage from the canals. An increased water depth and expanded the wetted perimeter, due to poor canal maintenance and growth of vegetation, further increasing losses through seepage and evaporation. This study finds the inflow-outflow method to be the most suitable for assessing seepage, though empirical formulas like the Moritz and Molesworth methods also provide reliable estimates when validated with field observations. During the study, seepage loss averaged 0.257 m³/s (or 25.7%), with evaporation losses deemed insignificant. These results differ from Kedir's 2012 study, which reported 12.36% seepage loss. Standard conveyance efficiency values significantly impact the irrigation scheme's overall performance.

5.2 Recommendations

Based on the findings regarding hydraulic and hydrologic factors, it was essential to implement a regular maintenance and repair program for the irrigation canals within the schemes. To enhance the efficiency and longevity of the irrigation system, the following recommendations were proposed:

- The schemes should create a comprehensive irrigation water supply plan that aligns with current conditions, replacing existing pumps with those that meet the design capacity and ensuring adequate canal cross-sections.
- Hydraulic factors such as perimeter, depth, and roughness coefficient should be emphasized in order to identify loss areas and increase the efficiency of the canal water conveyance system. Regular evaluations helped to understand the influence of these parameters on system performance.
- For precise computation of seepage loss in the Wonji Shoa irrigation canal, the inflow-outflow approach and the empirical methods of Moritz and Molesworth were advised.
- In order to save huge amounts of water, provide a consistent irrigation supply, and reduce the possibility of water scarcity, it is urgently recommended that priorities canal lining be installed in response to high seepage loss.

By implementing these recommendations, the Wonji Shoa irrigation scheme can improve its operational efficiency, reduce water losses, and enhance the overall productivity of the agriculture.

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APPENDIX-A

Table 1. 1 Main canal hydraulic dimensions, and discharges of Wonji Shoa Irrigation canal

canal Section	Reach Length(m)	WD(m)	Bw	Tw(m)	Vm(m/s)	Pw(m)	Aw(m ²)	Qin(m ³ /s)	Qout(m ³ /s)	CE %
MC A	80	2.400	4.45	6.87	0.16	9.42	12.98	2.550	2.350	92
MC B	80	2.260	2.19	3.40	0.15	6.90	6.310	1.100	0.96	87
A+B	280	2.330	3.320	5.135	0.153	7.08	9.646	2.819	2.692	96
MC end	480	1.600	2.35	4.80	0.42	6.40	5.720	2.768	2.557	92
	average							2.31	2.14	92
Overall CE%										90.7

Table 1. 2 Secondary right branch canal hydraulic dimensions and discharges of canal

section length	Bw(m)	Tw(m)	Dw(m)	PW(m)	Aw(m ²)	Vmean(m/s)	Q out (m ³ /s)	Qin (m ³ /s)	CE%
200	2.7	4.8	1.85	8.3	6.94	0.35	2.454	2.557	
400	2.2	4.65	1.8	6.54	6.17	0.36	2.213	2.454	
600	2.2	4.5	1.81	6.12	6.06	0.36	2.178	2.213	
800	2.5	4.8	1.65	6.52	6.02	0.36	2.155	2.178	
avg									84.3
1000	2.3	4.65	1.67	6.38	5.80	0.36	2.095	2.155	
1200	2.2	4.3	1.74	6.26	5.66	0.37	2.070	2.095	
1400	2.22	4.5	1.68	6.28	5.64	0.36	2.014	2.070	
Avg									93.4
1600	2.24	4.7	1.63	6.18	5.66	0.35	1.952	2.014	
1800	2.22	4.6	1.53	6.1	5.22	0.36	1.854	1.952	
2000	2.25	4.3	1.54	5.95	5.04	0.36	1.825	1.854	
2200	2.21	4.3	1.53	5.91	4.98	0.36	1.720	1.825	89.4
							Overall		67

Table 1. 3 Secondary left branch canal canal hydraulic dimensions, and discharges of canal

Reach No	R Length(m)	mean velocity(m/s)	Q out (m ³ /s)	Qin (m ³ /s)	CE%
1	250	0.366	2.333	2.557	91.24
2	500	0.364	1.982	2.240	88.48
3	750	0.377	1.744	2.198	79.32
4	1000	0.399	1.328	1.705	77.89
5	1250	0.416	1.079	1.320	81.72
6	1500	0.421	1.007	1.076	93.65
7	1750	0.375	0.985	1.004	98.11
Reservoir	overall before				38.52
1	2000	0.359	1.542	1.738	88.72
2	2250	0.376	1.476	1.728	85.42
3	2500	0.379	1.405	1.721	81.66
4	2750	0.383	1.358	1.672	81.23
5	3000	0.376	1.354	1.645	82.33
6	3250	0.353	1.354	1.640	82.54
7	3500	0.376	1.354	1.617	83.72
8	3750	0.347	1.354	1.568	86.37
	overall after				74.08
	overall				52.95

Table 1. 4 Comparison of calculated value for “n” for Wonji Shoa irrigation canal

Canal Section	WD(m)	Bw (m)	Tw (m)	PW (m)	Aw (m ²)	So(m/m)	R (m)	m(H:V)	Vm(m/s)	Qin(m ³ /s)	n
Mc lined	2.19	4.41	6.84	9.42	5.14	0.00024	0.546	1/1.6	0.152	3.650	0.021
	1.64	2.64	5.23	6.93	4.45	0.00024	0.642	1/1.6	0.153	2.819	0.018
	1.59	2.47	5.15	6.07	4.45	0.00024	0.733	1/1.6	0.418	2.692	0.021
SCL unlined	1.45	2.86	4.68	6.30	4.45	0.00025	0.705	1/1.4	0.385	2.557	0.022
	1.46	2.21	4.40	5.86	4.45	0.00016	0.759	1/1.5	0.398	2.025	0.023
	1.42	2.17	4.50	5.83	4.45	0.00010	0.762	1/1.6	0.394	1.916	0.019
	1.32	2.14	4.40	5.55	4.45	0.00011	0.802	1/1.7	0.397	1.786	0.023
SCR unlined	1.78	2.40	4.69	6.87	6.30	0.00012	0.917	1/1.2	0.357	2.557	0.025
	1.69	2.24	4.48	6.33	5.70	0.00010	0.901	1/1.9	0.361	2.160	0.025
	1.56	2.23	4.48	6.08	5.22	0.00012	0.860	1/1.4	0.356	2.010	0.026

Table 1. 5 General water efficiency and loss in the lined and un-lined Wonji Shoa canal.

Efficiency and Water loss in the lined and un-lined watercourses				
Canal types	Qin(m ³ /s)	Qo(m ³ /s)	Water efficiency (%)	Water loss (%)
Main Canal	2.819	2.557	90.7	9.28
SC Left branch	2.557	1.354	52.95	47.05
SC Right branch	2.557	1.720	67	33
Tertiary canal Total	0.0750	0.0480	64.63	35.37

Table 1. 6 Generally details dimensions and seepage loss inflow-outflow method (Field observation)

Canal Name	Length(m)	WD(m)	Bw	Tw(m)	Vmean(m/s)	Pw(m)	Aw(m ²)	R(m)	Qin(m ³ /s)	Qout(m ³ /s)	SL(m ³ /s)	SL%/100m	SL(m ³ /s/100m)	SL(l/s/m ²)
Mc	280	1.64	2.6	5.23	0.15	6.93	4.45	0.96	2.819	2.692	0.1270	1.60898	0.04536	0.06546
	480	1.6	2.4	4.8	0.418	6.4	5.72	0.92	2.768	2.557	0.2110	1.58809	0.04396	0.06868
Seepage water loss in the main irrigation canal.										Average	0.1793	1.59853	0.11524	0.13547
SCR	200	1.85	2.7	4.8	0.35	8.30	6.94	0.84	2.557	2.454	0.1030	2.01479	0.05152	0.06207
	600	1.65	2.5	4.8	0.36	6.12	6.06	0.99	2.55	2.155	0.3905	2.55702	0.06509	0.10636
	1000	1.74	2.2	4.3	0.37	6.38	5.80	0.91	2.45	1.952	0.5020	2.04564	0.05020	0.07868
	1400	1.63	2.2	4.7	0.36	6.28	5.65	0.89	2.454	2.014	0.4400	1.28096	0.03143	0.05005
	1800	1.54	2.3	4.3	0.35	6.10	5.22	0.85	2.213	1.825	0.3884	0.97489	0.02158	0.03537
	2200	1.53	2.2	4.3	0.36	5.91	4.98	0.84	2.178	1.799	0.3794	0.79157	0.01724	0.02918
Seepage water loss in the SCR irrigation canal.											0.3672	1.61081	0.03951	0.06029
SCL	250	1.51	3.3	4.8	0.366	6.65	6.09	0.91	2.557	2.440	0.1166	1.82492	0.04666	0.07016
	1250	1.4	2.2	4.3	0.421	5.7	4.55	0.79	2.440	2.025	0.4146	1.35946	0.03317	0.05820
	1750	1.53	2.2	4.7	0.359	6.16	5.31	0.86	2.173	1.936	0.2364	0.62184	0.01351	0.02193
	3000	1.23	2.3	4.8	0.404	5.8	4.37	0.75	1.936	1.786	0.1505	0.25913	0.00502	0.00865
	3750	1.28	2.1	4.42	0.412	5.56	4.17	0.75	1.786	1.678	0.1080	0.16136	0.00288	0.00518
	4500	1.35	2.0	4.09	0.385	5.01	4.42	0.88	1.678	1.587	0.0911	0.12076	0.00203	0.00404
Seepage water loss in the SCL irrigation canal.								average unlined canal			0.1862	0.72458	0.01721	0.02803
										Avg	0.2573	1.1677	0.0457	0.0442
										Total	3.8589	14.1890	0.6861	0.7087

Table 1. 7 Estimation of evaporation losses

Canal Name	Length(m)	WD(m)	Bw(m)	Tw(m)	Vmean(m/s)	Pw(m)	Aw(m ²)	Qin(m ³ /s)	kE	Ep(mm/day)	R(%)
MC	78	2.19	4.41	6.84	0.16	9.42	5.14	2.550	0.70	3.57	0.0012
	280	1.64	2.64	5.23	0.15	6.93	4.45	2.819	0.70	3.57	0.0034
	480	1.6	2.35	4.8	0.42	6.4	5.72	2.768	0.70	3.57	0.0042
SCR	200	1.85	2.7	4.8	0.35	8.3	6.94	2.557	0.70	3.57	0.0016
	600	1.65	2.5	4.8	0.36	6.12	6.06	2.546	0.70	3.57	0.0054
	1000	1.74	2.2	4.3	0.37	6.38	5.80	2.454	0.70	3.57	0.0087
	1400	1.63	2.24	4.7	0.36	6.28	5.64	2.454	0.70	3.57	0.0137
	1800	1.54	2.25	4.3	0.35	6.1	5.22	2.213	0.70	3.57	0.0194
	2200	1.53	2.21	4.3	0.36	5.91	4.98	2.178	0.70	3.57	0.0252
SCL	250	1.51	3.27	4.8	0.38	6.65	6.09	2.557	0.70	3.57	0.0022
	1250	1.4	2.2	4.3	0.42	5.7	4.55	2.440	0.70	3.57	0.0140
	1750	1.53	2.24	4.7	0.35	6.16	5.31	2.173	0.70	3.57	0.0206
Avg											0.0095

APPENDIX-B



Figure 4.1 Main canal conveyance system at Cipoletti weir



Figure 4.2 Vegetated growth left branch secondary canal and dimension measurement



Figure 4.3 Right branch canal characteristics and discharge estimation



Figure 4.4 Poor management of NSR and inlet of water from left branch canal



Figure 4.5 Left branch canal geometry dimension and discharge measurement



Figure 4.6 Water velocity measurement and canal dimension



Figure 4.7 Malfunction of canal bank and poor management of division box/offtakes



Figure 4.8 vegetation growth at the bank and bed of the secondary canal left branch



Figure 4.9 Main canal discharge measurement and canal dimension at water marked