Maximizing Water Use Efficiency through Intra-Basin Canal System: The Case of Awash River Basin

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A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Master of Science in Hydraulic Engineering.

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Certification

The undersigned certify that he has read the thesis entitled**: Maximizing Water Use Efficiency through Intra-Basin Canal System: The Case of Awash River Basin** and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

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This is to certify that the thesis prepared by Betelhem Wondimneh Demeke, entitled: Maximizing Water Use Efficiency Through Intra-Basin Canal System: The Case of Awash River Basin and Submitted in partial Fulfillment of the Requirement for the Degree of Master Science in Civil Engineering (Major in Hydraulic Engineering) complies with the regulations of the University and meets the accepted standards with respects to originality and quality.

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Abstract

The pressure on the world's fresh water is increasing from time to time due to rapid population growth, agricultural expansion and industrialization. This situation is also observed in the Awash River Basin which calls for water resource management measures. In situations where developing new water sources has difficulties, effective use of the available water is the management measure that can be applied. The agricultural sector, which is the major water user and the base for the economy of the country, is the sector where management of existing resource is critical. For one thing the sector is facing competition for water from other sectors such as industries, domestic water supply and livestock. Also, the sector has one of the least water use efficiencies due to loss of great volume of water in conveyance and application. This research was carried out with the objective of maximizing agricultural water use efficiency in Awash River Basin by improving conveyance and application efficiencies. The research tried to meet this objective by proposing artificial waterway (canal system) instead of the current natural river-course to convey the water exiting Koka dam. A specific study area within the Awash River Basin was first identified. Within this study area canals were designed to convey water exiting Koka dam to irrigation schemes. The canal system improves conveyance efficiency and deliver the head required to operate pressurized irrigation systems without external energy requirement. In addition, land suitability analysis was carried out to identify total area suitable for irrigation within the study area by considering slope, soil type, and land use. The results of the suitability analysis show that there is 298,709.2 ha of land suitable for irrigation within the study area. The results of the canal design indicate that conveyance and application efficiencies were improved. This improvement in water use efficiency resulted in water saving that is estimated to irrigate 134,299.6416 ha of land which is twice the area of the existing irrigation schemes. The water saved could be used to irrigate the unirrigated land or it could be released downstream. With additional control structures, the canal system will also help manage the released water better through transparent and equitable allocation and pricing.

KEYWORDS: Water Use Efficiency, Conveyance Efficiency, Application Efficiency, Canal, Suitability Analysis

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List of Acronyms

ARBA	Awash River Basin Authority
DEM	Digital Elevation Model
ET_o	Reference Evapotranspiration
ET_c	Crop Water Requirement
Ha	Hectare
hrs	Hours
Kc	Crop Coefficient
NIR	Net Irrigation Requirement
WUE	Water Use Efficiency
WEAP	Water Evaluation And Planning

1. Introduction

1.1 Background

Water is a very essential resource for humans. It is a scarce resource that needs to be conserved and nourished. There is a growing pressure on the world's fresh water due to several reasons. Some of which are: rapid population growth, industrialization and increase in agricultural production. As a result, many countries in the world are facing water shortage. This problem is also observed in Ethiopia particularly in the Awash River Basin, as the basin is home of several activities that require large quantity of water.

The Awash River Basin is experiencing water scarcity due to growing demands from different sectors. Rapid population increase, expansion of agricultural fields and increase in number of industries are the factors contributing to the shortage of water in the basin. This basin contains important economic activities for the country such as power generation, mining, agriculture and tourism. As a consequence, the existing water stress in the basin can have negative impacts for human beings, ecosystems and economic activities. This highlights the need to come up with immediate management measures to solve the problem.

The economy of Ethiopia depends mainly on agriculture. Agriculture is the main food supplier to the nation. This sector is facing competition for water from non-agricultural sectors like industries (due to fast industrialization) and the domestic sector (due to rapid population growth) etc. One of the possible solutions to the increased water demand is maximizing water productivity. Maximizing water productivity implies improving yield of a crop while utilizing less water. Agricultural crop productivity can be achieved by using improved crop variety, applying precise agriculture, using modern irrigation, diversifying cropping pattern and most importantly improving water management. This research focuses on the application of two measures which are improving water management and using modern irrigation methods (drip, sprinkler etc…) to maximize water productivity within the Awash River Basin.

A considerable reduction in agricultural output results from losses like conveyance loss, application loss and others. A huge amount of irrigation water is usually conveyed over large distances through watercourses. During conveyance water is lost through evaporation or seepage. Also, loss of water occurs during the application of irrigation water in the field especially in case of traditional irrigation methods. If we can minimize the conveyance loss by using efficient canals and the application loss by using advanced irrigation methods we can save a huge volume of water and maximize the water use efficiency.

1.2 Statement of the Problem

Awash River Basin is the most exploited river basin in Ethiopia. Since the water is being used for several purposes, scarcity of water is a serious problem in the River Basin. The prevailing water use efficiency in the basin is very low which aggravates the water scarcity. There are several irrigation schemes within the basin which are facing competition for water from other sectors. As the pressure on the existing water increases, higher water productivity is a possible solution to improve food production with the existing water.

If we come up with a way of using the existing water efficiently by minimizing the losses, we can reduce the problem of water shortage in the basin. In this study enhancing agricultural water productivity is suggested as a response to the growing water scarcity. Improvement of water use efficiency was achieved through the use of intra-basin canal system that takes water just downstream of Koka dam. If this canal system is delivering water at a higher elevation then the possibility of adopting efficient irrigation system (drip, sprinkler etc…) becomes easy. This research explored this possibility.

1.3 Objective of the Study

1.3.1 General Objective

The main objective of this research is to maximize water use efficiency using a canal system that conveys water with minimum conveyance loss and high head.

1.3.2 Specific Objectives

- Designing an efficient canal system with minimum loss with the aim of improving water use efficiency
- Selecting an optimal canal route
- Evaluating the conveyance efficiency of the proposed canal system and comparing it with that of the natural river course

- Minimizing the need of external energy source to operate modern irrigation methods (pressurized irrigation system like drip, sprinkler etc…) by proposing a canal layout that deliver a head that will operate the systems without need of other energy sources.

1.4 Organization of the Thesis

This report is organized into five chapters.

Chapter 1 presents the problem statement, objectives and background of the study.

Chapter 2 presents a conceptual background of the research matter with a literature review.

Chapter 3 contains a brief description of the methodology used to meet the objectives of the study.

Chapter 4 presents the results obtained using the methodology described in chapter 3 and the interpretation of the results.

Chapter 5 contains conclusions that were drawn based on the findings of the study and recommendations for future works.

2. Literature Review

2.1 Concepts

2.1.1 Water Use Efficiency

Water use efficiency is a measure of efficiency of water use for a defined user type with specified boundaries, and is expressed without units (i.e. as a percentage) requiring the formulation of the net and gross amount of water utilized for the activity under study. (Machibya, Mdemu, & Lankdord, 2004).

Water is lost in irrigation during various processes, thus there are different kinds of irrigation efficiencies which are explained below. (Garg, 2005)

Efficiency of water conveyance; It is the ratio of water delivered into the fields from the outlet point of the channel, to the water entering into the channel at its starting point. It takes conveyance losses into account. (Garg, 2005)

Efficiency of water application; It is the ratio of the quantity of water stored in the root zone of the crops to the quantity of water actually delivered into the field. It takes the water lost in the farm into consideration thus it is also called on farm efficiency. (Garg, 2005)

Efficiency of water storage; It is the ratio of water stored in the root zone during irrigation to the water needed in the root zone prior to irrigation. (Garg, 2005)

Efficiency of water use; It is the ratio of the water beneficially used, including leaching water, to the quantity of water delivered. (Garg, 2005)

2.1.2 Canal

Canal is an open channel that conveys water from a source to a given area of interest. Open channels are designed to carry a design discharge in a safe and economical way. They are usually designed for uniform flow conditions. Designing an open channel involves the selection of channel alignment, size, shape, longitudinal slope, and the type of lining material. Selection of channel alignment is the first step in designing an open channel. (Akan, 2006)

Irrigation canals may be aligned as a watershed canal, contour canal or as a side slope canal. A canal which is aligned along any natural watershed (ridge line) is called a watershed canal or ridge canal. Contour canals follow a contour except for giving the required longitudinal slope. A contour canal irrigates only on one side because the area on the other side is higher. A side slope canal is a canal which is aligned at right angles to the contours. (Garg, 2005)

Whenever it is planned to supply irrigation water to an area, the crops to be grown in that area should be known. The maximum rate of water requirement of all crops in the area should be worked out. The capacity of the canal should be sufficient to fulfill the maximum water demand of all the crops planned to be irrigated. (Garg, 2005)

2.1.3 Irrigation Water Demand

2.1.3.1 Crop Water Requirement

Crop Water Requirement refers to the total quantity of water required by a crop during its base period. It is the amount of water needed to meet the water loss through evapotranspiration. The crop water requirement depends on climate, crop type and growth stage of crops. The influence of climate on crop water needs is given by reference evapotranspiration and the influence of crop type and development stage is represented by crop coefficient Kc.

$$ETcrop = Kc * ETo$$

Where,	ET_{crop}	crop water requirement
	Kc	crop coefficient
	ETo	potential evapotranspiration

2.1.3.2 Net Irrigation Requirement

The net irrigation requirement is the difference between the crop water requirement and the effective rainfall. Whenever the amount of available water drops below the crop water demand, irrigation is needed. (Laycock, 2007)

$$NIR = Kc.ETo - RFeff$$

Where,	NIR	net irrigation requirement
	ETo	potential evapotranspiration
	RFeff	effective rainfall

2.1.4 Reference Evapotranspiration

Evaporation is the process by which liquid from a variety of surfaces such as lakes, rivers, soils pavements is converted into water vapor. Transpiration is the vaporization of water contained in plant tissues. Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Evapotranspiration expresses the amount of water lost from a cropped surface in units of water depth.

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, soil factors and management practices. Thus it expresses the evaporating power of the atmosphere at a specific location and time of the year. The FAO Penman-Monteith method is the most commonly used method for determining ETo. The method has been selected because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Moreover, procedures have been developed for estimating missing climatic parameters. (FAO, 2006)

2.1.4.1 The Penman- Montheith Method

The Penman-Montheith Method is used to determine the open water evaporation, ETo, from meteorological parameters: sunshine hours, air temperature, air humidity and wind velocity.

$$\lambda ET = \frac{\Delta(R_n - G) + \rho C_p \frac{e_s - e_a}{r_a}}{\Delta + r\,(1 + \frac{r_c}{r_a})}$$

Where, ET reference evapotranspiration

R_n net radiation

G the soil heat flux

$e_s - e_a$ vapor pressure deficit of the air

r psychrometric constant

Δ slope of the vapor pressure temperature curve

λ latent heat of vaporization

C_p Specific heat of moist air at constant pressure

p air density

r_a aerodynamic resistance to turbulent heat and vapor transfer

r_c surface resistance

By considering the reference surface of actively growing and well-watered green grass surface with crop height h = 0.12m, fixed surface resistance rc of 70 s.m $^{-1}$ and an albedo of 0.23, the equation for ETo becomes

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

Where, ETo reference evapotranspiration (mm/day)

Rn net radiation ($MJm^{-2}day^{-1}$)

G soil heat flux density ($MJm^{-2}day^{-1}$)

T mean daily air temperature at 2m height (°C)

u_2 wind speed at 2m height (ms^{-1})

e_s saturation vapor pressure (Kpa)

e_a actual vapor pressure (Kpa)

$e_s - e_a$ saturation vapour pressure deficit (Kpa)

Δ Slope of the vapour pressure curve (Kpa °C^{-1})

γ spychrometric constant (Kpa°C^{-1}) $\gamma = \frac{C_p P}{0.622\lambda}$

Where Cp = specific heat of water at constant pressure (0.001013KJ/Kg/ °C)

λ = latent heat of vaporization $\lambda = 2.501 - (2.361 * 10^{-3})\, T$

P = atmospheric pressure

2.1.5 Calculation Procedure and Meteorological Parameters Determining ETo

i. Mean Saturation Vapor Pressure (es)

Saturation vapor pressure depends on air temperature and it can be calculated using the equation below.

$$e(T) = 0.6108\exp(\frac{17.27T}{T + 237.3})$$

Where, $e(T)$ = saturation vapor pressure at the air temperature, T (Kpa)

T = air temperature (°C)

Due to the non-linearity of the above equation the saturation vapor pressure should be calculated as the mean between the saturation vapor pressure at the mean daily maximum and minimum air temperatures for that period.

$$es = \frac{e(T_{max}) + e\,(T_{min})}{2}$$

Where, es = saturation vapor pressure at the air temperature, T (Kpa)

$e(T_{max})$ = saturation vapor pressure at maximum daily temperature

$e(T_{min})$ = saturation vapor pressure at minimum daily temperature (°C)

ii. Slope of the Saturation Vapor Pressure Curve

For the calculation of evapotranspiration, the slope of the relationship between saturation vapor pressure and temperature, Δ, is required. The slope of the curve at a given temperature is given by:

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T + 273}\right)\right]}{(T + 237.3)^2}$$

Where, Δ = slope of saturation vapor pressure curve at air temperature, T (Kpa°C^{-1})

T = air temperature (°C)

iii. Actual Vapor Pressure

The actual vapor pressure can be calculated from relative humidity

$$e_a = \frac{e_s RH}{100}$$

Where, e_a actual vapor pressure (Kpa)

e_s saturation vapor pressure (Kpa)

RH relative humidity (%)

iv. Vapor Pressure Deficit

The vapor pressure deficit is the difference between the saturation (e_s) and actual vapor pressure (e_a) for a given time period.

v. Extraterrestrial Radiation (Ra)

The solar radiation received at the top of the earth's atmosphere on a horizontal surface is called the extraterrestrial (solar) radiation, Ra. Extraterrestrial radiation is given by the equation below.

$$R_a = \frac{24(60)}{\Pi} G_{sc}\, d_r\, (\omega_S \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\sin(\omega_S))$$

Where, R_a extraterrestrial radiation ($MJm^{-2}day^{-1}$)

G_{sc} solar constant = $0.0820 MJm^{-2}min^{-1}$

d_r inverse relative distance Earth-Sun

ω_S sunset hour angle

ϕ latitude (rad)

δ solar declination (rad)

The inverse relative distance Earth-Sun, d_r, and the solar declination, δ, are given by:

$$dr = 1 + 0.033\cos\left(\frac{2\Pi J}{365}\right)$$

$$\delta = 0.409\sin\left(\frac{2\pi J}{365} - 1.39\right)$$

$$\omega s = arcos\,(-\tan(\varphi)\tan(\delta))$$

Where, J is the number of the day in the year

vi. **Relative Sunshine Duration (n/N)**

The relative sunshine duration is a ratio that expresses the cloudiness of the atmosphere. It is the ratio of the actual duration of sunshine, n, to the maximum possible duration of sunshine or daylight hours N.

vii. **Solar or Shortwave Radiation (Rs)**

The amount of radiation reaching a horizontal plane is known as the solar radiation, Rs. It is given by the equation below:

$$R_S = \left(0.25 + 0.5\left(\frac{n}{N}\right)\right)R_a$$

viii. **Relative Shortwave Radiation (R_s /R_{so})**

The relative shortwave radiation is the ratio of the solar radiation (R_s) to the clear-sky solar radiation (R_{so}). R_s is the solar radiation that actually reaches the earth's surface in a given period, while R_{so} is the solar radiation that would reach the same surface during the same period but under cloudless conditions.

ix. **Albedo (α) and Net Solar Radiation (R_{ns})**

Albedo is a measure of the light reflectance property of surfaces. It is the fraction α, of the solar radiation reflected by a surface.

The net solar radiation, R_{ns}, is the fraction of the solar radiation Rs that is not reflected from the surface. Its value is given by:

$$R_{ns} = (1 - \alpha)R_s$$

Where, R_{ns} net solar shortwave radiation ($MJm^{-2}day^{-1}$)

α albedo

R_s incoming solar radiation (MJm^{-2}/day^{-1})

x. **Net Longwave Radiation (R_{nl})**

Net longwave radiation is the difference between outgoing and incoming longwave radiation. As the outgoing longwave radiation is almost always greater than the incoming longwave radiation, Rnl represents an energy loss.

$$R_{nl} = \sigma T^4 (0.34 - 0.14\sqrt{ea})(\frac{1.35R_S}{R_{so} - 0.35})$$

Where, σ Stefan-Boltzmann Constant ($4.903*10^{-9}$ MJ/K^4m^2day)

T mean ten day temperature (K)

R_{so} clear sky radiation ($MJm^{-2}day^{-1}$) calculated as R_{so} =0.75Ra

xi. Net Radiation (R_n)

The net radiation, Rn, is the difference between incoming and outgoing radiation of both short and long wavelengths. It is the balance between the energy absorbed, reflected and emitted by the earth's surface or the difference between the incoming net shortwave (R_{ns}) and the net outgoing longwave (R_{nl}) radiation:

$$R_n = R_{ns} - R_{nl}$$

xii. **Soil Heat Flux (G)**

The soil heat flux, G, is the energy that is utilized in heating the soil. G is positive when the soil is warming and negative when the soil is cooling. Although the soil heat flux is small compared to Rn and may often be ignored, the amount of energy gained or lost by the soil in this process should theoretically be subtracted or added to Rn when estimating evapotranspiration

2.1.6 Land Suitability Analysis

Land Suitability is the degree of appropriateness of land for a certain use. The most important factors affecting the suitability of a land for irrigation are relief (slope), soil, land use. The most important soil characteristics in land evaluation include drainage, texture, soil depth and type, nutrient retention, alkalinity. (S, Wahyunto, F, & H, 2007). Different irrigation methods require different land slope. Land use has an important influence on the suitable of an area for irrigation.

2.2 Review of Previous Studies

2.2.1 Previous Studies Regarding Water Use Efficiency

Joshua W. Faulkner investigated the performance and profitability of two small reservoirs and irrigation schemes in the upper east region of Ghana. He evaluated the performance and efficiency of the irrigation systems by quantifying the amount of water used for irrigation and comparing it to water demand (by using relative water supply). He examined the profitability of the irrigation systems, in terms of water use and cultivated land area. The two reservoir and irrigation schemes that he compared are called the Tanga System and Weega system. In the Tanga system water is carried to the plots through two canals and irrigation is carried out by basin and bucket method. In the Weega system water is conveyed to the filed through two canals and Irrigation is done by trench system. Through his research he found that the Tanga system has a greater relative water supply (RWS) value than the Weega system, often by a magnitude of 2 or more. Based on profitability of released water, the Tanga system is less profitable than Weega system.

From these results, He was able to note the following points.

- The relatively high profit per volume of water in Weega system is as a result of the trench irrigation technique and improved management structure.
- The higher availability of water in the Tanga system is hypothesized to be the primary cause of a less efficient irrigation method and a more relaxed management structure.
- In Weega system, due to relatively less water available, the management is increased to make efficient use of the available water.

He concluded that as the irrigation method and management structure are results of the overall water availability, the higher profitability of water is ultimately a result of lower water availability. If water stress were to become a critical factor, management would become a very important factor in the productivity of irrigation systems. (Faulkner, 2006)

From Joshua's research the importance of using efficient method of irrigation, in increasing profit from an irrigation system can be observed. In Awash Basin water stress is a critical problem. Using advanced techniques of irrigation is thus necessary to make efficient use of the available water.

Ajay K Jha ,et al. (2016) compared the effect of drip and furrow irrigation on the productivity of fodder species using a split-plot design in Gandaki River Basin (GRB), Nepal. Field experiments were conducted at farmers' fields at three locations representing various agro-ecological zones of the Gandaki River Basin (GRB).The primary finding of the research is that drip irrigation yielded similar dry biomass as compared to the traditional furrow irrigation method, while drastically reducing water use. (Drip system of irrigation results in a better water use efficiency than furrow irrigation). The improved water use efficiency of drip irrigation could allow sustainable expansion of irrigated area and cost-effective provision of adequate fodder for livestock systems in water-limited districts of Nepal. Water use efficiency was compared between furrow and drip irrigation at three sites. Across the three sites, water use efficiency (WUE) increased by a factor of 3.99 from furrow to drip irrigation. It was thus concluded that drip irrigation has better efficiency and allow better utilization of limited water. (Ajay, et al., 2016)

P. B. Jadhav, R. T. Thokal, M.S. Mane, H.N. Bhamge and S.R.Kale studied the effect of lining conveyance canals and adopting drip irrigation method in improving water use efficiency. They determined conveyance losses from lined and unlined sections of canal irrigation network under existing situations. They found the overall efficiency of the lined, unlined section the main canal and the unlined section of the field channel to be 75, 52 and 35 percent. These results revealed that management interventions of converting the unlined canal network sections into lined sections can improve conveyance efficiency up to 75%. Under present conditions the losses for canal network are 3.6 times than net irrigation requirement. These losses are reduced by increasing conveyance efficiency by lining the unlined sections of the main canal network and field channels. If both the unlined sections of canal network are converted into lined sections 0.376Mm^3 of water can be saved from which about 43 ha additional area can be irrigated through improving conveyance efficiency up to 75 percent from the present efficiency. To utilize the saved water for irrigation different management strategy were developed. By adapting drip irrigation on 10 percent area, 24.42 percent of water can be saved and 0.99 ha additional area can be brought under irrigation. When the drip irrigation system is adopted for 90 percent area of the seasonal and annual crops in the command area, total 26.8 ha area can be brought under irrigation. (Jadhav, Thokal, Mane, Bhamge, & Kale, 2014)

A report entitled 'More with Less: Agricultural Water Conservation and Efficiency in California: A Special Focus on the Delta' presents the findings of a study carried out to evaluate changes in agricultural water use based on farmers decision regarding crop type, irrigation method and management practices. The study focused on four scenarios for improving agricultural water use efficiency, with a focus on the Sacramento-San Joaquin Delta in California. These were modest crop shifting, smart irrigation scheduling, advanced irrigation management and efficient irrigation technology. Using land and water use data a baseline estimate of irrigated crop area, agricultural water use and economic productivity was constructed. The result of the baseline scenario was compared with those of the four alternatives. The result showed that each scenario has a potential to improve the efficiency of agricultural water use in the region. The annual water savings achieved through the water conservations ranged from 0.6 - 3.4 million acre-feet. Based on the findings of the research, it was concluded that with the existing technologies and improved management practices reduction in agricultural water withdrawal and improved water use efficiency can be achieved. (Cooley, Christian-Smith, & Gleick, 2008)

Robert G. and E. John Sadler discussed the methods and strategies for improving productivity of water. Agriculture's access to water is decreasing as the competition for water increases due to rapid population growth, urbanization, recreation, tourism and related reasons. The water scarcity is observed all over the world. This calls for a paradigm shift from maximizing productivity per unit of land area to maximizing productivity per unit of water consumed. There are several approaches for improving crop productivity. The approach suitable for a given watershed depends on soil, water supply and climatic characteristics and other factors. Three overlapping options can be exercised to reduce water loss at farm and field level. These are increasing crop productivity per unit of water, improving management capacity of growers and spatially optimizing water application and use. Increasing crop productivity per unit of water can be practiced via planting drought tolerant cultivars or reducing inputs such as fertilizers. Improving management capacity of growers can be realized by increasing grower's ability to optimize irrigation amounts in time and space utilizing site specific irrigation techniques and enhanced water delivery systems. Spatially optimizing water application and use can be achieved through several scientific irrigation scheduling scenarios such as deficit irrigation, geographically relocating specific crops to areas of maximum adaptation. Large water saving can be achieved from irrigation through the use of the different management techniques. (Evans & Sadler, 2008)

Tariq Usman and Taj Li Khan presented the findings of a study carried out to assess the effect of conveyance losses, seepage losses maintenance status of irrigation channels on agricultural yield. The study was conducted on three watercourses, at Urmar Minor of Warsak Gravity Canal irrigation system in Pakistan. The study group applied inflow-out flow and ponding methods to determine conveyance and seepage losses in the canals respectively. It was found that in the canals located in totally shady area with high siltation low evaporation and seepage loss were observed. Higher losses were observed in the canals having numerous turnouts which increase seepage losses. It was found that among the several reasons, the main reason for the conveyance losses was poor canal maintenance. The water losses due to inadequate maintenance has led to low agricultural productivity. If the average water losses are saved through improving the canal courses, more water could be saved that is sufficient to irrigate additional area of 13,000 acres. It was suggested that in order to minimize losses and improve agricultural yield, periodic maintenance and clearance of water courses should be practiced. (Saeed & Khan, 2014)

2.2.2 Previous Studies Regarding Conveyance Efficiency

T. Sultan et al. (2014) evaluated conveyance losses in the lined and unlined tertiary canals of irrigation systems in South Asia (Pakistan and India). They found that in Pakistan almost 43.5% of the water losses occur in lined watercourses and 66% of the losses in unlined watercourses and in India 11% of the water losses occur in lined watercourses while 20-25% occur in unlined watercourses. This shows that lining of watercourses increase conveyance efficiency by 22.5% and 12% in Pakistan and India respectively. From their study they made the conclusion that watercourses must be lined to minimize water loss during transport and thus improve conveyance efficiency. (T.Sultan, Latif, Shakir, Kheder, & Rashid, 2014)

Manuel Rijo and Luis Santos Pereira studied the conveyance efficiency of Canal de Salvaterra, in the Sorraia Irrigation Project, Portugal. A special discharge measurement structure was installed at sections of the canal to measure flow and to determine canal inflow - out flow water balance. The conveyance efficiencies were calculated as the ratio between the volume diverted to the conveyance canal and the volume diverted to the distribution system and directly to the farms. The results show that losses are mainly due to discharging excess water and that losses are higher during the night. The conveyance efficiencies obtained were low which suggests the need for the reduction of water losses through better water management. Based on the result obtained, the study suggested to automate the main control structure and to automate on farm irrigation in order to reduce water losses, improve efficiencies and minimize constraints to irrigation during water stressed periods. (Rijo & Pereira, 1987)

A report entitled 'Characterization of Conveyance Losses in Irrigation Distribution Networks in the Lower Rio Grande Valley of Texas presents the findings of a research that analyzed the potential water savings from district renovations and changes in on-farm irrigation. It also presents a literature review on conveyance losses and results of seepage loss tests. The potential water savings were calculated as the difference between the existing conveyance efficiencies and the efficiencies that could be achieved through renovations. The innovations considered were metering, gated pipe replacement of field ditches and siphon tubes and improved irrigation technology such as drip and sprinkler. The analysis resulted that a potential water saving of 230,000 ac-ft/yr could result from improving the conveyance efficiency of the district and a saving of 200,000 ac-ft/yr could be obtained from improved on-farm practices and water management. (Fipps, 2000)

2.2.3 Previous Studies in Awash River Basin

A project called 'Coping with Water Scarcity, the Role of Agriculture, Developing a Water Audit for Awash Basin' was conducted in the Awash River basin. The project has a main objective of assessing current and future demand and water availability in the Basin. The project has three core sub-systems: Database, Water Management and Hydrological–Demand (or Supply-Demand) sub-systems which link to a single decision support system.

In order to achieve the objective of the project land use and soil data, meteorological data, hydrological data for the basin were collected. Agricultural water use was estimated from actual irrigated area, cropping patterns and climatic data for which baseline survey was carried out. Locations, irrigated area, method of irrigation and cropping pattern of irrigation schemes in the basin were collected through questionnaire. Crop coefficient (Kc) values were taken from FAO I & D Paper No. 56, and weighted average monthly Kc values were computed based on the cropping pattern. The net irrigation water requirement was computed using FAO-CROPWAT 8.0 and assumed irrigation efficiency. The survey considered whether the irrigation schemes face water shortage or not and this was assessed in terms of numbers of planned and actual irrigations. The assessment indicated that the number of actual irrigations are on average 68% of the area equipped for irrigation which shows that actual water use is reduced. The reduction in actual water use is attributed to either damage on irrigation structure or shortage of water. The water withdrawal of irrigation schemes which are affected by either one of the reasons is determined by multiplying the irrigation water requirement by 68%. The crop water requirement of rain-fed crops were also computed after collection of data on area under each crop and planting calendar.

Information on the number of each type of livestock for each Woreda was collected during the survey. Using the collected data the livestock water demand was computed by applying daily consumption rate per head per type of livestock. Domestic water demand was computed using population data of 2007 (collected from CSA) and applying per capita consumptions. Industrial water use was also computed after collection of such data from several factories.

Once the demand was computed WEAP model was used for the water balance calculations. The model was used to assess the water available in the basin (by simulation of natural hydrological processes) and to evaluate the effect of water management scenarios. The result of the water balance shows that 72.5% of the annual flow occurs in the rainy season. This indicates the basin is characterized flood in the rainy season and water stress in the dry season thus indicating the critical need for water harvesting and developing effective water management strategy.

It was identified that water shortage is increasing in the basin from time to time due to uncoordinated expansion of irrigation without properly assessing the available water resources and consulting the Authority, mismanagement of water and siltation of Koka reservoir. The mismanagement of water and low irrigation efficiency can be explained by the fact that ground water level at Wonji irrigated field is increasing and the drain outflow is in the range of 1.5-3 m^3/s. It was found that a total of 375 MCM irrigation demand is unmet under current conditions and when the planned irrigation schemes are fully developed the unmet demand increased to 526 MCM.

It was also found that Irrigation efficiency is low and the amount of water withdrawal for irrigation is unknown (The lack of measurement on the volume of water abstractions in the basin has made quantifying water withdrawals and losses difficult) but the farms are paying water charges. There is always disagreement between the farms and Authority on the amount of payment because irrigation charges are based neither on measurement of water withdrawal nor appropriate estimate of crop water requirements.

In addition to expansion of irrigated area of existing irrigation schemes wherever topography situation allows and extending canals, new diversion schemes are being constructed on same river within a short distance of downstream or upstream of an existing irrigation scheme without considering the adequacy of the available water supply. Due to this, water shortage is increasingly becoming a serious problem in many irrigation schemes and this forced to extend irrigation intervals sometimes by more than 150% of the optimum interval. This shortage combined with inefficient irrigation practices would undoubtedly affect crop yields.

The above problems identified from the study stress the need for interventions to alleviate the problem. The most important intervention in reducing water scarcity is improving water management through infrastructural development, technical skills and logistical support.

In this project the effect of different management scenarios were analyzed. The unmet irrigation demand each month was determined for the basin under different water management scenarios. They found that a total of 525.67MCM irrigation demand is unmet when the planned irrigation schemes are fully developed. And when irrigation efficiency increases by 50% and 55%, the unmet irrigation water demand reduces to 312.3 and 235.7 MCM respectively. (FAO, 2013)

The findings of the above project shows that water management has a great effect on irrigation water demand. One of such water management is improving water use efficiency.

In an article entitled 'Assessment of water scarcity and its impacts on sustainable development in Awash Basin, Ethiopia' different options that minimize the gap between supply and demand existing in Awash River Basin were recommended after assessment of the total surface water available, water demand and the gap between the two.

Water resources availability was estimated using Soil and Water Assessment Tool (SWAT) model which requires meteorological data (precipitation, temperature, and solar radiation), spatial data (DEM, land use land cover, soil map) and observed data (stream flow). The climatic data used by the model can be a measured data or it can be generated by the model using inbuilt weather generator. For this study only measured climatic data were used. After supplying the necessary data to the model, it was set up to simulate the various hydrological components of the basin. The uncertainty of parameters such as measured data uncertainty, model uncertainty and parameter uncertainty were checked by using sequential uncertainty fitting (SUFI2). The goodness of fit and the degree to which the calibrated model accounts for the uncertainties were assessed by running p-factor and r-factors test. The output of SWAT model includes surface runoff, evapotranspiration, stream flow, interception storage, infiltration, reservoir water balance and shallow and deep aquifer that have been developed and validated. Since the interest of this study is only the surface water availability of the basin, the outflow of the basin from each sub-basin is added to get the total surface water availability. The total runoff for each sub-basin is obtained by determining and routing runoff for each HRUs (hydrologic response units).

The total demand within the basin was determined by adding the different demand components which are domestic demand, agricultural demand (Irrigation and livestock water demand) and environmental flow.

Once the available water and the demand were determined the difference between the two was computed to assess water scarcity in the basin. The study has reviled that there actually is water scarcity in the basin. The current situation of the basin reflects a water crisis by the general mismanagement and over exploitation of water resources.

In order to solve the increasing water scarcity in the basin several measures are suggested in this study. Some of which are reducing overuse of water, increasing agricultural water use efficiency through modern system of irrigation like drip, sprinkler (this would save significant amount of water, since agriculture is the main user of water in the basin), metering of water (which helps in demand management). Implementation of such measures will enhance the potential of the Awash River to sustainably serve the basin communities. (Dereje, M. L., & Sen, 2015)

Tadesse Fufa conducted a study in Upper Awash Catchment in the Central Rift Valley of Ethiopia, to investigate the consequences of climate change and irrigation expansion on current and future release of Koka dam for the irrigation schemes located downstream of the dam. It was done using WEAP model. The model was used to simulate current and future stream flow (supply) and to compute irrigation demand. The current demand-supply situation were compared to those of the future (where irrigation expansion and climate change scenarios were considered) focusing on irrigations schemes that get water from Koka dam. The findings of the study indicate that, comparing the baseline with the future, there is an increase in unmet demand for both the irrigation expansion and climate change scenarios. One of the recommendations of the study is manage water in order to reduce the unmet current and future demands. (Fufa, 2016)

Mekonen Ayana, et al (2015) investigated the effects of water pricing on water management practices in Awash River Basin Authority (ARBA). The objective of the study was to evaluate the effects of water and service charges on scheme level irrigation performances and user's willingness to pay for irrigation water. In order to undertake the study primary and secondary data were collected from different sources. Primary data was collected via interviews on 29 legally registered irrigation schemes. Willingness to pay for irrigation water was assessed using structured interviews on 31 legally registered irrigation water users. Scheme specific data such as area cultivated, amount of water diverted, water fees, service charges, operation and maintenance fees were collected from Awash Basin Authority. Climatic data were obtained from meteorology stations. Market prices of irrigated crops were obtained from the Ethiopian Central Statistical Authority. Once data was collected logit model was used to identify determinants of willingness to pay for irrigation water. Relative water supply, relative irrigation supply, irrigation efficiency, and water productivity were used as measurements of performance indicators. Comparison of farms that operate under water pricing and non-pricing system in the basin based on the performance indicators shows that there is no significant difference in their overall performance including irrigation efficiency. This leads to the conclusion that the current pricing mechanism (which is low) as a financial incentive is not adequate to encourage irrigators to conserve water and also engage in water saving irrigation technologies. This is due to the fact that neither irrigators nor the authority considers water pricing as a measure of water demand management also the water charge adapted by the basin is fixed in 1994 and hasn't been revised since then. The money collected is used to operate the basin authority and to maintain canals rather than being used as a tool to manage water. Increasing water price in Awash River Basin is unlikely to be feasible due to several reasons some of which are low level of irrigator's knowledge to manage water, poor water conveyance and distribution systems, public ownership over large and medium scale irrigation scheme and inability to control water. Users are willing to pay more than they currently pay in spite of the poor water delivery services. Increasing water charges would increase the income of the basin but reduces that of the farmer's income without much impact on water management practices. The Awash River Authority needs to build its capacity to measure the amount of water used by individual farms and implement of water delivery and distribution systems to minimize losses to implement efficient volumetric water pricing systems. (Ayana, Teklay, Abate, Eshetu, & Mada, 2015)

3. Research Methodology

The general methodology adopted in this study can be summarized in a flow chart as shown below. (Figure 1). The main objective of the thesis which is maximizing water use efficiency was met through maximization of two water use efficiency determinants: conveyance and application efficiency. The maximization of the conveyance and application efficiency was achieved by the introduction of an efficient canal system.

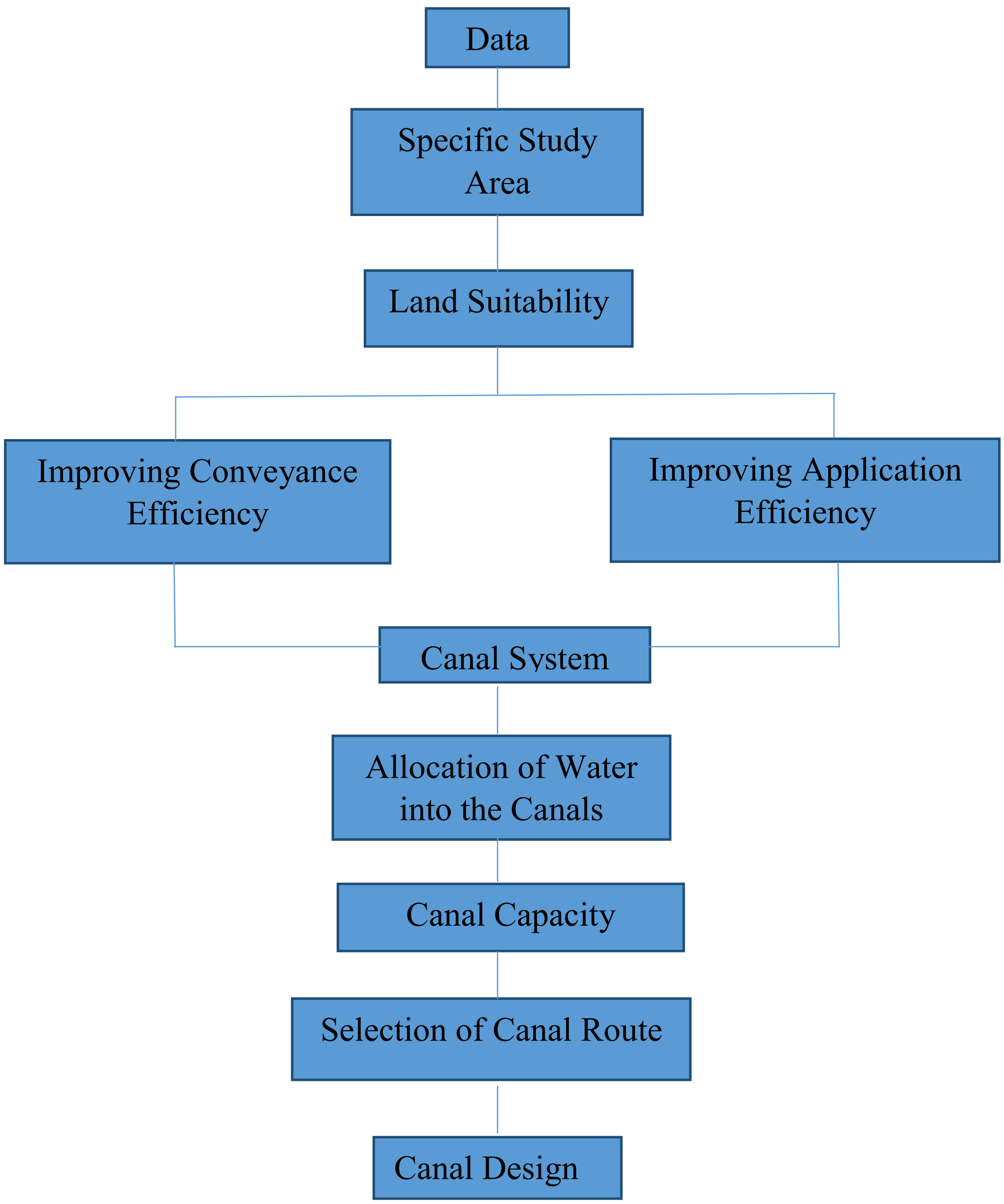

Figure 1: General flow chart describing the methodology

3.1 Data Collection

Topographic map, soil data, land use, climatic data, woreda map, crop coefficient, total area of land irrigated under the current irrigation method and efficiency were some of the data required to carry out the study. These data were collected from different sources.

The topographic map of the basin (30m X 30m DEM) was downloaded. It was used for generating the contour map and the slope map of the study area. The soil data like soil type and soil depth and land use data of Awash River Basin were obtained from Awash River Basin Authority. These data were needed for identifying land suitable for irrigation within the study area. Climatic data that are needed to compute ETo such as temperature, wind speed, relative humidity and sunshine hour were collected from Ethiopian Meteorological Agency. Rainfall data needed to compute the net irrigation requirement was collected from Ethiopian Meteorological Agency. Crop coefficient was required for the computation of crop water requirement. This data was collected from previous research done at Woreda level. The Woreda map of Awash River Basin was needed in order to identify the Woredas within the study area so that weighted average crop coefficient could be determined. It was collected from Awash River Basin Authority. The total area of land irrigated under the current method of irrigation and efficiency was obtained from Awash River Basin Authority. This was used to compare land irrigated under the current irrigation efficiency with the one that can be irrigated after the introduction of the canal system.

3.2 Maximizing Conveyance Efficiency

The conveyance efficiency was improved by providing a canal system that takes water to the irrigation schemes instead of the natural river course. This saves a large volume of water by reducing seepage and evaporation losses. The proposed canals originate from the exit of Koka dam. This site was selected because of two reasons. The first is due to the fact that after the water exits the dam it has sufficient head that can drive the water into the canal without the need of external energy. The second reason is due to the fact that the water is silt free, as it comes from a reservoir where the silt has already been settled. This minimizes the cost of silt exclusion devices.

Two canals were proposed to convey the water that exits Koka dam to irrigation schemes located downstream of the dam. One of the canals takes water to irrigation schemes located to the right of the main Awash River and the other one takes water to the schemes located to the left of the river. Here after they are referred as right canal and left canal.

3.2.1 Location of Study Area

Before selecting alignment and dimension of the canals, the specific study area had to be selected. In order to do that, first the DEM of Awash River Basin was extracted from DEM of Ethiopia (30m X 30m resolution). Contour was generated using the DEM of the basin with a contour interval of 10m (Figure 2). This was done using the Spatial Analyst Tools in Arc Toolbox of ArcGIS 10.1.

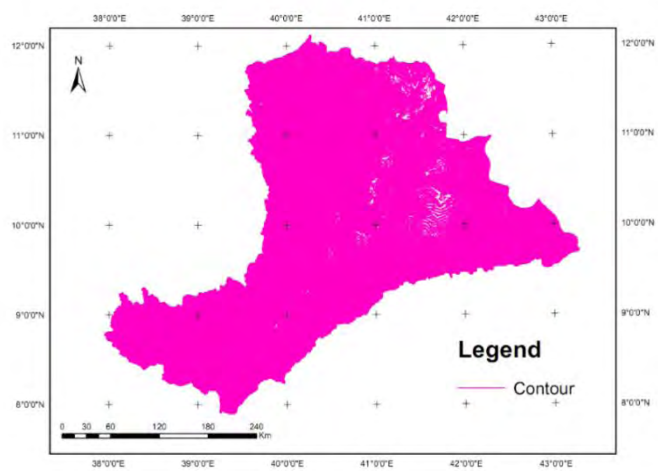

Figure 2: Contour map of Awash River Basin

A picture of the powerhouse of Koka dam taken from Google Earth was added into GIS containing the contour map of Awash River Basin as shown in Figure 3. The picture was georeferenced to locate it in its exact position in the GIS. Once the location of the exit of Koka dam was identified in the GIS, the contour at this location was selected using selection by attribute in ArcGIS (Figure 4). The contour at the exit of the dam was used as the boundary of the study area. With the contour as a boundary, a polygon was created using the Editor tool in ArcGIS. (Figure 5).

Figure 3: Powerhouse of Koka dam

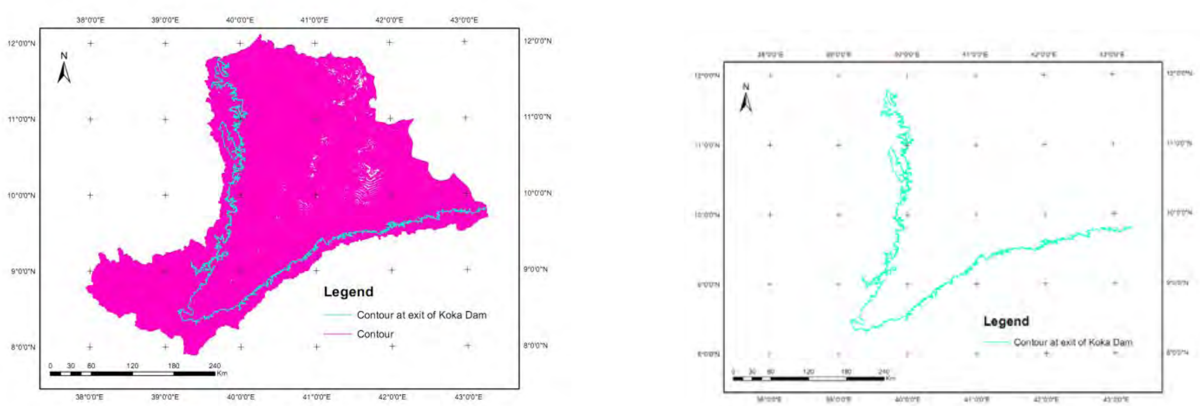

Figure 4: Contour at exit of Koka dam

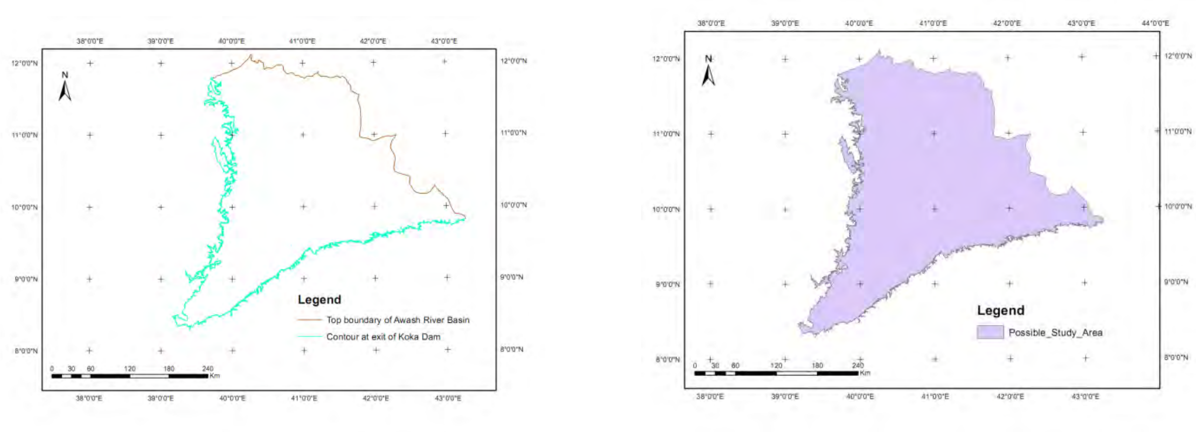

Figure 5: Polygon created using the contour at the exit of Koka dam as a boundary

This polygon was considered as a possible study area. In order to decide whether to take the whole polygon as a study area or to reduce it, the irrigable land within the polygon and the volume of water stored in Koka dam were considered. It means it was needed to check whether the water stored in the dam is sufficient to irrigate the land suitable for irrigation within the possible study area.

The capacity of Koka was 1.667 Bm^3 when it was first constructed in 1959. According to a recent bathymetric survey, the capacity has reduced to 1.186 Bm^3 in 1998 due to sedimentation. (Honningsvag, Midttomme, K.Repp, K.Vaskinn, & T.Esteren, 2001).The current capacity of the dam which is determined by considering its annual sedimentation rate is 1.0385 Mm^3. To decide the area of land that can be irrigated with this water, the case of other countries like Israel was considered. Israel's agriculture is characterized by high technological level, pressure irrigation systems, automatic and controlled mechanization and every year 1129 million cubic meter of water is used by agriculture to irrigate 230,000 ha of land. (Megersa & Abdulahi, 2015).

If advanced irrigation techniques like drip and sprinkler are used, with the water available in Koka dam we can irrigation more area of land than that irrigated in Israel. This is because Israel is characterized by desert and semi desert climatic conditions due to which the crops need more water.

To decide on the particular study area suitability analysis was required. This was first done by considering slope only. The DEM for the polygon was extracted from the DEM of the whole Awash River Basin using the polygon as a mask and slope was generated using the Spatial Analyst Tools in Arc Toolbox of GIS. The slope was reclassified in to three classes of slopes (0-3) %, (3-8) % and > 8%. And the area of land within each slope range was calculated using 'Zonal Statistics as Table' tool in ArcGIS. Land that has a slope of less than 8% is considered to be suitable for irrigation. (FAO, 1996)

To fix the exact area for analysis a trial boundary that can be irrigated by the stored water and the existing hydraulic head is sought. The land that has a slope of 8% within the polygon (the polygon shown in Figure 5) was determined and found to be 60,414,320 ha which is much larger than that can be irrigated using the water stored in the dam. Thus, this polygon cannot be taken as a study area. A trial top boundary was drawn right before Hertale and a new polygon was constructed (Figure 6). Similarly, the area of land with a slope suitable for irrigation in the new polygon was determined and found to be 9,978,818 ha. This is also larger than that can be irrigated with the available water in the dam. Thus, another boundary had to be chosen. A line was drawn beyond Metehara and a smaller polygon was constructed using the line as a top boundary (Figure 7). Within that section the land that has a slope less than 8% was 355,858.927 ha. When other factors that affect the suitability of land for irrigation like soil type, soil depth and land use are considered, arable land within this polygon would decrease and can be irrigated with the water stored in Koka dam. Thus, this polygon was taken as the specific study area (Figure 8). This implies that the maximum length of the canals is up to the end of this polygon.

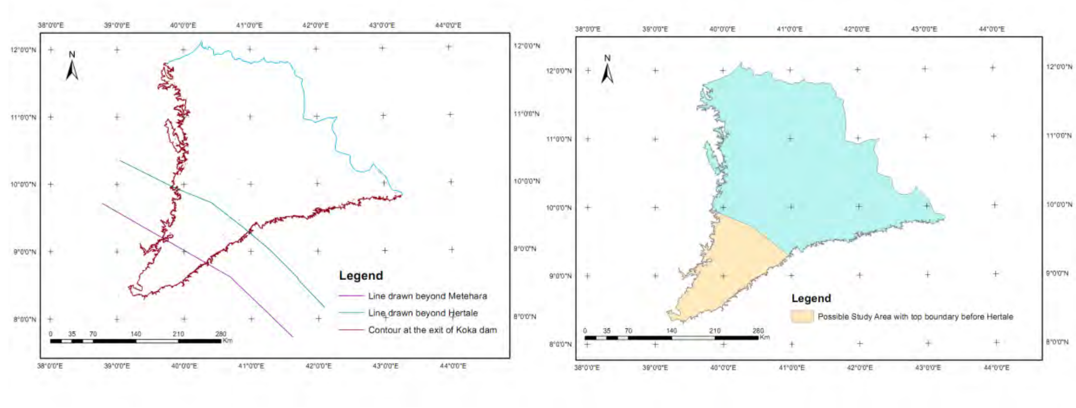

Figure 6: Polygon constructed using a line right before Hertale as a boundary (Possible study area)

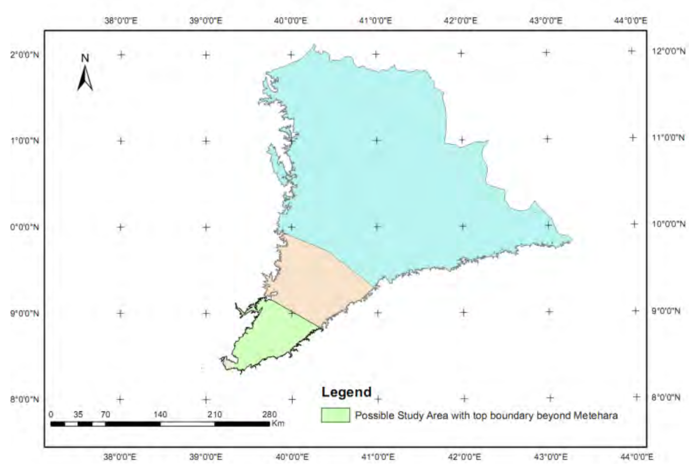

Figure 7: Polygon constructed using a line beyond Metehara as a boundary

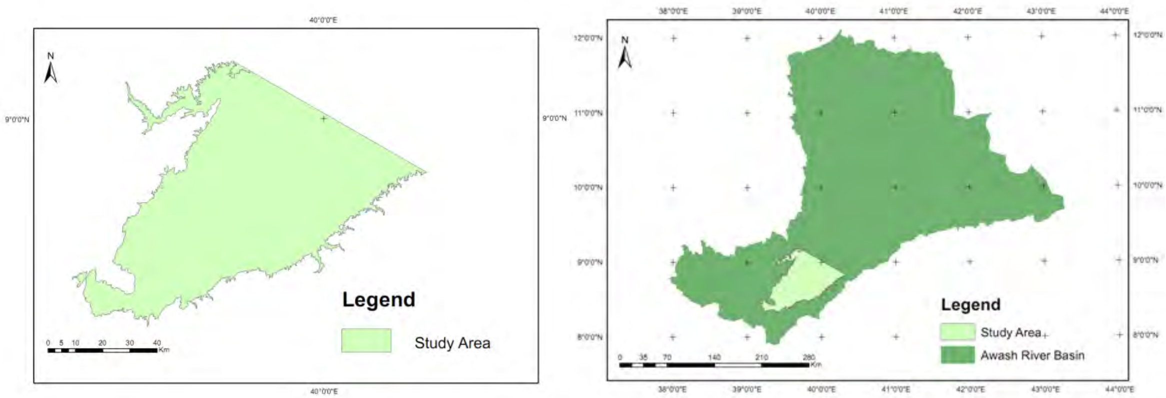

Figure 8: Specific Study Area

The study area was split into two by taking the main Awash River as a dividing line. The portion of the study area to the right of the main stream was named right study area and the portion to the left was named left study area (Figure 9). The location of the study area within the map of Ethiopia is shown in Figure 10 below.

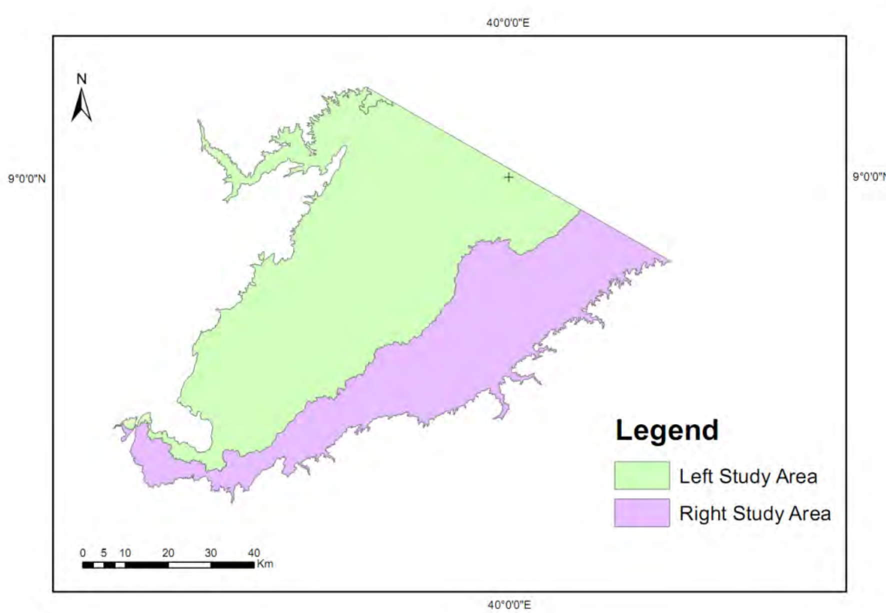

Figure 9: Right and Left Study Area

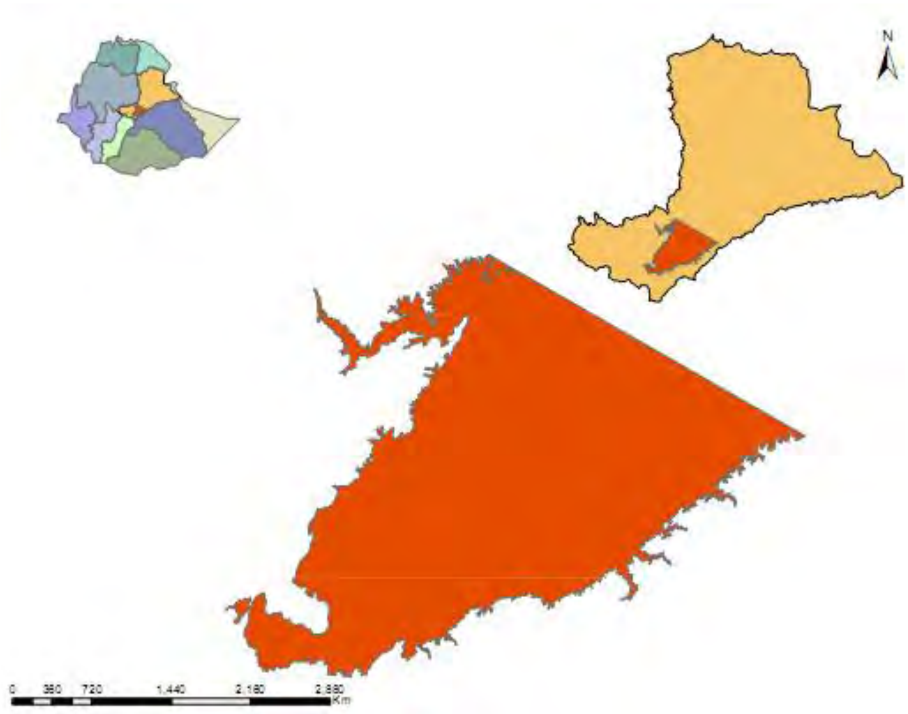

Figure 10: Location of the Study Area

3.2.2 Description of the Study Area

3.2.2.1 Physical Characteristics of Awash River Basin

Awash River Basin is one of the 12 river basins in Ethiopia. It's found between 7.87° to 12.14°N and 37.94° to 43.29°E. It originates from central west part of the country and covers a total area of 110,000 km^2. The main river has a length of 1200Km. It rises at an elevation of about 3,000 masl in the central Ethiopian Highlands, West of Addis Ababa and flows north-eastwards to the Koka reservoir then along the Rift Valley into the Afar Triangle where it terminates in Lake Abe at an elevation of about 250 masl. The total mean annual flow of the river is estimated to be 4900 million cubic meters. Based on physical and socio-economic factors, the basin is divided into Upper Valley (above 1,500 masl), Middle Valley (between 1.500 m and 1.000 masl), and Lower Valley (below 1,000 masl) as well as the Eastern Catchment between 2,500 masl and 1,000 masl) that joins Awash River just before it ends at lake Abe. It is the most intensively utilized river basin in the country. The economy in the basin depends mainly on agriculture. Preliminary assessments indicate that the irrigation potential of the Basin is about 206,000 ha (about 4.76% of the total irrigation potential in the country). This assessment considered only gravity system with land slope not exceeding 5% and medium to large scale irrigation schemes. (FAO, Coping with Water Scarcity, the Role of Agriculture, 2013)

3.2.2.2 Land Use and Soils

Awash River Basin is dominated by exposed rock with about 34.88% of the total land area followed by cultivated land of about 26.98%, open shrub land (20.9%), forest (7.35%) and grassland (6.6%). Water bodies and built up areas make up 3.16% and 0.13% of the total basin respectively. Awash Basin contains 28 different soil types dominated by Lithic Leptosols, Eutric Leptosols and Eutric Vertisols which cover about 70% of the total land area the basin. (FAO, Coping with Water Scarcity, the Role of Agriculture, 2013)

3.2.2.3 Climate

The climate of Awash Basin is influenced by the low pressure zone called the Inter-Tropical Convergence Zone (ITCZ), which marks the convergence of dry tropical easterlies and moist equatorial westerly. There are two distinct rainy periods in the northern plains of the basin. The western part of the basin has mono-modal rainfall with the peak rainfall in July-August while the eastern part is dominated by bi-modal rainfall in Belg (short) and Kiremt (long) rainfall peaks. The major peak is located in the northern Awash in July-August and the minor peak in March-April months. The annual rainfall within the basin has high variability. Spatially, annual rainfall varies from less than 200 mm at Logiya towards the east of the basin to 1700 mm at Ginager in the highlands northeast of Addis Ababa. (FAO, Coping with Water Scarcity, the Role of Agriculture, 2013)

3.2.2.4 Temperature

Mean annual temperature varies from about 12 °C in the north highlands to more than 29 °C in the eastern lowland, with the respective highest temperatures of 17 °C and more than 37 °C. Mean monthly temperature varies from about 12.5 °C in the highlands in July to more than 33.7 °C in the lowlands in June. (FAO, Coping with Water Scarcity, the Role of Agriculture, 2013)

3.2.2.5 Reference Evapotranspiration

Reference evapotranspiration (ETo) varies from 1,200 mm in the western and northern highlands to more than 2,200 mm in the eastern lowlands of the basin. (FAO, Coping with Water Scarcity, the Role of Agriculture, 2013)

3.2.3 Suitability Analysis

Once the specific study area was selected, suitability analysis was carried out to identify sites suitable for irrigation within the whole study area (i.e the total area of land suitable for irrigation within the study area was determined.). The suitability analysis was done by considering slope, soil type, soil depth and land use. The data needed to carry out the suitability analysis which are soil type, soil depth and land use of Awash River Basin were collected from Awash River Basin Authority. The land use, soil type, soil depth of the study area were clipped from those of the Awash River Basin using the polygon of the study area as a mask.

3.2.3.1 Slope Suitability Analysis

Slope is one of the factors that affect suitability of land for irrigation. To generate the slope map of the study area the steps followed are described below. First the DEM of the study area was extracted from the DEM of the Awash River Basin by using the shape file of the study area as a mask. The slope was generated from the DEM of the study area using 'Spatial Analyst tool' in ArcGIS. It was then reclassified using the 'Reclassification tool' in into three classes of slopes i.e. (0-3) %, (3-8) % and (> 8%). The area of land that has a slope less than 8% was considered to be suitable for irrigation as per FAO recommendations.

3.2.3.2 Soil Suitability Analysis

The soil map of the study area was clipped from the soil map of the whole Awash River Basin. The properties of the soils were considered in identifying irrigable land within the study area.

3.2.3.3 Land Use

The land use map of the study area was clipped from the land use map of the whole study area using the shape file of the study area as a clip feature. All land use types but forest, inland water and Herbaceous wetland (sud) were considered suitable for agriculture.

Using the raster calculator in GIS the land within the study area that fulfils all of the suitability criteria for irrigation was identified. The area of the land suitable for irrigation was calculated using the 'Zonal statistics as table' tool from the Arc Toolbar.

3.2.4 Allocation of Total Water in Koka Dam into the Right and Left Canal

The allocation of water into the right and left canal (determining the volume of water that should be released from the dam each month) was carried out based on the assumption that irrigation has priority over power production. To do that the water available in the dam and the irrigation water requirement were considered. As mentioned above currently 1.0385Bm^3 volume of water is stored in Koka dam in a year. From the total water stored in the dam a certain amount (called environmental flow) must be released to maintain aquatic habitats and ecological processes in a desirable state. To fulfil environmental water demand 3 to 5 m^3/s of water is released from the dam each month. (This is from 5 to 10 percent of the total water released each month from the dam.) (Interview with Awash River Basin Authority). For this research, the average value i.e 4 m^3/s (126.144 MCM) was taken as environmental flow and the remaining water i.e 912.356 MCM was allocated into the right and the left canals.

The allocation of water into the left and the right canals was done based on the net irrigation requirement of the area of land located to the right and to the left of the main stream within the study area. In order to calculate NIR, the reference evapotranspiration had to be calculated.

3.2.4.1 Calculation of Potential Evapotranspiration

The Penman-Montheith method was used for calculating potential evapotranspiration. In order to calculate reference evapotranspiration using this method the data required were minimum and maximum temperature, relative humidity, wind speed and sunshine hour. These data were collected from Ethiopian Meteorology Agency. Coordinates of all meteorology stations in Ethiopia and the data recorded were collected. The coordinates of the stations were used to add the stations into GIS as point file. Theissen polygon was generated with all of the stations using Arc Toolbox in GIS to identify the area of land whose meteorological character is represented by each station. The Theissen polygon for the left and right study area were clipped from the total thessien polygon using the shape files of the right and left study areas as a mask. Thus the stations representing the meteorology of the right and left study area were identified. For the left study area the stations were Nazareth, Metehara, Melkasa (IAR), Abomsa, Shola Gebeya, Awash Arba. For the right study area the stations were Nazareth, Metehara, Melkasa (IAR), Abomsa, Gelemso, Awash Arba. Thus for the whole study area seven stations were found to represent the meteorology which are Nazareth, Melkasa(IAR), Abomsa, Gelemso, Awash Arba, Shola Gebeya and Metehara (Figure 11).

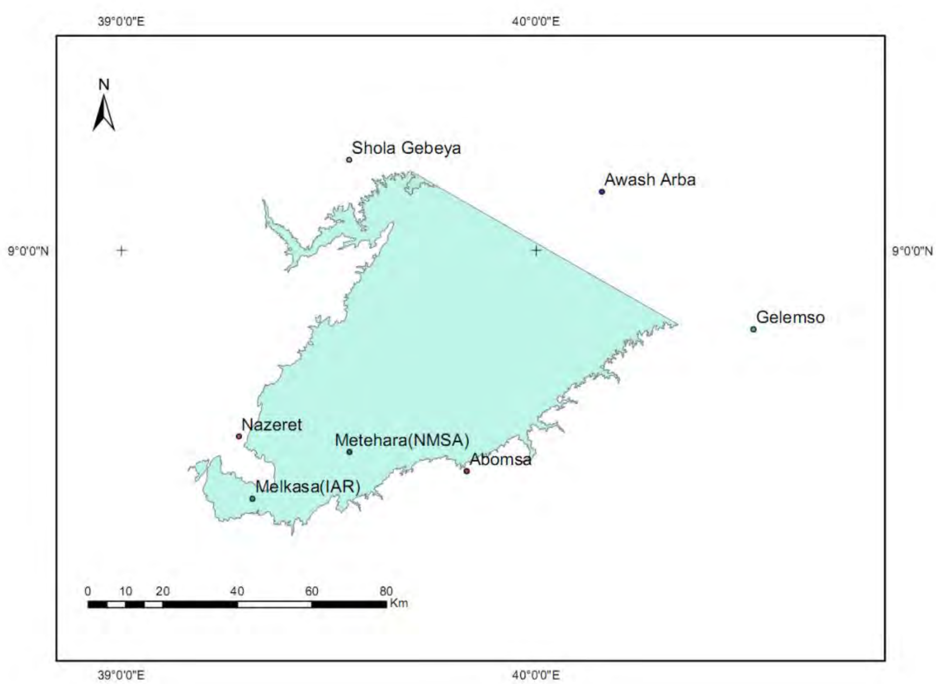

Figure 11: Stations that represent the meteorological character of the study area

The data collected from Ethiopian Meteorology Agency was a monthly data for several years. The duration of the data collected varies from one station to another. (Table 1). It also varies with the data type. Considering the stations in the study area, in one of the stations a 26 years precipitation data was found while in another station 8 years precipitation data was found. The maximum duration of rainfall data is 20 years and the minimum is 8 years. For relative humidity the duration varies from a maximum of 21 to a minimum of 6 years. For sunshine hours the duration of the data varies from 21 to 3 years while for wind speed it varies from 21 to 8 years. The duration of each type of data obtained for each station in the study area is given in table 1 below. For Melkasa station wind speed data was not obtained. Thus it was decided to take the data of Metehara because it is the nearby station.

Table 1: Duration of Data for each Stations in the Study Area

Station	PRECIP	RELHUM	SUNHRS	TEMP	WINDSPEED
Nazareth	1996 - 2015	2010-2015	2010-2014	1996-2015	1996-2014
Melkasa	1996 - 2013	1996-2013	1996-2013	1996-2013	1996-2013
Abomsa	1996-2015	1998-2015	1996-2014	1996-2015	-
Gelemso	2000-2015	2010-2015	2006-2014	2001-2015	2001-2014
Awash Arba	2008-2015	2010-2015	2008-2015	2008-2015	2008-2015
Shola Gebeya	2006-2015	2013-2015	2010-2012	2006-2015	1996-2005
Metehara	1984-2009	1994-2014	1994-2014	1994-2014	1994-2014

Once the stations in the study area were identified the average minimum temperature, maximum temperature, humidity, wind, sunshine hour were calculated for each station at monthly time step. Using the calculated average meteorological parameters, the ETo was calculated at each station using Penman-Montheith Method by preparing excel template.

The next step was the calculation of weighted average ETo. This was done by multiplying the ETo at each station by the ratio of the area that a station represents to the area of the whole study area. Each Theissen polygon was clipped from the total Theissen polygon so that its area can be calculated.

$$Weighted\ Average\ ETo = ET_O \frac{A_I}{A}$$

Where, ETo reference evapotranspiration calculated at a station

Ai area of each Theissen polygon

A area of the right or left study area

3.2.4.2 Net Irrigation Requirement

After the reference evapotranspiration (ETo) was computed, the crop water requirement was determined. To calculate crop water requirement monthly crop coefficient for each station was needed. Monthly Kc values were collected from previous study carried out by Awash River Basin Authority. (ARBA, 2016) For the study a survey was done at Woreda level in which data on crop types and cropping pattern were collected. By considering the crop type and the cropping pattern, they calculated monthly average crop coefficients (Kc) for each Woreda in Awash River Basin. This data along with the Woreda map of the Awash River Basin was used to calculate monthly crop coefficients for each station. This was needed since each station represents area containing more than one Woreda. The Woreda map of the basin was obtained from Awash River Basin Authority. The Woreda map of the study area was extracted from the map of that of Awash River Basin by using the 'Extraction by mask' tool in ArcGIS Arc toolbox. To calculate Kc for each station the Woredas found within a polygon represented by a station were identified. In order to do that first the polygon represented by each station was clipped from the thessien polygon map of the study area. Using the polygon represented by each station as a mask the Woreda map of the study area was clipped. Thus, the Woredas in each polygon and their respective area were identified for the right and left study area. Using this, monthly weighted average crop coefficient was calculated for each station. Crop water requirement was then determined by multiplying ETo by Crop coefficient.

$$ET_C = ET_O K_C$$

Where, ET_c Crop water requirement

ET_o Reference evapotranspiration

K_c Crop Coefficient

Once the crop water requirement was determined the monthly net irrigation requirement was determined by subtracting rainfall from the crop water requirement. The calculation was done for both the right and the left study area at each station. The weighted average NIR was calculated the same way as the weighted average ETo was calculated i.e. by multiplying NIR at each station by the ratio of the area of the Theissen polygon of that station to the area of the total study area.

$$NIR = ET_C - RF$$

$$Weighted\ average\ NIR = NIR\frac{Ai}{A}$$

Where, NIR net irrigation requirement

RF rainfall

Ai area of Theissen polygon represented by each station

A area of the right or left study area

The total water available in Koka dam was divided into the left and the right canals based on the ratio of net irrigation requirement (NIR) of the right and left study areas. NIR was determined on monthly basis, thus the flow rate was allocated into the left and right canal at monthly basis.

After NIR (mm) was determined it was converted into NIR in m^3/ha of land. This was used to calculate the area of land that can be irrigated each month. The area was calculated by dividing the water allocated each month by the corresponding NIR in m^3/ha. $A = \frac{Xi}{NIR}$

Where, A area of land in ha that can be irrigated each month (ha)

X_i water allocated into the right and left canal in month (cumec)

NIR net irrigation requirement (m^3/ha)

3.2.5 Determination of Canal Capacity

The next step was determination of the design discharge for the left and the right canals. Taking the maximum of the monthly discharges (from the discharge allocated to the left and right canal each month based on NIR) as design discharge causes loss of land while taking the minimum discharge as design discharge causes loss of water. Thus, optimization was required to fix design discharge. The objective function was maximizing total area of land irrigated (maximizing sum of land irrigated each month). The constraints were equalizing the area of land irrigated each month and the sum of the discharge allocated each month must be equal to the available water. The output of the optimization is monthly flow rate and area of land irrigated each month.

Objective function maximizing $\sum(\frac{Xi}{NIR})$

Constraints Equalizing $\frac{X_i}{NIR}$

$$\sum Xi \leq total\ yearly\ flow$$

Where, Xi is a decision variable that is the flow rate released every month in m^3/s

NIR is the net irrigation requirement in $m^3/s/ha$

The maximum of the flows obtained from the optimization was selected as the design discharge for the canals. The optimization avoids the loss land or water that would occur if the maximum or minimum discharges were selected as design discharge without optimization. If the maximum discharge was selected as design discharge without optimization, during the months where the maximum flow is not available there will be shortage of water to irrigate the prepared land. This results in loss of land. If the minimum discharge was selected without optimization, the water available during other months is larger than the capacity of the canal (the canal won't be large enough to carry the available water). This causes loss of water. The optimization gives flows that should be released each month to irrigate equal area of land avoiding loss of land and water.

3.2.6 Design of Canal

The canals were designed to carry the design discharge determined using the method described above. Non-erodible or lined channels were selected to check seepage losses and to prevent erosion. In designing the canals maximum and minimum permissible velocities were considered. When the percentage of silt present in a channel is small, a mean velocity of 2 to 3 fps may be used safely and a mean value of not less than 2.5 fps will prevent the growth of vegetation. (Chow, 1959). Since the silt is expected to be small as the water has come from the dam where the silt has already been settled, the average value (2.5 fps = 0.726m/s) is taken as minimum permissible velocity for this research. For a concrete lined channel, the maximum velocity should be between 2.5 - 3 m/s. (Swamee, Mishra, & Chahar, 1999)

The selection of channel material depends on the availability and cost of the material, the method of construction and the purpose for which the channel is to be used. (Chow, 1959). For this research concrete is selected because of its availability. The longitudinal bottom slope of a channel depends on the topography, the energy head required for the flow of water and the purpose of the channel. (Chow, 1959). In this research, since the canals are to be used to deliver water for irrigation (to use advanced irrigation methods), a high head is required at the point of delivery. Therefore, a gentle bed slope is selected.

The side slope of a channel depends mainly on the material from which the channel is made of. Rectangular and trapezoidal cross-sections were proposed to be used. For the trapezoidal section a side slope that results in an economical section is selected. Since non-erodible channels are chosen, there is no need to check the side slope against the criteria of maximum permissible velocity or principle of tractive force. Freeboards varying from 5% to 30% of the depth of flow are commonly used in design. (Chow, 1959). For this research a free board of 17.5 % of the depth of flow was used.

The canals were designed using Manning's equation with the chosen material, side slope and bed slope. With the provided bed slope the head of water supplied by the canals to the locations with highest elevation in the main irrigation schemes within the study area was calculated. If sufficient head is supplied to the locations with highest elevation, then it is obvious that the necessary head will be supplied for the locations with lower elevations.

In determining the head supplied by the canal, the main irrigation schemes that take water from Koka dam were considered. These were Wonji, Tibila, Welenchiti, Fentale, Nurahera and Metehara. The coordinates of these irrigation schemes were obtained from Awash River Basin Authority. It was added into google earth to view the schemes. A polygon was constructed around these polygons in google earth. This polygon was saved as KML file. The KML file was converted to a shape file and saved as a shape file in ArcGIS. This was done for each irrigation schemes. Using the shape files as a mask the DEM of each irrigation scheme was extracted from the DEM of the whole study area. The highest elevation of the schemes was identified from the DEM and the head at these locations was determined. This was necessary in order to check if the head required to operate advanced irrigation techniques like drip, sprinkler was delivered by the canals.

3.3 Maximizing Application Efficiency

The second objective of the thesis which is improving application efficiency was achieved by encouraging the use of advanced irrigation methods like drip and sprinkler. This was done by aligning the canals in such a way that they provide the head required to operate the systems. As it is known, the limitation of these systems of irrigation is their cost of operation. It is because of this reason that they are not commonly used. By providing the head required to operate these irrigation schemes, their use within the study area could be increased. The canals are contour canals. They are aligned in such a way that they follow the contour at the exit of Koka dam. This alignment is selected because the head of water at the exit of the dam can push the water into the canal without the need of additional energy source like pump. The alignment of the canals was drawn in ArcGIS by drawing lines that follow the contour at the exit of Koka dam. This was done using the Editor tool in ArcGIS.

The pressure at which sprinklers operate differs depending on the type of the sprinkler. One type of sprinkler called Hose-fed sprinkler operates at low pressures (from 5 to 20 psi). Another type called Orchard Sprinkler operates at a high pressure (from 10 to 30 psi). (National Engineering Handbook) . Thus 20 psi (15m) was taken as minimum head and 30 psi (22m) the maximum residual head required for the operation of the pressurized systems.

4. Results and Discussion

This section contains the results of each step followed to attain the objectives of the study. The results of the steps followed to improve conveyance efficiency and application efficiency are presented.

4.1 Suitability Analysis

The irrigation suitability analysis was performed in the study area by considering slope, soil type and land use characters of the study area. Accordingly, the results obtained are discussed in the following sections.

4.1.1 Slope Suitability

The slope map of the study area which was generated based on the DEM and reclassified into three range of slopes as shown in Figure 12. As it can be seen from the figure most part of the land within the study area has a slope of less than 8% and is suitable for irrigation. The area of land within each slope range is given in the Table 2.

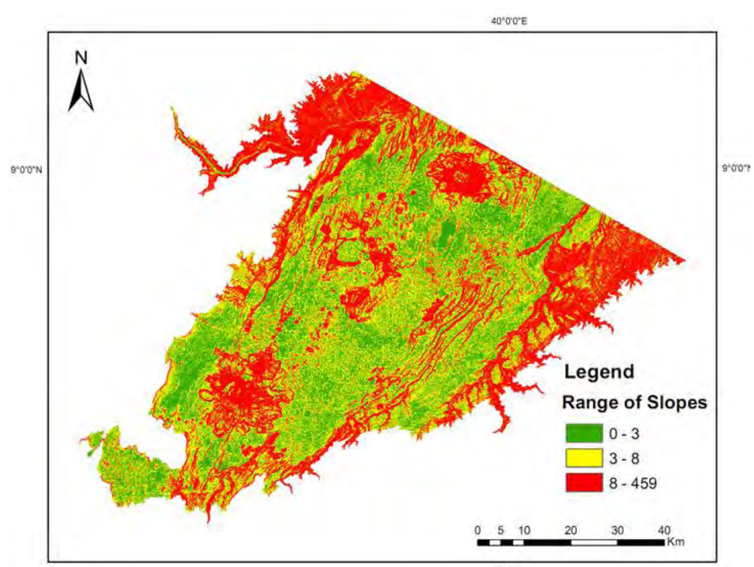

Figure 12: Slope map of the study area

The slope maps of the right and the left study area were also generated separately so that the portion of the total slope based land suitable for irrigation is known in the respective study areas. (Figure 13).

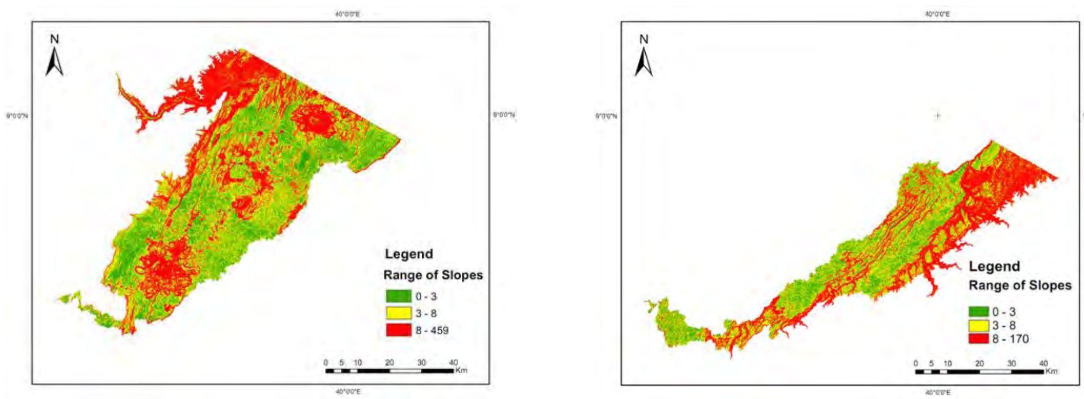

Figure 13: Slope map of the left and right study area

Table 2: Area of land in each slope range

	Area (ha)		
Slope	Right Study Area	Left Study Area	Total Study Area
(0-3)%	45,993.79	106,030.13	151,771.66
(3-8)%	74,106.77	129,799.87	204,088.27
> 8%	76,427.87	122,183.04	198,972.44

4.1.2 Soil

The soil types found in the total, left and right study area are given in Figure 14 and Figure 15. The properties of these soils along with their depth were considered in identifying sites suitable for irrigation. All the soils in the study area but Chronic Luvisols and Calcic Xerosols were considered suitable for irrigation.

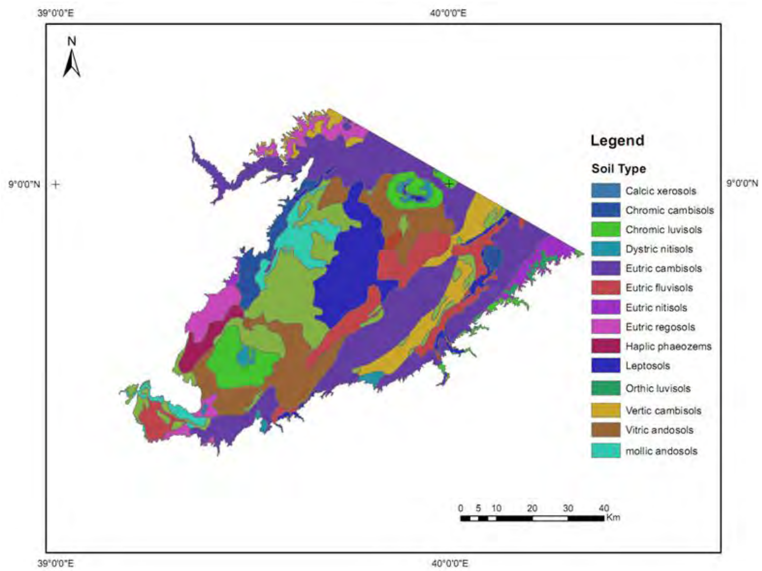

Figure 14: Soil map of the total study area (Source: Awash River Basin Authority)

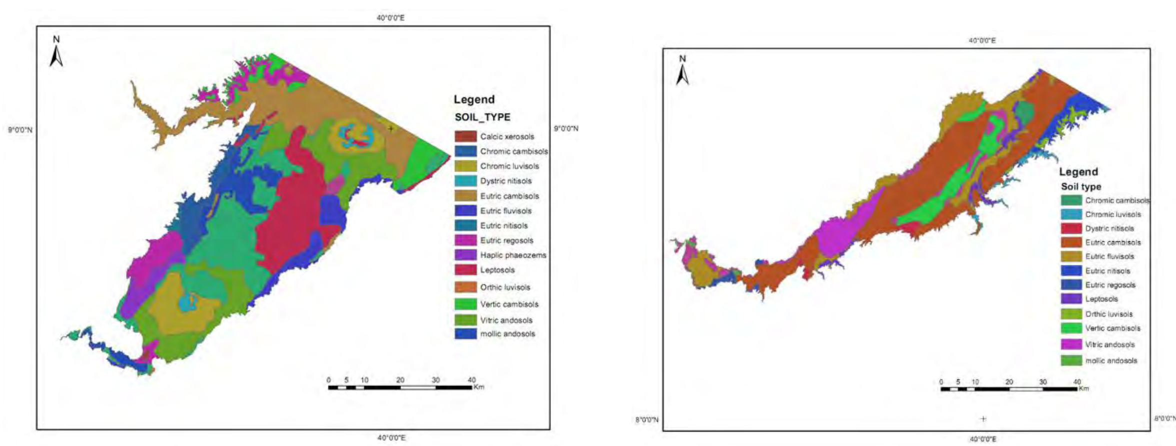

Figure 15: Soil map of the left and right study area (Source: Awash River Basin Authority)

4.1.3 Land Use

The land use maps of the total, left and right study area are given in Figure 16 and Figure 17. All land use types except forest, inland water and Herbaceous wetland (Sud) were considered suitable for agriculture.

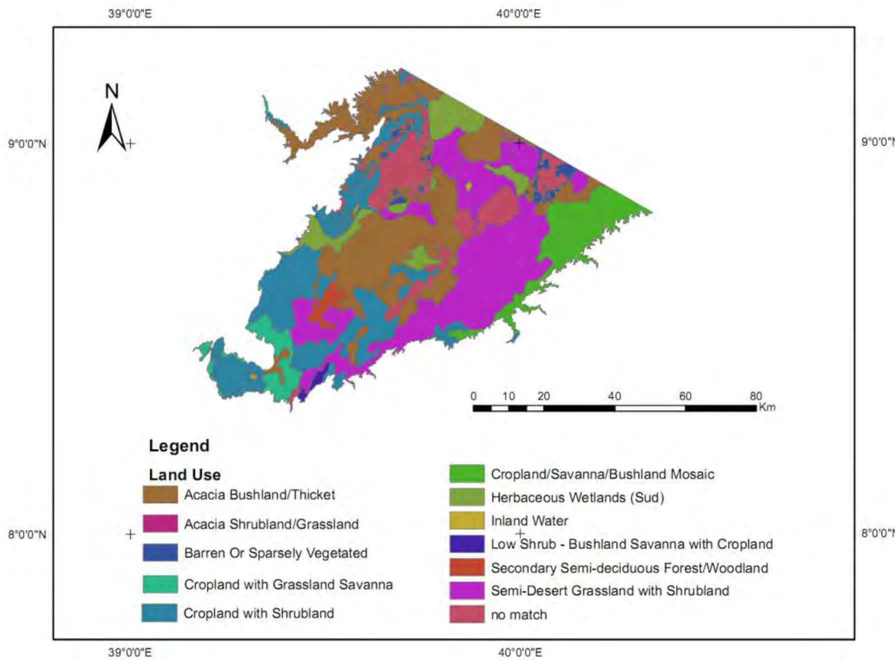

Figure 16: Land use map of the total study area (Source: Awash River Basin Authority

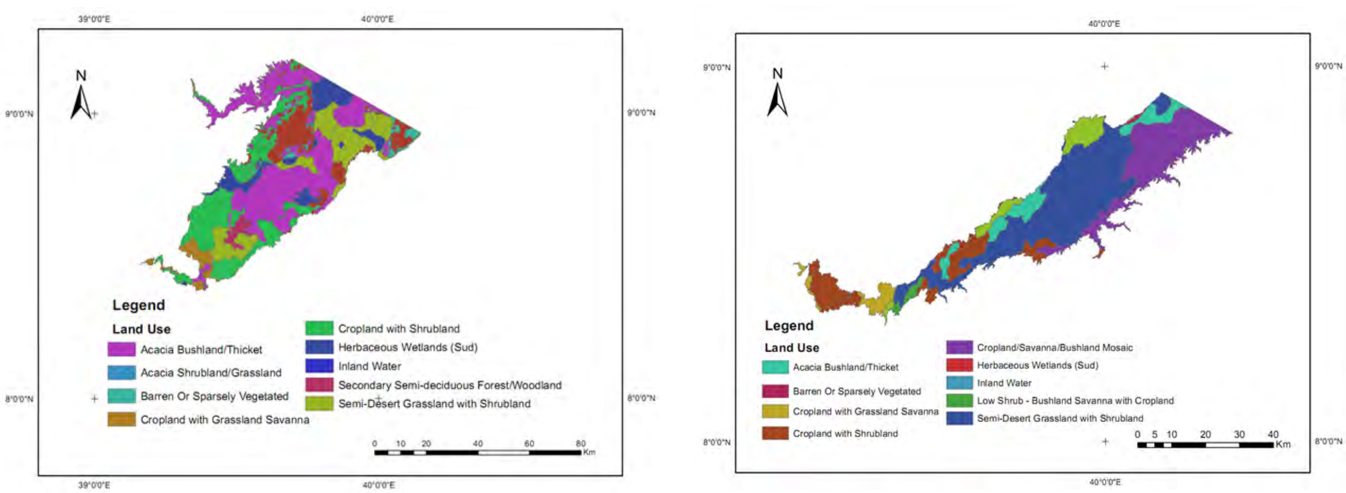

Figure 17: Land use map of the left and right study area (Source: Awash River Basin Authority)

Total arable land within the study area was determined using raster calculator. All factors (slope, soil type and land use) were given equal weight. Thus, the land that fulfilled the suitability criteria in terms of slope, soil type and land use was taken as irrigable land. The suitability analysis showed that a total of 298,709.2 ha of land suitable for irrigation is available within the study area. Out of the total irrigable land within the study area 118,607.6 ha is found in the right study area and

179,006.5 ha is found in the left study area. The identified irrigable sites in the total, left and right study area are shown in Figure 18 and Figure 19.

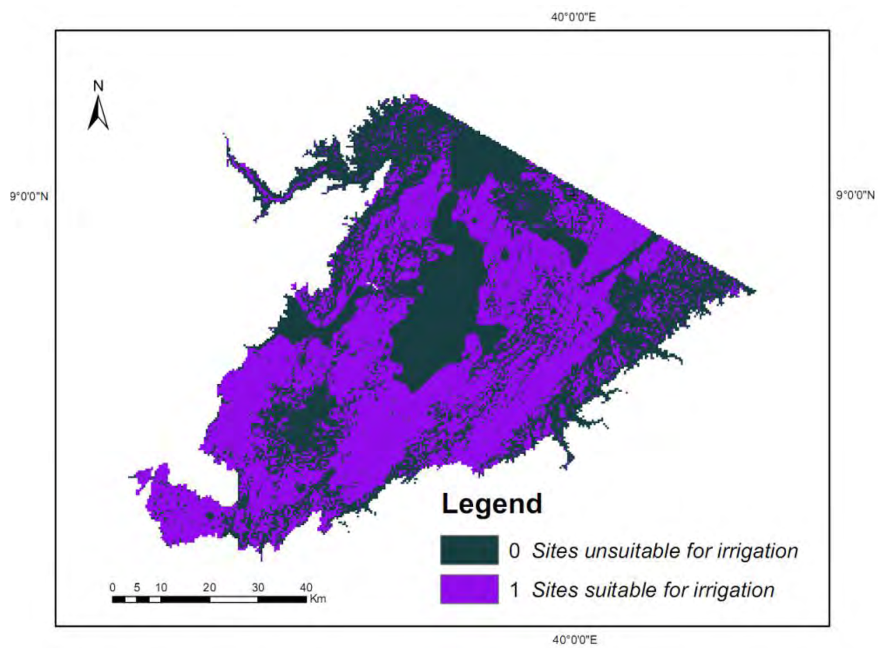

Figure 18: Sites suitable for irrigation in the total study area

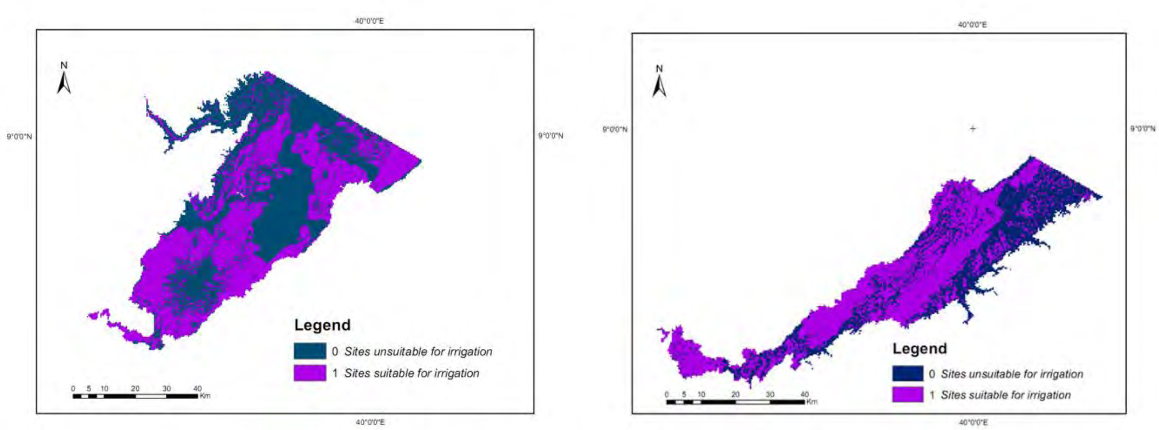

Figure 19: Sites suitable for irrigation in the left and right study area

Based on data collected from Awash River Basin Authority, it is found that the total area of irrigation schemes that take water from Koka dam is 67,037.294 ha. This figure includes irrigation schemes in Amibara which is found outside the study area of this research. Excluding Amibara the total area of the irrigation schemes that take water from the dam is 53,603.294 ha. The difference between the total area obtained from the suitability analysis and the existing schemes is 245,105.906 ha. This implies that if water is saved due to the introduction of the canal system, it can be used to irrigate the land suitable for irrigation which is not currently being used for agriculture.

In this study, the suitability analysis was carried out by considering a land having a slope less than 8% to be suitable for irrigation as shown above, but advanced irrigation methods such as drip and sprinkler can be used on steeper slopes. This implies that if steeper slopes were considered more arable land could be found at near distances avoiding the need of longer canals. The length of the canals and the results of the suitability analysis are conservative.

4.2 Reference Evapotranspiration

Having decide on the potential irrigable land in the study area, it is vital to estimate the reference evapotranspiration of the region so that the irrigation water requirement in the study area is understood.

The climatic data collected for the computation of reference evapotranspiration is of several years duration. The average climatic parameters like relative humidity, wind speed, sunshine hours, maximum and minimum temperature were computed using the data collected from Ethiopian Meteorological Agency. The Meteorological stations found in the study area include Nazareth, Melkasa, Gelemso, Awash Arba, Abomsa, Shola Gebeya, and Metehara. The average monthly climatic parameters calculated at all the stations in the study area are given in the Appendix.

The reference evapotranspiration was calculated using the average monthly climatic parameters using Penman-Monthetih method. The monthly reference evapotranspiration calculated at all stations in the study area is given in Table 3.

Table 3: Monthly ETo at all the stations in the study area

	Eto (mm/day)											
Station	January	February	March	April	May	June	July	August	September	October	November	December
Nazareth	4.64	5.44	5.25	5.37	5.03	5.33	4.21	3.96	4.19	5.04	4.84	4.8
Metehara (NMSA)	4.5	5.35	5.52	5.6	5.76	6.16	5.26	4.86	5.07	5.12	4.8	4.43
Melkasa (IAR)	5.11	6.56	5.97	5.72	6.07	5.73	4.41	4.1	4.4	4.99	5.4	5.16
Abomsa	3.99	4.66	4.86	4.8	4.92	5.2	4.45	4.19	4.1	4.26	4.15	4.03
Gelemso	4.38	4.69	4.81	4.22	3.98	3.97	3.63	3.58	3.44	3.56	3.6	4.19
Awash Arba	4.33	4.77	5.5	5.69	5.76	6.73	5.61	4.98	4.99	5.17	4.87	4.32
Shola Gebeya	3.43	3.94	4.14	3.77	3.98	3.82	2.76	2.58	2.97	3.72	3.04	2.98

In order to calculate the weighted average potential evapotranspiration, Theissen polygon was constructed and the area of each Theissen polygon was determined. (Table 4 and Table 5). This area defines the portion of the land whose meteorological character can be represented by a station.

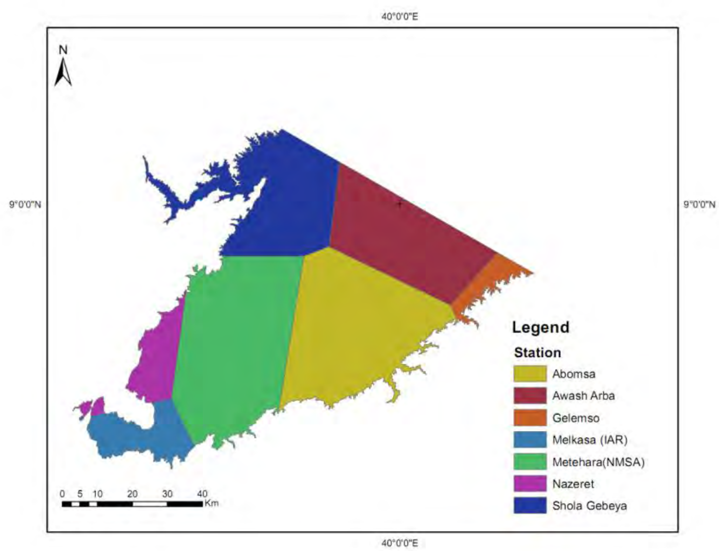

Figure 20: Theissen polygon map of the total study area

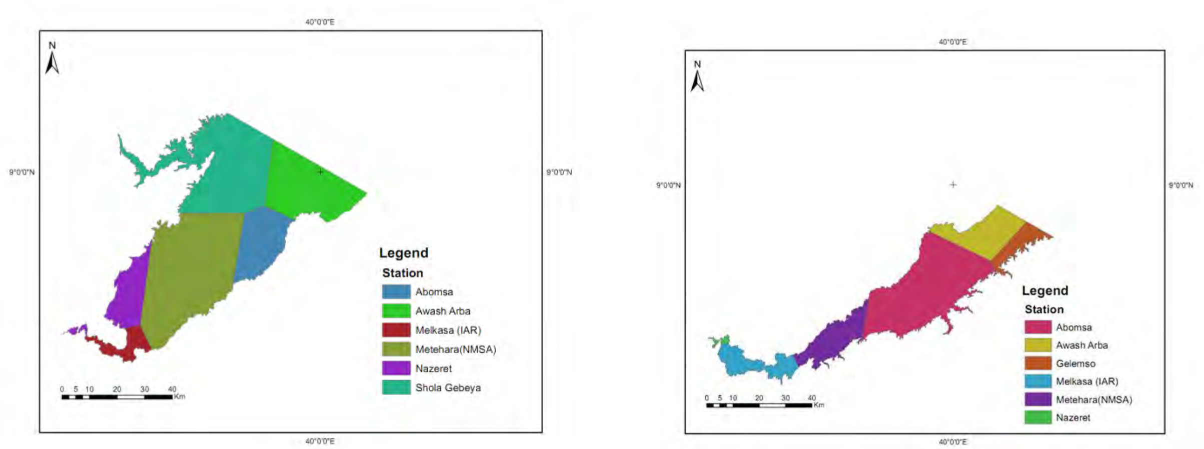

Figure 21: Theissen Polygon map of the left and right study areas

Table 4: Areas of each Theissen polygon (Right study)

Station	Area of Theissen Polygon (ha)
Nazareth	1,203.8
Metehara(NMSA)	27,671.33
Melkasa(IAR)	19,825.93
Abomsa	101,136.04
Gelemso	13,871.26
Awash Arba	33,036.78

Table 5: Areas of each Theissen polygon (Left study)

Station	Area of Theissen Polygon (ha)
Nazareth	27,891.81
Metehara(NMSA)	121,893.81
Melkasa (IAR)	11,586.06
Abomsa	36,555.88
Shola Gebeya	99,199.39
Awash Arba	60,991.34

Using the ratio of the area of each Theissen polygon to the total area and the ETo calculated at each station, the weighted average ETo was calculated for the right and left study areas. The result obtained is given in the Table 6 and Table 7.

Table 6: Monthly weighted average ETo of the right study area

	Weighted Average Eto (mm/day)											
Station	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Nazareth	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03
Metehara(NMSA)	0.63	0.75	0.78	0.79	0.81	0.87	0.74	0.68	0.71	0.72	0.67	0.62
Melkasa(IAR)	0.52	0.66	0.60	0.58	0.61	0.58	0.44	0.41	0.44	0.50	0.54	0.52
Abomsa	2.05	2.39	2.50	2.47	2.53	2.67	2.29	2.15	2.11	2.19	2.13	2.07
Gelemso	0.31	0.33	0.34	0.30	0.28	0.28	0.26	0.25	0.24	0.25	0.25	0.30
Awash Arba	0.73	0.80	0.92	0.96	0.97	1.13	0.94	0.84	0.84	0.87	0.82	0.72
Total	4.27	4.97	5.17	5.12	5.23	5.56	4.70	4.36	4.37	4.56	4.45	4.26

Table 7: Monthly weighted average ETo of the left study area

	Weighted Average Eto (mm/day)											
Station	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Nazareth	0.36	0.42	0.41	0.42	0.39	0.41	0.33	0.31	0.33	0.39	0.38	0.37
Metehara(NMSA)	1.53	1.82	1.88	1.91	1.96	2.10	1.79	1.65	1.72	1.74	1.63	1.51
Melkasa(IAR)	0.17	0.21	0.19	0.19	0.20	0.19	0.14	0.13	0.14	0.16	0.17	0.17
Abomsa	0.41	0.48	0.50	0.49	0.50	0.53	0.45	0.43	0.42	0.43	0.42	0.41
Shola Gebeya	0.95	1.09	1.15	1.04	1.10	1.06	0.77	0.72	0.82	1.03	0.84	0.83
Awash Arba	0.74	0.81	0.94	0.97	0.98	1.15	0.96	0.85	0.85	0.88	0.83	0.73
Total	4.15	4.84	5.06	5.01	5.13	5.43	4.44	4.09	4.28	4.64	4.28	4.02

The reference evapotranspiration of the right study area is slightly greater than that of the left study area in all the months except October as we can see from the chart below. (Figure 22)

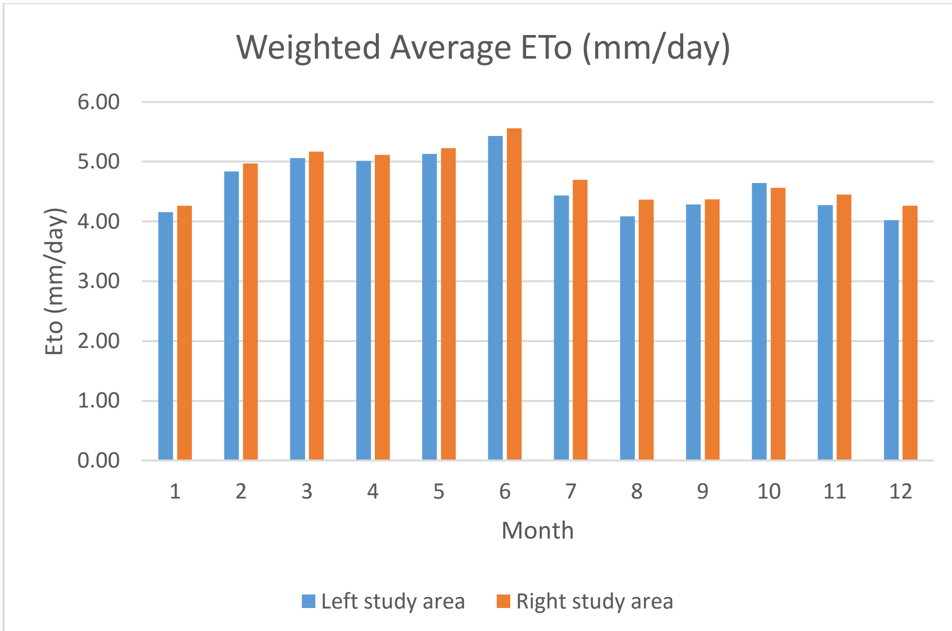

Figure 22: Monthly weighted average ETo of right and left study area

4.3 Net Irrigation Requirement

The average reference evapotranspiration does not consider the amount of rainfall in the study area. Thus, the irrigation requirement defines the water requirement beyond the rainfall amount in a particular area and time. Besides the type of crop to be planted in the area need to be specified for proper irrigation water need estimation. To calculate the net irrigation requirement (NIR), weighted average crop coefficient (Kc) was first calculated. To calculate the weighted average Kc, the Woredas in each Theissen polygon were identified as described in the methodology section. (Figure 23). The Woredas and the area they cover are given in the Table 8 and Table 9.

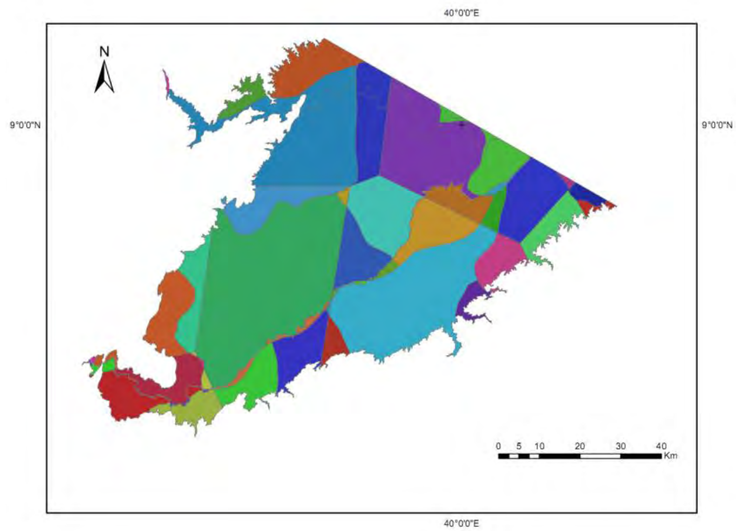

Figure 23: Woredas in each Theissen polygon

Table 8: Woredas within a polygon represented by a station (Right Study Area)

Station (Polygon)	Woredas	Area(ha)
Gelemso	Anchar	9460.55
	Goba Koricha	1297.93
	Mieso	2566.09
Awash Arba	Anchar	20303.71
	Awash Fentale	880.88
	Fentale	7878.45
	Merti	3377.99
	Mieso	546.96
Abomsa	Anchar	9368.92
	Aseko	3399.82
	Boset	1278.29
	Fentale	15268.18
	Jeju	4032.35
	Merti	66655.07
Metehara	Boset	2471.52
	Dodotana Sire	11486.23
	Jeju	13044.18
	Merti	154.53
Melkasa	Adama	11375.44
	Boset	11.99
	Dodotana Sire	7834.08
Nazareth	Adama	1049.46
	Lome	63.83

Table 9: Woredas within a polygon represented by a station (Left Study Area)

Station	Woredas	Area(ha)
Nazareth	Adama	15440.67
	Boset	11800.18
	Lome	162.74
Melkasa	Adama	9993.91
	Boset	895.89
	Dodotana sire	228.67
Metehara	Adama	151.03
	Boset	106287.19
	Dodotana Sire	6.56
	Fentale	805.10
	Jeju	25.11
	Minjarina Shenkora	14222.51
Abomsa	Boset	13398.36
	Fentale	22764.89
	Merti	220.18
	Minjarna Shenkora	0.27
Awash Arba	Anchar	37.69
	Awash Fentale	13331.59
	Fentale	47319.22
Shola Gebeya	Berehet	16641.35
	Fentale	19302.83
	Gimbichu	285.57
	Hagere Mariamna Kesem	4885.73
	Minjarna Shenkora	56537.65

The calculated weighted Average Crop Coefficients at each station of the right and left study area are given in Table 10 and Table 11. The values are weighted average of the crop coefficients at Woreda level.

Table 10: Monthly Crop Coefficient (Kc) for each station of the right study area

	Station					
Month	Gelemso	Awash Arba	Abomsa	Metehara	Melkasa	Nazareth
January	0.69	0.68	0.59	0.19	0.62	0.90
February	0.92	0.85	0.61	0.19	0.62	0.90
March	0.86	1.01	0.84	0.28	0.77	1.11
April	0.86	1.01	0.84	0.28	0.77	1.11
May	0.74	0.89	0.68	0.21	0.73	1.07
June	0.07	0.34	0.30	0.25	0.73	0.97
July	0.07	0.36	0.48	0.88	1.01	1.01

August	0.07	0.37	0.48	0.88	1.01	1.01
September	0.07	0.37	0.48	0.88	1.01	1.01
October	0.12	0.35	0.47	0.88	0.96	0.93
November	0.28	0.33	0.22	0.03	0.57	0.87
December	0.28	0.33	0.22	0.03	0.57	0.87

Table 11: Monthly Crop Coefficient for each Station of the left study

	Station					
Month	Nazareth	Melkasa	Metehara	Abomsa	Awash Arba	Shola Gebeya
January	0.69	0.86	0.43	0.76	0.87	0.79
February	0.69	0.86	0.34	0.74	0.84	0.83
March	0.89	1.06	0.51	0.93	0.90	1.10
April	0.89	1.06	0.51	0.93	0.90	1.10
May	0.80	1.02	0.37	0.86	0.88	0.93
June	0.63	0.93	0.13	0.73	0.94	0.44
July	0.82	1.01	0.47	0.87	0.94	0.44
August	0.82	1.01	0.47	0.87	0.98	0.44
September	0.82	1.01	0.47	0.88	0.99	0.44
October	0.78	0.94	0.47	0.84	0.93	0.41
November	0.52	0.83	0.01	0.65	0.90	0.41
December	0.52	0.83	0.01	0.65	0.90	0.41

After the average crop coefficient was determined, the net irrigation requirement was calculated at each station. This is done with the assumption that the same type of crops are cultivated in the right and left study area. The total net irrigation requirement of the right and left study areas obtained by adding the net irrigation requirement at all the stations in the respective study areas is given in Table 12.

Table 12: Total weighted average NIR of the right study area

Month	**Weighted Average NIR(mm/day) of right study area**	**Weighted Average NIR(mm/day) of left study area**
January	1.71	2.34
February	2.48	2.47
March	2.02	2.66
April	1.92	2.43
May	1.56	2.18
June	0.51	1.32

July		0.29
August	0.08	0.29
September	0.50	0.85
October	0.99	1.74
November	0.46	1.37
December	0.81	1.47

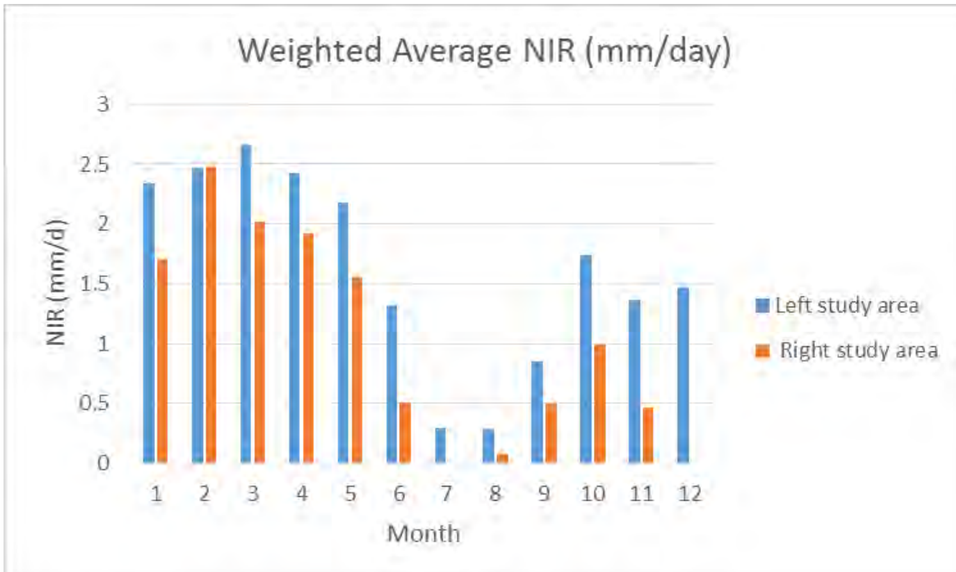

Figure 24: Monthly weighted average NIR of the right and left study area

The net irrigation requirement (NIR) of the left study area is larger than that of the right study area in all the months except in February. (Figure 24). The net irrigation requirement in both study areas is minimum in July and August. This is because rainfall is high during these months.

The reference evapotranspiration of the right study area is greater than that of the left study area in all months except October while the NIR of the right study area is smaller than that of the left study area in all months except February. This is due to larger rainfall in the right study area than that of the left study area.

The NIR is maximum in February followed by March in both study areas. (Figure 24). Thus, it is recommended that the farmers use these months for land preparation so that water can be saved.

The water stored in Koka dam was allocated into the right and left canals according to the net irrigation requirement (NIR). If the reference evapotranspiration (ETo) was used to allocate the water into the right and left canals, more water would have to be diverted into the right study area as Eto of the right study area is larger than that of the left study area. But actually, more water should have been diverted into the left canal as the NIR is greater. Thus, NIR was used to allocate the water into the right and left canals.

4.4 Allocation of Water into the Right and Left Canal

From the total water stored in Koka dam 4 m^3/s (126.144 MCM) is released to satisfy environmental water demand. The remaining was allocated into the right and left canal on monthly basis based on the ratio of net irrigation requirement of the right and left study areas. (Table 13). Xli is the volume of water allocated into the left canal on monthly basis while Xri is that allocated into the right canal. More water is diverted into the left canal due to the fact that the net irrigation requirement of the left study area is higher than that of the right study area.

Table 13: Volume of water that should be diverted into the right and left canals

Month	Xli(MCM)	Xri(MCM)
January	65.42	48.42
February	68.99	70.41
March	74.36	57.30
April	67.88	54.50
May	60.96	44.24
June	36.95	14.37
July	8.20	
August	7.99	2.18
September	23.80	14.22
October	48.55	28.21
November	38.17	13.06
December	41.16	23.02
Total	542.43	369.93

After the determination of the volume of water that should be diverted into the right and left canal each month, the area that can be irrigated using the water was calculated on monthly basis. The area that can be irrigated using the water diverted into the right and left canals is calculated by dividing the allocated water (m^3) by the NIR (m^3/ha). (Table 14)

Table 14: Area that can be irrigated each month

	Area that can be irrigated (ha)	
Month	Left Study Area	Right Study Area
January	90165.32	91548.93
February	99825.89	101357.74
March	90165.32	91548.93
April	93170.83	94600.56
May	90165.32	91548.93
June	93170.83	94600.56
July	90165.32	
August	90165.32	91548.93
September	93170.83	94600.56
October	90165.32	91548.93
November	93170.83	94600.56
December	90165.32	91548.93

The area that can be irrigated each month was plotted to observe the variation of irrigated land each month. (Figure 25 and Figure 26). As can be seen from the graph there is large variation in land irrigated each month which results in loss of land in some of the months and loss of water in other months. For example if we observe the area of land that can be irrigated in January and February of the left study area, in January 90,165.32 ha of land can be irrigated with the released water this same area of land will be irrigated in February as the crops need more than one month to develop. The water released from the dam in February can irrigate 99,825.89 ha of land. But the prepared land is only 90,165.32 ha showing that there will be loss of water. For April and May in the same study area, in April 93,170.83 ha of land is prepared and irrigated. In May the water released can only irrigated 90,165.32 ha of land while the land prepared is 93,170.83 ha thus there will be loss of land. This stresses the need to come up with a release rule that results in consistent production throughout the year. This was done through optimization.

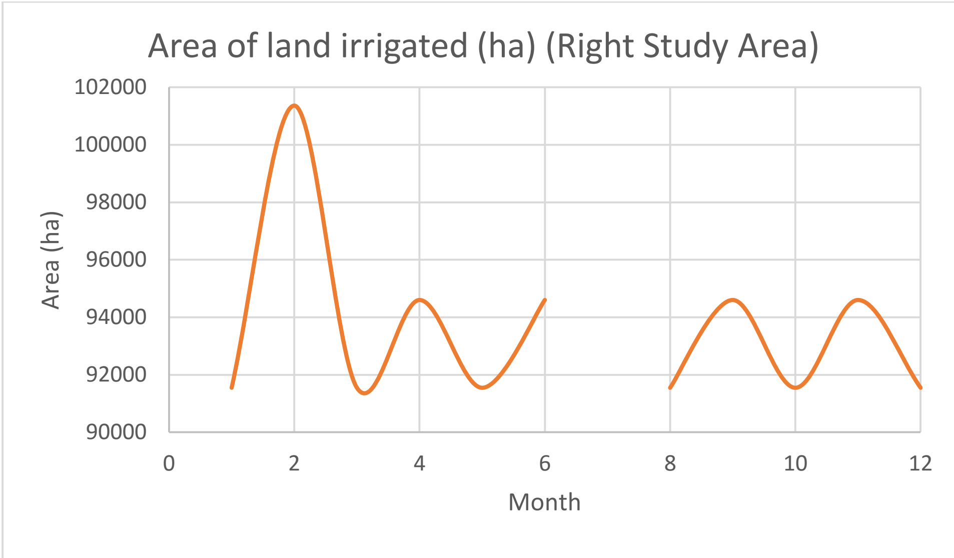

Figure 25: Variation of land irrigated each month (Right study area)

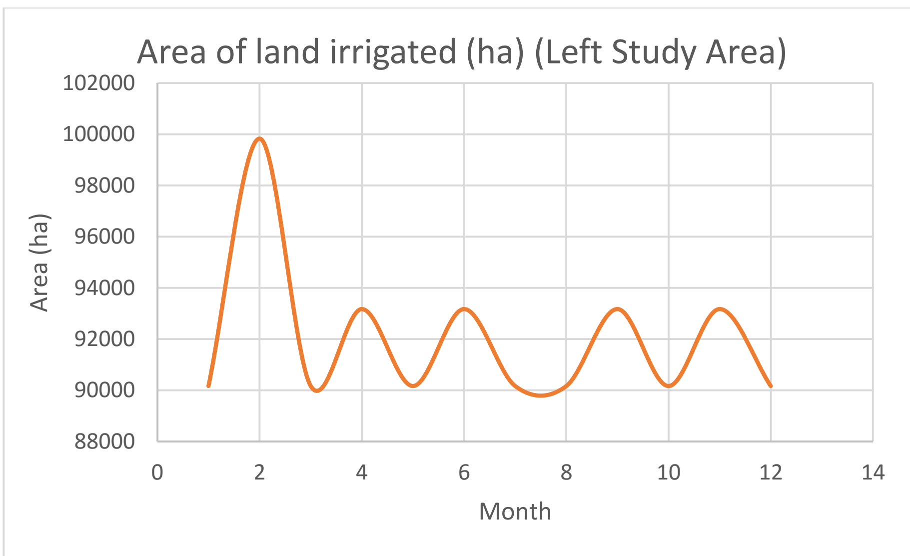

Figure 26: Variation of land irrigated each month (Left study area)

After the optimization is done, the area of land that can be irrigated each month is made constant. 94,208.97 ha and 92,318.31 ha of land can be irrigated every month within the right and left study area respectively. (Table 15). The optimization gives the water that should be released every month from the dam in order to maximize sum of area of land irrigated every month. This is advantageous in that there is consistent production every month. (Sufficient water is released from the dam that can irrigate the land prepared). The result is conservative as water may not be required during the months where land preparation is done. It means that the water can be saved during the months where land preparation will be done and used for other purpose such as water supply for livestock.

Table 15: Monthly flow rate and irrigated area (right and left study area)

	Right Study Area		**Left Study Area**	
Month	Xri(cumec)	Area (ha)	Xli(cumec)	Area (ha)
January	18.60	94208.97	25.01	92318.31
February	27.05	94208.97	26.37	92318.31
March	22.01	94208.97	28.43	92318.31
April	20.94	94208.97	25.95	92318.31
May	17.00	94208.97	23.30	92318.31
June	5.52	94208.97	14.13	92318.31
July			3.13	92318.31
August	0.84	94208.97	3.05	92318.31
September	5.46	94208.97	9.10	92318.31
October	10.84	94208.97	18.56	92318.31
November	5.02	94208.97	14.59	92318.31
December	8.84	94208.97	15.73	92318.31

The maximum of the monthly discharges is taken as the design discharge for the right and left canals. Thus, for the right canal Q_{design} = 27.050 m^3/s and for the left canal Q_{design} = 28.4276m^3/s. Even though the discharge released each month has large variation, the land that can be irrigated every month is the same resulting in consistent production. This is because water that should be diverted into the right and left canal every month is decided based on the net irrigation requirement avoiding excess application of water. Thus there will not be loss of land or loss of water.

4.5 Canal Design

4.5.1 Alignment of the Canals

It was decided that both the right and the left canals should follow the contour at the exit of Koka dam (1570 m). (Figure 27). The total length of the right canal is 165 Km and that of the left canal is 147.1 Km. The length of the canals to the main irrigation schemes was calculated (Table 16). The main irrigation schemes that take water from Koka dam found in the right study area are Wonji, Tibila, Nurahera and Metehara while the irrigation schemes found in the left study area are Wonji, Welenchiti, Fentale and Metehara. (Figure 27)

Table 16: Length of the right and left canals to the main irrigation schemes

	Right study area				Left study area			
	Wonji	Tibila	Nurahera	Metehara	Wonji	Welenchiti	Fentale	Metehara
Length (km)	15.4	67.7	96	130	21	58.6	87.6	119

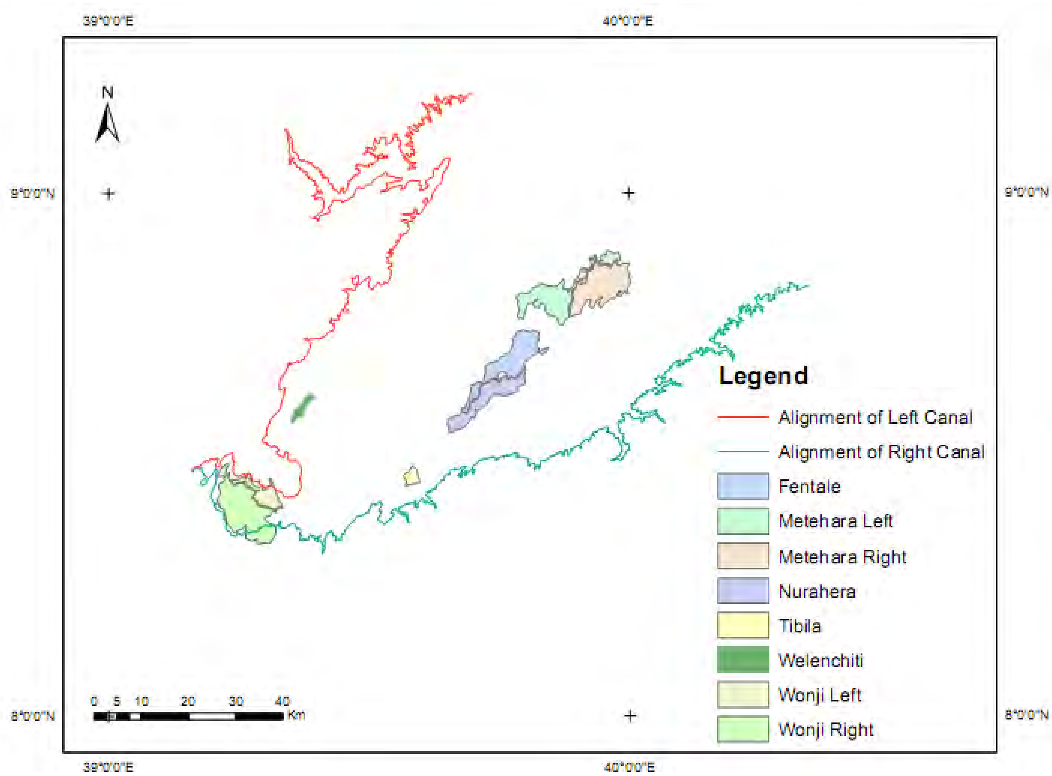

Figure 27: Canal alignment and existing irrigation schemes in the study area

A bed slope of 1:1000 was used for the left and right canals to minimize loss since the head delivered by the canals should be high enough to operate pressurized irrigation systems. With the bed slope provided (1:1000), the head delivered by the canals to the location with highest elevations within the main irrigation schemes is given in Table 17.

Table 17: Head supplied by the right and left canals

	Right study area				**Left study area**			
Irrigation Schemes	Wonji	Tibila	Nurahera	Metehara	Wonji	Welenchiti	Fentale	Metehara
H(m)		153.3	226	378		48.4	288.4	343

As can be seen from Table 17, sufficient head is provided that can operate advanced irrigation systems like drip and sprinkler without the need of additional energy source. Thus, using a gentler slope is not necessary as it increases construction cost and increases the change of creating water logging (it may have negative effect on the environment). The head provided at the irrigation schemes is larger than the maximum head required for the operation of the pressurized irrigation methods (22m). (Table 17). This is even without considering the head due to the water depth (only considering the bed elevation). This implies that there is sufficient head that can be used to irrigate additional land beyond Metehara and in between the existing irrigation schemes within the study area. For Wonji irrigation scheme it is suggested that they use pump since a certain portion of the irrigation scheme lies outside the study area due to the expansion in the irrigation scheme. (The elevation of a certain portion of the scheme is above the elevation of the contour at the exit of Koka dam).

The length of the canals was measured following the contour. If the canals were aligned using the proposed bed slope, the length obtained would be smaller and higher head could be delivered. Thus, the length and the head given are conservative.

4.5.2 Canal Dimensions

The canals were designed using Manning's equation. The dimensions of the right and left canals are almost equal as the design discharge nearly is equal. Concrete lined section is proposed to be used so that seepage loss could be minimized. For a canal lined with concrete, unfinished n = 0.014 (Chow, 1959) was adopted. If efficient trapezoidal section and the selected lining is used, the required dimensions of the canals is 3m width and 2.6m depth. Adding 17.5% of the total depth as free board the depth of flow required becomes 3m. The velocity of flow with this cross-section is 2.605 m/s which is greater than the minimum permissible velocity and less than the maximum permissible velocity for concrete lined canals.

If a square flow section is used the width and depth of flow becomes 3.5 m. Adding a freeboard of 17.5% of the total flow depth, the depth becomes 4m. The velocity of flow at this cross-section 2.74 m/s which is again within the permissible velocity ranges.

The dimensions of the canals were calculated in order to carry out a rough cost estimate for the canals. The cost of construction of the canals include cost of masonry and cost of lining. The cost was determined using unit cost of masonry and lining which were obtained using cost break down analysis. The cost of masonry and lining (plastering) which includes material cost, cost of machinery and labor is 1,274 birr/m^3 and 170 birr/m^2 respectively. The total cost of the canals determined based on the dimensions of the canals is given in the Appendix.

4.6 Potential Increase in Irrigated Land

To determine the increase in area of land irrigated due to the introduction of the canal system, conveyance efficiency for the canals and irrigation application efficiency were taken into consideration. Typical canal conveyance efficiency (80%) was taken for the main canals. To decide on the application efficiency, two conditions were considered. The first condition is if the farmers keep using the current surface irrigation techniques and the second is if they use advanced irrigation methods such as drip and/ or sprinkler. For the first case, the typical application efficiency (70%) was taken. This gives overall efficiency of 56%. The actual area of land that can be irrigated within the right and left study area under this efficiency is 52,757.0232 ha and 51,698.2536 ha respectively. These figures were obtained by multiplying the overall efficiency by the area of land that can be irrigated assuming 100% efficient system (94,208.97 ha for the right study area and 92,318.31 ha for the left study area). Thus a total of 104,455.2768 ha of land can be irrigated with the water available in the dam. The area of existing irrigation schemes that take water from Koka dam is 67,037.294 ha. This implies that the area of land irrigated using the water in Koka dam can be increased by 56% due to the introduction of the efficient canal system.

As described earlier, the canal system encourages the use of advanced irrigation systems by supplying the head required to operate the systems. If the farmers decide to use this system, the application efficiency becomes (90%) resulting in overall efficiency of 72%. This efficiency resulted in actual irrigated area of 67,830.4584 ha and 66,469.1832 ha in the right and left study areas respectively giving a total of 134,299.6416 ha of land. This is twice the area of land currently irrigated using the water in Koka dam.

This shows that because of the introduction of the canal system, water that can irrigate additional land which is equal to the existing area is saved. The saved water can be used to irrigate additional land or it can be released to the downstream to help resolve conflicts arising because of water shortage.

4.7 Implications of the Result

The introduction of efficient canal system has the following implications

1. It saves large volume of water by reducing conveyance losses. It is stated in previous studies that poor water conveyance is one of the reasons for the irrigation inefficiency and low performance in the Awash River Basin. The canal system helps reduce this problem by improving conveyance efficiency.
2. It encourages advanced irrigation technology by supplying the head required to operate the systems there by avoids additional costs for energy while operating these pressurized systems Previous studies show that surface irrigation methods such as furrow, basin and border are widely used in the Awash River Basin. These methods are characterized by inefficient water use. The canal system helps avoid this problem.
3. It helps in water management. It is stated in previous researches that one of the reasons for the widespread irrigation inefficiency in the Awash River Basin is inability to measure and control

water. The canal system proposed in this study makes the measuring of discharge possible and allow a good control of the water. Thus it helps in better management of the water exiting Koka dam. (All the water exiting the dam can be accounted for).

4. It makes water pricing possible. Several researches advocate water pricing as policy and economic instrument that enhance efficient use of water. Irrigation water pricing is practiced in the Awash River Basin. The basin authority collects water charges on volumetric basis from all legal water users but the amount of water withdrawal is unknown. The charge is based on the water requirement not on the water delivered. The canal system is conducive for measuring water delivered to the irrigation schemes. Discharge measuring structures can be installed at the required sections of the canal to measure the water delivered.
5. The canal system provides the basin authority better control over the water.

5. Conclusion and Recommendations

5.1 Conclusion

This research proposed a way by which the water shortage and the associated conflict in the Awash River Basin could be alleviated. It assessed a way by which the overall water use efficiency could be improved within the Awash River Basin. The overall water use efficiency was improved by maximizing conveyance and application efficiencies. These were achieved by the introduction of a canal system that conveys water with minimum conveyance loss thus improving conveyance efficiency and supplying sufficient head that can operate advanced irrigation methods like drip and sprinkler. Since the necessary head is delivered to the irrigation schemes, the use of advanced irrigation methods is encouraged thus improving application efficiency. Two canals were proposed to convey water from Koka dam to the irrigation schemes located on the right and left of the main Awash River. They terminate a little downstream of Metehara. The head delivered by the canals to the main irrigation schemes that take water from Koka dam was computed and found to be sufficient to operate pressurized irrigation systems.

The volume of water that should be diverted from Koka dam into the right and left canals to irrigate equal area of land every month was determined using optimization. If the Koka dam is operated according to the suggested release rule, the yearly agricultural production will be maximized and consistent yield can be obtained every month. The volume of water that should be diverted into the right and left canals was determined based on the net irrigation requirement of the study area which avoids loss of water.

The water saved due to the improvement in overall efficiency can be used for other sectors or to irrigate additional land in the study area. To identify if there is currently unirrigated land which can be irrigated using the saved water, land suitability analysis was carried out. The land suitability analysis revealed that a total of 298,709.2 ha of land suitable for irrigation is available within the study area while the total area of the existing irrigation schemes in the study area is 53,603.294 ha. Thus, the saved water can be used to irrigate the unirrigated area of land.

The results revealed that the proposed canal system has improved overall water use efficiency in the study area which resulted in water saving that is sufficient to irrigate additional area of land equal to the area of existing irrigation schemes.

5.2 Recommendations

Based on the results of the study the following recommendations are made:

- During the months where the net irrigation requirement (NIR) is maximum, land cultivation should be avoided and land preparation should be done instead.
- To get maximum yield every year it's recommended that Koka dam be operate according to the release rule suggested by this study.
- The canal system can be used to implement water pricing which has been planned by the Awash River Basin Authority. The challenge with water pricing is determining the exact volume of water delivered to the irrigation schemes. The proposed canal system enables measuring water diverted to all schemes by installing water meters at the diversion points.

5.2.1 Future Research

- Suitability analysis carried out in this research was by considering slope, soil type and land use only. Further study should be done by considering other factors that affect land suitability for irrigation to obtain more realistic result regarding the total irrigable land in the study area.
- Further study is recommended to be done on the design of the canals to fix where exactly rectangular section and where should trapezoidal section be used or to decide where the canals should be lined and where they should unlined.
- The exact alignment of the canals is affected by the outlet points to the irrigation schemes. Further study should be done to identify the exact diversion locations of the existing schemes and additional irrigations that can be developed.
- In determining the head delivered by the canals only state farms and main irrigation schemes were considered. Future research should take into account the minor irrigation developments as well.

- Instead of open channels, closed conduits can be designed to carry the design discharge alternatively. Closed conduits are advantageous in that they are suitable for monitoring purpose.

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7. Appendices

Appendix 1: Irrigated farms that use water from Koka dam

No.	User	Area	Crop type
1	**Wonji sugar factory**	**12931.5**	
1.1	Wonji Old Out grower	1056.49	Sugarcane
1.2	State (Wonji intake)	5700	Sugarcane
1.3	Waketio (Waketio intake)	587.92	Sugarcane
1.4	Welenchit irrigation (Awash Melkasa intake)	3474.43	Sugarcane
1.5	Dodota (Dodota intake)	2112.66	Sugarcane
2	**Adama Wereda**	**4280**	Vegetable
3	**Boset Wereda**	**4386**	Vegetable
4	**Africajuice Dagaga pump**	**200**	Fruit
5	**Tibila**	**2507.61**	
5.1	Africajuce	600	Fruit
5.2	Tibila farmers	1907.61	Vegetable
6	Africa juice pump (factory)	100	Fruit
7	Upper Awash Abadiska pump	**691**	
7.1		484.7	Fruit
7.2		206.3	Vegetable
8	**Nura hera**	**5741.3**	
8.1	Farmers	2033	Vegetable
8.2	Upper Awash Ag/industry	3708.3	Vegetable & Fruit
9	**Merti jeju canal**	**4733.134**	
9.1	Upper Awash Ag/industry	627.1	Vegetable & Fruit
9.2	Awash woinery	517	Fruit
9.3	Farmers	3589.034	Vegetable
10	**Kawa (fentale project)**	**4022**	Vegetable

11	**Qey meskel**	**100**	Vegetable
12	**Golgota**	**850**	Vegetable
13	**Metekola (pump)**	**730**	Vegetable
14	**Fentale Woreda**	**1121**	Vegetable
15	**Abadir canal**	**3984.75**	
15.1	Metehara sugarcane	3600	Sugarcane
15.2	Farmers	384.75	Vegetable
16	**Merti canal**	**6799**	
16.1	Metehara sugarcane	6630	Sugarcane
16.2	Farmers	169	Vegetable
17	**Awash Fentale**	426	Vegetable
18	**Amibara**	**13434**	
18.1		6017	Sugarcane
18.2		3212	Cotton
18.3		465	Vegetable
18.4		1989	Cotton
18.5		1045	Maize
18.6		706	Vegetable

Appendix 2: Meteorological Parameters at Nazareth Station

Station Nazareth: Latitude 8.55 - Longitude 39.2833 - Altitude 1622m						
Month	Min Temp (°C)	Max_Temp (°C)	Humidity (%)	Wind speed (m/s)	Sunshine hrs (hrs)	Precipitation (mm)
January	13.36	26.92	54.67	2.81	8.18	18.35
February	14.62	28.84	50.77	2.88	8.98	17.2
March	15.55	29.65	51.3	2.43	7.3	66.89
April	16.23	30.08	52.6	2.24	8.13	41.78
May	16.85	30.83	56.4	2.14	7.3	52.04
June	17.58	29.77	57.63	2.86	7.83	62.36
July	16.32	26.54	70.25	2.93	6.2	236.78
August	16.21	25.95	71.84	2.43	5.8	219.38
September	15.52	27.29	68.64	1.56	7.13	110.28
October	14.18	27.71	52.4	2.05	9.5	45.14
November	13.72	26.92	55.45	2.56	9.6	16.35
December	12.41	25.94	51.4	2.78	9.9	7.84

Appendix 3: Meteorological Parameters at Melkasa (IAR) Station

Station Melkasa (IAR): Latitude 8.4 - Longitude 39.31667 - Altitude 1540m						
Month	Min_Temp (°C)	Max_Temp (°C)	Humidity (%)	Wind speed (m/s)	Sunshine hrs (hrs)	Precipitation (mm)
January	11.54	28.13	62.47	5.01	9.01	17.43
February	12.25	29.96	52.23	5.46	9.6	17.29
March	14.63	30.6	59.15	4.38	8.6	62.09
April	14.9	30.68	63.56	4.34	8.48	54.02
May	15.26	31.69	59.69	4.3	8.79	53.63
June	16.21	30.41	65.06	5.28	8.32	70.42
July	15.41	26.79	73.77	4.88	6.88	220.33
August	15.15	26.11	76.31	3.79	6.86	196.25
September	14.17	27.76	71.08	2.49	7.54	112.32
October	11.14	28.62	62.25	3.25	8.76	48.85
November	10.19	28.37	56.5	4.16	9.64	14.34
December	10.17	27.56	58.25	4.62	9.48	11.49

Appendix 4: Meteorological Parameters at Abomsa Station

Station Abomsa: Latitude 8.4667 - Longitude 39.833 - Altitude 1630m						
Month	Min_Temp (°C)	Max_Temp (°C)	Humidity (%)	Wind speed (m/s)	Sunshine hrs (hrs)	Precipitation (mm)
January	13.8	26.62	58.68	1.57	8.27	27.28
February	14.68	28.77	52.64	1.76	8.2	16.3
March	16.12	29.56	54.46	1.67	7.84	79.3
April	17.43	29.79	56.49	1.53	7.6	70.96
May	18.08	30.76	52.5	1.51	7.86	68.53
June	17.84	31.04	52.13	2.04	7.73	59.05
July	16.71	28.49	63.67	2.12	6.52	158.78
August	16.4	27.37	69.26	1.73	6.8	178.25
September	16.31	27.77	67.14	1.39	6.48	109.25
October	15.09	27.86	57.61	1.37	7.31	69.57
November	13.82	26.94	55.69	1.42	8.43	32.97
December	12.76	26.02	56.15	1.5	9.26	11.66

Appendix 5: Meteorological Parameters at Gelemso Station

Station Gelemso: Latitude 8.80933 - Longitude 40.525 – Altitude 1739m						
Month	Min_Temp (°C)	Max_Temp (°C)	Humidity (%)	Wind speed (m/s)	Sunshine hrs (hrs)	Precipitation (mm)
January	11.91	26.28	54.15	2.2	8.8	11.36
February	12.37	27.74	55.88	2.24	8.47	17.24
March	13.63	28.74	51.2	1.68	7.89	57.53
April	14.68	27.52	61.44	1.37	6.66	131.48
May	14.85	27.73	68.85	1.02	7.03	118.32
June	15.04	27.8	67	1.08	7.04	70.08
July	15.07	26.68	71.56	1.06	5.83	136.58
August	14.91	26.01	72.64	0.97	5.61	173.42
September	14.35	26.18	74.52	0.79	5.23	143.76
October	11.53	26.19	65.8	0.85	6.45	57.77
November	10.21	25.94	64.93	1.37	7.51	29.04
December	11.53	25.18	51.67	2.08	8.69	14.79

Appendix 6: Meteorological Parameters at Awash Arba Station

Station Awash Arba: Latitude 9.14 - Longitude 40.16 - Altitude 826m						
Month	Min_Temp (°C)	Max_Temp (°C)	Humidity (%)	Wind speed (m/s)	Sunshine hrs (hrs)	Precipitation (mm)
January	15.56	32.54	73.44	1.82	9.33	15.96
February	16.48	34.68	74.8	2.04	8.95	4.22
March	18.24	36.6	69.3	2.08	8.99	27.51
April	20.36	36.94	65.32	2.13	8.37	35.83
May	21.5	38.16	68.85	2.13	8.93	38.46
June	23.1	39.35	60.47	3.08	8.71	24.13
July	20.25	36.25	69	3.47	6.98	109.8
August	19.42	34.74	73.6	2.7	7.08	99.92
September	20.23	35.82	76.1	2.07	7.74	60.5
October	18.97	35.29	69.14	1.86	8.83	29.22
November	17.48	33.84	63.48	1.72	9.11	17.4
December	14.6	32.25	67.65	1.6	9.35	2.82

Appendix 7: Meteorological Parameters at Shola Gebeya Station

Station Shola Gebeya: Latitude 9.22 - Longitude 39.55 - Altitude 2500m						
Month	Min_Temp °C	Max_Temp °C	Humidity (%)	Wind speed (m/s)	Sunshine hrs (hrs)	Precipitation (mm)
January	7.26	19.71	64.07	1.84	8.97	4.43
February	8.61	20.96	59	2.17	8.53	12.11
March	10.15	21.46	60.87	2.36	7.67	29.62
April	10.71	20.34	65.4	2.45	6.2	48.67
May	11.42	21.95	64	2.69	6.5	47.38
June	11.01	21.82	61.27	2.11	6.1	68.95
July	10.52	19.02	79	1.87	3.6	269.76
August	10.35	18.38	82.87	1.67	3.2	246.41
September	10.12	18.79	75.3	1.67	4.4	101.5
October	7.92	19.13	68.1	1.95	9.1	30.91
November	7.29	19.14	70.71	1.86	6.7	8.14
December	6.29	18.86	68.86	1.77	7.5	5.01

Appendix 8: Meteorological Parameters at Metehara Station

Station Metehara: Latitude 9.51 - Longitude 39.55 - Altitude 944m						
Month	Min_Temp °C	Max_Temp °C	Humidity (%)	Wind speed (m/s)	Sunshine hrs (hrs)	Precipitation (mm)
January	15.05	31.58	56.91	1.57	8.92	11.62
February	15.92	33.56	53.3	1.76	9.77	23.85
March	18.19	34.72	54.2	1.67	8.82	47.65
April	19.69	35.67	54.61	1.53	8.76	46.5
May	20.18	36.89	50.97	1.51	9.17	29.76
June	21.78	37.03	49.29	2.04	8.68	33.6
July	20.41	33.44	61.19	2.12	7.55	120.17
August	20.02	32.32	65.25	1.73	7.43	115.7
September	19.76	34.13	59.82	1.39	7.86	42.11
October	16.67	33.88	53.25	1.37	8.81	28.46
November	14.66	32.32	53.14	1.42	9.58	9.09
December	13.39	31.12	55.62	1.5	9.47	9.69

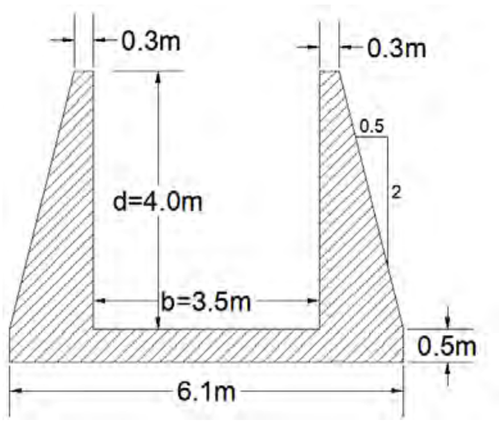
Appendix 9: Monthly crop coefficient at Woredas in the study area (Source: Awash River Basin Water Allocation Modeling and Conflict Resolution Study (2016))

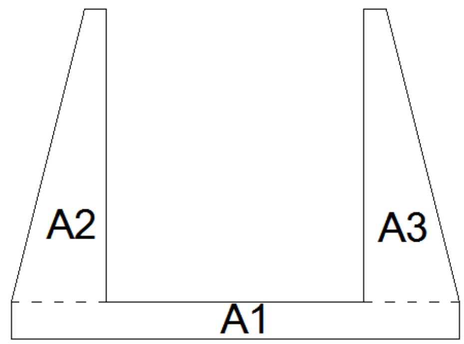
Woreda	January	February	March	April	May	June	July	August	September	October	November	December
Adama	0.9	0.9	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.0	0.9	0.9
Lomme	0.6	0.6	0.9	0.9	0.6	0.1	0.2	0.2	0.2	0.2	0.0	0.0
Boset	0.4	0.4	0.6	0.6	0.4	0.1	0.5	0.5	0.5	0.5	0.0	0.0
DodotanaSire	0.2	0.2	0.3	0.3	0.2	0.3	0.9	0.9	0.9	0.9	0.1	0.1
Jeju	0.2	0.2	0.2	0.2	0.2	0.2	0.9	0.9	0.9	0.9	0.0	0.0
Merti	0.5	0.5	0.8	0.8	0.6	0.2	0.4	0.4	0.4	0.4	0.1	0.1
Anchar	0.6	0.9	1.1	1.1	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Aseko	0.7	0.7	1.1	1.1	0.8	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Fentale	1.0	0.9	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0
Awash Fentale	0.4	0.4	0.0	0.0	0.0	0.4	0.4	0.6	0.6	0.6	0.4	0.4
Goba Koricha	0.6	0.9	1.1	1.1	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mieso	1.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.1	1.1
DodotanaSire	0.2	0.2	0.3	0.3	0.2	0.3	0.9	0.9	0.9	0.9	0.1	0.1
Minjarna Shenkora	0.8	0.8	1.1	1.1	0.9	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Berehet	0.7	0.9	1.1	1.1	1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Gimbichu	0.8	0.8	1.1	1.1	0.9	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Hagere Mariamna Kesem	0.8	0.9	1.1	1.1	1.0	0.5	0.5	0.5	0.5	0.4	0.4	0.4

Estimation of Cost of Canals

The total cost of construction of canals include cost of masonry and cost of lining. It was calculated for a rectangular section and trapezoidal section.

Rectangular Section





Cost of Masonry

Cost = Volume * Cost per unit volume

Volume of masonry = Area * Length

$A_1 = 6.1*0.5 = 3.05\ m^2$

$A_2 = (0.5*1*4) + (0.3*4) = 3.2\ m^2$

$A_3 = (0.5*1*4) + (0.3*4) = 3.2\ m^2$

$A_{total} = A_1 + A_2 + A_3 = 9.45\ m^2$

Volume = Area of the section * Total length of the canal

Length of right Canal = 165 Km

Length of left Canal = 147.1 Km

Volume of masonry of the right canal = 9.45* 165,000 = 1,559,250 m^3

Volume of masonry of the left canal = 9.45* 147,100 = 1,390,095 m^3

Cost of masonry of the right canal = 1,559,250 m^3 * 1274 birr/m^3 = 1,986,484,500 birr

Cost of masonry of the left canal = 1,390,095m^3 * 1274 birr/m^3 = 1,770,981,030 birr

Cost of Lining

Cost of lining = Area of lined section * Cost of lining per unit

Area of lined section = Perimeter *Length

Perimeter = (2d+b) = (2*4) + 3.5 = 11.5 m

Area of lined section of the right canal = 11.5 m * 165,000 m = 1,897,500 m^2

Area of lined section of the left canal = 11.5 m * 147,100 m = 1,691,650 m^2

Cost of lining of the right canal = 1,897,500m^2 * 170 birr/m^2 = 322,575,000 birr

Cost of lining of the left canal = 1,691,650 m2 * 170 birr/m2 = 287,580,500 birr

Total Cost

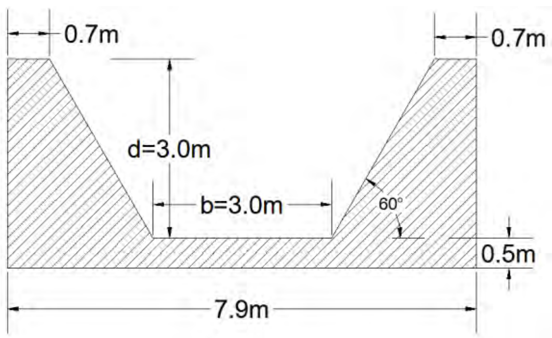
Total cost = Cost of masonry + Cost of lining

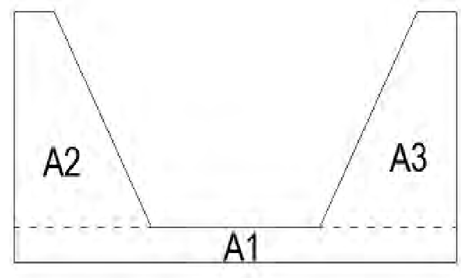
Total cost of the right canal = 2,309,059,500 birr

Total cost of the left canal = 2,058,561,530 birr

The total cost of the right and left canal is 4,367,621,030 birr

Trapezoidal Section





Cost of Masonry

A1 = 7.9*0.5 = 3.95 m^2

A2 = (0.5*√3 * 3) + (0.7*3) = 4.698 m^2

A3 = (0.5*√3 * 3) + (0.7*3) = 4.698 m^2

Total Area = 13.346 m^2

Volume of masonry for the right Canal = 13.346 m^2*165,000 m = 2,202,115.15 m^3

Volume of masonry for the left Canal = 13.346 m^2 * 147,100 m = 1,963,196.6 m^3

Cost of masonry of the right Canal = 2,202,115.15 m^3 *1274 birr/m^3 = 2,805,494,701.1 birr

Cost of masonry of the left Canal = 1,963,196.6 m^3*1274 birr/m^3 = 2,501,112,468.4 birr

Cost of Lining

Cost of lining = Area of lined section * Cost of lining per unit area

Area of lined section = Perimeter * Length

Perimeter = $(b+ 2\sqrt{(d^2 + \frac{d^2}{3})}) = (3+2*\sqrt{(3^2 + \frac{3^2}{3})}) = 9.93m$

Area of lined section of the right canal = 9.93 m * 165,000 m = 1,638,450 m^2

Area of lined section of the left canal = 9.93 m * 147,100 m = 1,460,703 m^2

Cost of lining of the right canal = 1,638,450 m^2*170 birr/m^2 = 278,536,500 birr

Cost of lining of the left canal = 1,460,703 m^2 * 170 birr/m^2 = 248,319,510 birr

Total Cost

Total cost = Cost of masonry + Cost of lining

Total cost of the right canal = 3,362,567,701.1 birr

Total cost of the left canal = 2,749,431,978.4 birr

The total cost of the right and left canal is 6,111,999,679.5 birr