



**ASSESSMENT OF SURFACE IRRIGATION POTENTIAL: THE CASE
OF GIDABO WATERSHED, RIFT VALLEY LAKES BASIN, ETHIOPIA**

MSc THESIS

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HAWASSA, ETHIOPIA

OCTOBER, 2019

**ASSESSMENT OF SURFACE IRRIGATION POTENTIAL: THE CASE
OF GIDABO WATERSHED, RIFT VALLEY LAKES BASIN, ETHIOPIA**

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DEDICATION

I dedicate this thesis manuscript to my beloved mother Siraye Adigo, my father Alemu Tiku and my sister Woinshet Alemu for nursing me with affection and for their dedicated partnership and prayer in ups and downs of my life.

Declaration

By signing below I declare that this thesis, which is titled “**Assessment of Surface Irrigation Potential: The Case of Gidabo Watershed, Rift Valley Lakes Basin, Ethiopia**” is the result of my genuine work. I have followed all the ethical and technical principles of research in the data collection, preparation, data analysis and write-up of the thesis. The thesis is deposited at the library of the University to be made available to borrowers for reference. I solemnly declare that I have not so far submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy process
CROPWAT	Crop Water Assessment Tool
DEM	Digital Elevation Model
Etc	Crop Evapo-transpiration
FAO	Food and Agriculture Organization
GIS	Geographical Information System
IWR	Irrigation Water Requirement
GIWR	Gross Irrigation Water Requirement
CWR	Crop Water Requirement
EPoCC	Ethiopian Panel on Climate Change
MoWIE	Ministry of Water, Irrigation and Electricity
GIS	Geographic Information System
GLCN	Global Land Cover Network
GPS	Global Positioning System
LULC	Land use / Land Cover
MoARD	Ministry of Agriculture and Rural Development
NASA	National Aeronautics and Space Administration
SPOT	Système Pour l'Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
SWAT	Soil and Water Assessment Tool
UNESCO	United Nations Educational Scientific and Cultural Organization
UTM	Universal Transverse Mercator
WWDSE	Water Works Design and Supervision Enterprise
MCM	million Cubic meters
SZAO	Sidama Zone Agricultural Office
GZAO	Gideo Zone Agricultural Office

ABSTRACT

Ethiopia has immense potential in expanding irrigated agriculture. Irrigable land assessment is essential for the development of irrigated agriculture. The study was aimed at assessing land potential of Gidado watershed. Land suitable for irrigation development was determined with a GIS-based multi-criteria evaluation, which considers the interaction of various factors such as slope, soil, LULC, proximity to river and road. The Analytical Hierarchal Process (AHP) and ArcSWAT were used for analyzing the different factors by assigning weights and mapping of suitable potential irrigable areas and surface water potential of the study area was estimated using SWAT model respectively. The model was calibrated and validated from observed stream flow data at three monitoring sites within the watershed using the periods of 1993-2004 and 2005-2012 respectively by using SWAT-CUP program and Global Sensitivity Analysis (GSA) was used for identifying important model parameters. The irrigable land of the area was identified using weighted overlay analysis of the suitability parameters, thus the result indicated that 1138.31 km² areas was classified suitable and 2042.19 km² area was classified as not suitable for surface irrigation. During calibration and validation, the results of model performance indicators were in the acceptable range ($R^2 = 0.68, 0.73, 0.72$), ($NSE = 0.60, 0.63, 0.71$) and ($PBIAS = 12.2, -9.0$ and -14.0) for Gidabo, Kola and Bedessa rivers respectively which indicated that a good to very good agreement between observed and simulated values. And average surface water resource potential of the catchment estimated to be 86.36m³/s or 223.86 MCM. However after analyzing 25 years river discharge and determined the water demand of the crop, 74390.89ha (23.39%) of the potential irrigable area was estimated and could be irrigated consistently with runoff from the river systems. For sustainable irrigation development, other suitability factors such as soil chemical properties, socio-economic, environmental issues, and distance from markets and town should be considered.

Key Words: *Surface Irrigation, Land Suitability, SWAT, GIS, AHP, Surface water availability.*

1. INTRODUCTION

1.1. Background

Agriculture is a mainstay of Ethiopian economy (World Bank, 2006; Makombe *et al.*, 2011). Agriculture plays a pivotal role in the economy of the country. It accounts for 47.3% of the GDP, compared to 13.5% for industry and 40.4 % for services (WWDSE 2010). Agriculture is essential for poverty reduction, particularly in the small holder farmers, where a large share of population relies on agriculture for their livelihood (Yohannes, 2011). For making stability with food of the rapid growing population of Ethiopia on sustainable basis, the rainfall dependent agriculture must be supplemented by irrigation farming system (Loiskandl *et al.*, 2008).

Ethiopia depends on the rain fed agriculture with limited use of irrigation for agricultural production. It is estimated that more than 90% of the food supply in the country comes from low productivity rain fed smallholder agriculture and hence rainfall is the single most important determinant of food supply and the country's economy (FDRE, 2011).

Irrigation development is essential to the sustainable and reliable agricultural developments in Ethiopia. Subsistence dominated smallholder farmers' economy can be improved through the use of irrigation in the Ethiopian agriculture (MoA, 2011b).

Hence, the solution for food insecurity could be provided by irrigation development that can lead to security by reducing variation in harvest, as well as intensification of cropping by producing more than one crop per year. In this regard, sustainable food production that can be expected through an optimal development of water resources in conjunction with development of land depends on the method of irrigation considered (FAO, 2003).

The suitability of the land must also be evaluated on condition that water can be supplied to it. The volume of water obtainable for irrigation will depend on the outcome of hydrological studies of surface water (FAO, 1985). Irrigation water supplies and their requirements are, therefore, important physical factors in matching the available supply to the requirements. However, these factors should be assessed in an integrated manner and mapped for surface irrigation development possibilities. Large area extent of GIS as well as its ability to collect

store and manipulate various types of data in a unique spatial database, helps performing various kinds of analysis and thus, extracting information about spatially distributed phenomena. Hence, this study was conducted to evaluate suitable land for surface irrigation and preparing the final suitable maps for each suitability parameters after weighted overlay analysis performed using ArcGIS and AHP. Surface water resources was evaluated using the stream flow data of the rivers and quantified in monthly basis after it has been simulated in each sub watersheds using SWAT model.

1.2. Statement of the Problem

Ethiopia has immense potential in expanding irrigated agriculture. According to Awulachew, (2010), the cultivable land area varies from 30 to 70 Mha. He estimated that the total irrigable land potential in Ethiopia is about 5.3 Mha assuming use of existing technologies, including 3.7 Mha from gravity-fed surface water, 1.1 Mha from ground water and 0.5 Mha from rainwater harvesting.

Irrigation would provide farmers with sustained livelihoods and improve their general well-being (Belay and Bewket, 2013; Hussain and Hanjra, 2004). Consequently, the agricultural economy of the country is largely based on rainfed cultivation, but while employing 85% of the population, it only contributes 50% to the gross domestic product (Berry, 2003). Agricultural production using irrigation is one of the main drivers to end poverty caused by insufficient output from these rainfed systems. The major problem associated with the rainfall-dependent agriculture in the country is the high degree of rainfall variability and unreliability. Due to this variability, crop failures due to dry spells and droughts are frequent. As a result, food insecurity often turns into famine with the slightest adverse climatic incident.

Analysis of irrigable land suitability is needed for various reasons in the study area, to make the community more beneficiaries on agriculture. Though, systematic land suitability assessment, current land use and irrigation land suitability description for potential natural resource is needed. Irrigation land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. Since there is no study which was conducted in the study area based on weighting the land resources for irrigation potential, this study added some asset to explore the irrigation resource (potential) in

the study area. And also potential irrigable lands in the study area have not been identified and matched with the water requirements of some crops commonly grown in the study area. Finally, this study was attempted to assess the potential irrigable land with their suitability map of the resources.

Therefore, to overcome these uncertainties, this study was carried out by using GIS, SWAT, and AHP as a tool for assessing irrigation potential in Gidabo watershed using input data from soil, digital elevation model (DEM), hydro-meteorological data, LULC and mapping of the assessment result in the context of surface irrigation development in the study area. Furthermore, the study attempted to estimate water resource potential of the sub basins in Gidabo river catchment using multi site calibration and validation and the irrigation water requirements of the identified irrigable areas for cultivating some selected crops in the area. Therefore, the current study is aimed to identify in the realm of surface irrigation potentials of major streams in Gidabo Watershed and extent of potentially irrigable lands in the area using surface irrigation method through GIS and ArcSWAT environment.

1.3. Objective of the Rresearch

1.3.1. General Objective of the study

The main objective of this study was to assess the potential area for surface irrigation development.

1.3.2. Specific Objective of the study

The Specific Objectives were:

- To identify land suitability for surface irrigation
- To analyze available water supply
- To compute irrigation water demand for selected crops in the study area
- To determine irrigation potential

1.4. Research Questions

- How to identify suitable land for surface irrigation?
- How much is the surface water potential of the watershed?
- How much is the crop water requirement for selected crops in the study area?

1.5. **Significant of the Study**

Irrigated agriculture plays a significant role in achieving food security and improves livelihood of people in Ethiopia as well as in the study area. This study was assessed surface irrigation potential by analysis of suitable land and surface water resources potential in the catchment and developing land suitability maps. Planners, decision makers and other concerning bodies can use this study output as a tool in planning, for decision making and implementation of irrigation development projects in the area according to its capacity.

1.6. **Scope of the Study**

This research dealt with the physical land characteristics and surface water potential, slope, distance to rivers and roads by making use of ArcGIS tools and Arc SWAT Model in Gidabo river catchment. Though it would be important considering the evaluation of ground water potential and chemical characteristics of the soil and water, it was not performed because of the study delimited to consider only the surface water potential of the watershed.

2. LITERATURE REVIEW

2.1. Importance of Irrigated Agriculture

It is obvious that irrigation agriculture plays an important role in agriculture sector; It produces high value crops, production of multiple crops in a season, increases the value of land, farmers may become wealthy, and raised up their living standard, generates employment opportunities for rural population due to irrigated agriculture requires labors at the field level thereby giving much of the contribution in the economic development of the country (FAO, 2011).

However, most irrigated farming systems are performing well below their potential, and there is considerable attempt for improving land and water productivity. It is important that developing small, medium, and large-scale irrigation infrastructure in the country to produce export commodities that makes use of earning foreign exchange and provides raw materials for the industrial production. But, in Ethiopia most of the irrigation development is through expanding small-scale irrigations practices through the application of surface irrigation methods (MoA, 2011).

Appropriate management and selection of applicable irrigation method is a prerequisite for wise utilization of scarce physical resources, land and water. To ensure adequate management and design of a particular irrigation system, a well-developed and suitable database is quite important. Thus it should be able to deal with spatially and temporally varying factors affecting the system (Negash, 2004).

Surface irrigation is the oldest and still the most widely used method of water application to agricultural lands. It offers a number of benefits for the less skilled and poor farmers (Saymen, 2005). Under such circumstances, more than 90% of the world uses surface irrigation, even if local irrigators have two least knowledge of how to operate and maintain the system (Saymen, 2005). Furthermore, these systems can be developed only at the farm level with slight capital investment. The main capital investment on surface system is mainly associated with land grading and planning, but if the topography is not too rising and falling, these costs are not

high. Hence, surface irrigation development requires favorable topography and information on land and water resources for proper planning (FAO, 1995).

2.2. Water Resources Potentials of Ethiopia

Ethiopia has a huge potential of water and land resources that could be easily used in expanding irrigation agriculture. Many rivers arising in Ethiopia are also the major water resources in adjacent countries. According to Abiti, (2011), Ethiopia has 12 river basins 9 wet and 3 dry, annual runoff volumes from the 9 river basins is 122 BCM. In general, the 12 River basins of the country generate an annual surface run off volume of approximately 125 BCM and 2.6 to 13.5 BCM ground water (Awulachew *et at.*,2010 and EPoCC, 2015), also reported that surface runoff volume of 124 BCM and ground water ranges from 2.6 to 30 BCM per year. These water sources can be categorized as follows:

2.2.1. Lakes and reservoirs

Ethiopia has 11 fresh and 9 saline lakes, 4 crater lakes and over 12 major swamps or wetlands. Majority of the lakes are found in the Rift Valley Basin. The total surface area of these natural and artificial lakes in Ethiopia is about 7,500 km². The majority of Ethiopian lakes are rich in fish. Most of the lakes except Ziway, Tana, Langano, Abbaya and Chamo have no surface water outlets, i.e., they are endhoric. Lakes Shala and Abiyata have high concentrations of chemicals and Abiyata is currently exploited for production of soda ash (IWMI Working Paper 123, 2007).

2.2.2. Ground water resources

As compared to surface water resources, Ethiopia has lower ground water potential. However, by many countries' standard, the total exploitable groundwater potential is high. Based on the scanty knowledge available on groundwater resources, the potential is estimated to be about 2.6 BCM annually rechargeable resources; which provide a little higher value. This figure appears to be extremely underestimated. (Tadesse, 2004), estimated that at least 13.2 BCM infiltrates into the groundwater system of which 50 percent could be extractable.

2.2.3. Surface water resources

For plans of surface irrigation development priority is given, for making sure that the existent enough amount of surface water potential in the river basin or catchment. If there is shortage of water supply during some part of irrigation season, suffering of crop production will occur, returns will decline, and the scheme's investment will lay idle (FAO, 2001). Quantifying the amount of surface water available for irrigation and determining the exact locations to which water can be economically transported are important in decision to expand its use. Where possible, the water source should be located above the command area so that the entire field can be irrigated by gravity (Kebede, 2010).

2.3. Irrigation Potential in Ethiopia

Irrigation potential is an important indicator to the extent of land suitable for irrigation development. This means that it is the possibilities for irrigation development. The area which can potentially be irrigated depends on the physical resources soil and water, combined with the irrigation water requirements as determined by the cropping patterns and climate. In countries like Ethiopia which has ample water resource, the concept of irrigation potential also comprises some considerations of suitability and economic feasibility of irrigated lands (FAO, 2015).

The estimates of the irrigation potential of Ethiopia vary from one source to the other, due to lack of standard or agreed criteria for estimating irrigation potential in the country. According to Awulachew, (2010), the cultivable land area varies from 30 to 70 Mha. He estimated that the total irrigable land potential in Ethiopia is about 5.3 Mha assuming use of existing technologies, including 3.7 Mha from gravity-fed surface water, 1.1 Mha from ground water and 0.5 Mha from rainwater harvesting. Most of these statistics are derived by adding up the irrigation potential of the country's 12 river basins.

Table 1: Irrigation potential of Ethiopian river basins and their catchment size

Basin	Catchment Area(km ²)	Irrigation Potential (ha)				Total Drainage Area (km ²)
		(Respective Master Plan Studies)				
		Small Scale	Medium Scale	Large Scale	Total	
Abay	198,890.70	N/A	130,395	639,330	815,581	201,346
Tekeze	83,475.94	N/A	N/A	83,368	83,368	90,001
Baro Akobo	76,203.12	N/A	N/A	1,019,523	1,019,523	74,102
Omo Gibe	79,000	N/A	10,028	57,900	67,928	78,213
Rift Valley	52,739	N/A	4,000	45,700	139,300	52,739
Awash	110,439.30	30,556	24,500	1,044,500	134,121	112,697
Genale Dawa	172,133	1,805	28,415	171,200	1,074,720	117,042
Wabi Shebele	202,219.50	10,755	55,950	110,811	237,905	102,697
Denakil	63,852.97	2,309	45,656	-	158,776	74,102
Ogaden	77,121				-	77,121
Ayisha	2,000			-		2,000
Total					3,731,222	982,060

Source: (Awulachew, 2010). Irrigation potential in Ethiopia

Ethiopia has a land area of 1.13 million km², most of the population in Ethiopia lives in highland areas, with 85% being rural and dependent on agriculture with a low level of productivity (Awulachew *et al.*, 2007; MoA, 2011a, EPoCC 2015).

The agricultural land currently under cultivation is about 12 million ha (MoA, 2011). Moreover, the potential and actual irrigated area is not precisely considered, the estimation of irrigable land in Ethiopia vary between 1.5 and 4.3 Mha, averaged about 3.5 Mha. However, it is surprising that the total land under irrigation now is estimated in the range between 160,000-200,000 ha which is only about 5% of the country's irrigable land (Awulachew *et al.*, 2007; Makombe *et al.*, 2007. MoA, 2011) again reported about 10 - 12% of the total irrigable potentials are currently under production using traditional and modern irrigation schemes. The

development of irrigation and agricultural water management holds significant potential to improve productivity and reduce climactic vulnerability.

2.4. Structure of the Suitability Classification

Determining suitable land for a particular use is a complex process involving multiple decisions that may relate to biophysical, socio-economic and institutional/organizational aspects. A structured and consistent approach to land suitability analysis is therefore essential. The systemic classification of the suitability of irrigation land adopts the following stages of classification.

2.4.1. Land suitability orders

According to FAO (1976), Land Suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. The two orders are represented as S and N respectively. Order S suitable: Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources. Order N not suitable: Land which has qualities that appear to preclude sustained use of the kind under consideration.

2.4.2. Land Suitability classes

Nyambe (2006) reported that land suitability classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic number, in sequence of decreasing degrees of suitability within the Order.

Class S1 Highly Suitable: Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.

Class S2 Moderately Suitable: Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.

Class S3 Marginally Suitable: Land having limitations in which aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increases

required inputs, that this expenditure will be only marginally justified. With the order Not Suitable, there are normally two classes:

Class N1 Currently Not Suitable: Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.

Class N2 Permanently Not suitable; Land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land in the given manner.

2.5. Irrigation Land Suitability Evaluation Factors

Land suitability is the fitness of a given type of land for a defined use. The land may be classified in its present condition or after improvements for its specified use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976).

Land evaluation is primarily the analysis of data about the land, its soils, climate, vegetation, and etc. in terms of realistic alternatives for improving the use of that land. For irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, to the distance from available water sources and to the terrain conditions in relation to methods of irrigation considered (FAO, 2007). In addition to these factors, land cover/land use types are considered as limiting factors in evaluating suitability of land for irrigation (Haile Gebrie, 2007; Meron, 2007).

In land evaluation for irrigated agriculture, a land is said to be well suited for a certain irrigated agriculture when it is suitable for the growth of selected crops and selected management systems, requires little or no land development and improvement costs. It should not be sensitive for land degradation and also should not a cause for raising socioeconomic problems (FAO, 1985). Various studies have been carried out on land suitability evaluation for irrigation. Some of them are reviewed as follows:

Gizachew (2014), studied on land suitability evaluation for surface and sprinkler irrigation using Geographical Information System in Guang watershed, highlands of Ethiopia. The land characteristics (LCs) used as criteria for irrigation land suitability evaluation were soil depth,

soil texture, electric conductivity, pH, drainage and slope factors. The irrigation suitability map was made by matching between reclassified LCs with irrigation land use requirements (LURs) using GIS model builder.

Dagnenet (2013), also conducted a study on assessment of irrigation land suitability and development of map for the Fogera catchment using GIS techniques. The suitability evaluation was made by identifying different land characteristics for irrigation purposes such as soil, topographic, water quality and drainage situation on the basis of FAO guidelines. After the suitability parameters has been indicated, the layer of those parameters were developed for overlay analysis to produce one suitability map which have the attribute of all land qualities with their theme attribute table through GIS.

Kassa *et.al.* (2010), conducted a study on land suitability assessment for different irrigation methods in korir watershed, Northern Ethiopia. To evaluate the land suitability for surface and drip irrigation, Kassa considered the following suitability, Parameters slope, drainage, soil texture, Soil depth, and electrical conductivity of soil solution, calcium content, organic matter (%OM), Cat ion Exchange Capacity (CEC), and pH in his study.

Kebede (2010), did a study in Dale woreda, Sidama zone, SNNP of surface irrigation potential assessment of river catchments for surface irrigation development using GIS techniques. In his study potential irrigable land was evaluated by considering the irrigation suitability factors like soil, slope, land cover/use, and distance from streams (water sources).

Hailegebriel (2007), conducted a study on Irrigation potential evaluation and crop suitability analysis using GIS and RS techniques in Beles sub basin, Beneshangul Gumuz. In his study the assessment of surface irrigation suitability was carried out under consideration of slope, soil, land cover/use, water resources, and climate factors.

Negash. W. (2004), conducted a study on GIS-based irrigation suitability analysis in Abaya Chamo lake basin. The study has been taken into consideration the soil, slope, land use and land cover and water resources availability in perennial rivers in the basin to identify potential irrigable land. In the study, Negash considered the terrain features (topography, slope), soil type and land use/cover as selection criteria to identify between surface and other methods of irrigation by mapping those major factors to display their spatial reference. In evaluating the

soil suitability, the criteria used for evaluation were soil drainage class, soil texture, soil depth, salinity, /alkalinity hazards of the soil. He states that soil depth greater than 100cm were taken as optimum for crop development and less than 50cm were taken as marginally suitable class.

According to FAO (1976), the suitability criterions listed in the above studies for surface irrigation methods and for the land utilization types can be expressed corresponding to the suitability classes as highly suitable(S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N).

Seleshi. *et al* (2016), carried out a study on land suitability analysis for agriculture in the Abbay basin using GIS, remote sensing and AHP techniques. According to them the identification and mapping of agricultural land-use suitability has the following importance:

- Essential to increase agricultural productivity to meet the fast-growing food demands,
- The growing risks of increased rainfall variability due to climate change in already water limited agricultural systems and
- The growing interest by local and regional policy and management bodies for evaluation of land capability for various land-use alternatives.

Slope: Slope is the incline or gradient of a surface and is commonly expressed as a percent. Slope is important for soil formation and management because of its influence on runoff, drainage, erosion and choice of irrigation types. The slope gradient of the land has great influence on selection of the irrigation methods. According to FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended (FAO, 1999).

Soils: The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such properties include drainage, texture, depth, salinity, and alkalinity (Fasina *et al.*, 2008). Even though salinity and alkalinity hazards possibly improved by soil amendments or management practices, they could be considered as limiting factors in evaluating the soils for irrigation (FAO, 1997).

Land use / land cover: LULC are often used interchangeably. However, they are actually quite different. GLCN (2006), defines land cover as the observed physical cover, as seen from the ground or through remote sensing (RS), including vegetation (natural or planted) and human

construction (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock or sand surfaces also count as land cover. A land use can be defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one, or more than one, pieces of land and several land uses may occur on the same piece of land. Definitions of land cover or land use in this way provide a basis for identifying the possible land suitability for irrigation (Jaruntorn *et al.*, 2004).

Water availability: It is important to make sure that there may no lack of irrigation water. If water is in short supply during some part of the irrigation season, crop production may suffer, returns may decline and part of the scheme's investment may lay idle (FAO, 2001). Therefore, water supply is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year when it is available (FAO, 1985).

Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source be near the centre of the irrigated area to minimize the size of the delivery channels and pipelines.

2.6. CROPWAT model

CROPWAT is a decision support system developed by the Land and Water Development Division of Food and Agriculture Organization (FAO) for planning and management of irrigation (FAO, 1992). CROPWAT is meant as a practical tool to carry out standard calculations for reference evapo-transpiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation.

Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No. 24(FAO, 1992) "Crop water requirements" and No. 33 "Yield response to water"(FAO, 1986). The development of irrigation schedules and evaluation of rain fed and irrigation practices are based on a daily soil

water balance using various options for water supply and irrigation management conditions. Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop and soil data. For the estimation crop water requirements (CWR) the model requires:

Crop Coefficient Approach: - Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the FAO Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., reference evapotranspiration (ET_o). Experimentally determined ratios of ET_c/ET_o, called Crop coefficient (K_c), are used to relate crop evapotranspiration under standard conditions (ET_c) to ET_o. This is known as the crop coefficient approach. Radiation, air Temperature, Humidity and Wind speed are all incorporated into the ET_o estimate. Therefore, ET_o represents an index of climatic demand, while K_c varies predominately with the specific crop characteristics and only to a limited extent with climate and soil evaporation. This enables the transfer of standard values for K_c between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the K_c factors developed in past studies. The reference ET_o is defined and calculated using the FAO Penman-Monteith equation (FAO, 1998). The crop coefficient, K_c represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These characteristics are crop height, Albedo of the crop soil surface, canopy resistance, and evaporation from soil, especially exposed soil (FAO, 1998).

Reference Crop Evapo-transpiration (ET_o) values measured using the FAO Penman Montieth equation based on decade/monthly climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and wind speed; Rainfall data (daily/decade/monthly data); monthly rainfall is divided into a number of rain storm each month.

Effective Rainfall: - For agricultural production, effective rainfall refers to the portion of rainfall that can effectively be used by plants. This shows not all rain is available to the crops as some is lost through runoff and deep percolation. How much water actually infiltrates the soil depends on soil type, slope, crop canopy, storm intensity, and the initial soils water content.

During the rainy season in tropical and some semi-tropical regions, a great part of the crop's water needs are covered by rainfall, while during the dry season, the major supply of water should come from irrigation. How much water is coming from rainfall and how much water should be covered by irrigation is, unfortunately, difficult to predict as rainfall varies greatly from season to season. In order to estimate the rainfall deficit for irrigation water requirements, a statistical analysis needs to be made from long-term rainfall records (FAO, 1998).

A Cropping Pattern consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0-100% of the total area); a set of typical crop coefficient data files are provided in the program. Once all the data is entered, CROPWAT8.0 Windows automatically calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly.

2.7. Water Requirement

Water requirement is the quantity of water, regardless of its source, required by a crop or diversified patterns of crops in a given period of time for its normal growth under field conditions at a place (FAO, 1985). Water requirement includes the losses due to evapotranspiration (ET) or consumptive use (CU) plus the losses during the application of irrigation water (unavoidable losses) and the quantity of water required for special operations such as land preparation, transplanting, leaching, etc.

2.8. Analytical Hierarchy Process (AHP)

The AHP method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix, in which all relevant criteria identified are compared against each other based on preference factors. The weights can then be aggregated. GIS based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria. It has been applied to a variety of decision making problems (Chen et al., 2010 cited in Feizizadeh and Blaschke, 2011). This tool is very important to give criteria weight and is easily available.

2.9. Selection of the Model

To select the appropriate models for solving specific problems, the classification of models depending on the spatial scale and physical detail of the model are important to know the determination of model behavior as required data, required expertise, expected accuracy and user-friendliness. However, some models are better in spatial water quality analysis, supply and demand management in the catchment, whereas others are good analysis of project for river and reservoir routing.

Currently there are different types of hydrological models developed and available freely. As their availability, their differences concern the types of input data needed, the temporal and spatial scale, the operating system, the compatibility with GIS, their complexity and reliability. Thus, another point of interest was to consider if the models were used widely or not (Le Gune, 2005).

This study would have applied ArcGIS10.3, ERDAS2014 and Arc SWAT2012 in Gidado River Catchment. The models were preferred to others because of their strength and ease of use depending on data availability. The main aim of these models is to determine the surface water and irrigable land resources problem and issues.

2.10. Overview of GIS Technology

GIS have become an increasingly important means for understanding and dealing with the pressing problems of water and related resources management in world. GIS concepts and technologies help us collect and organize the data and understand their spatial relationships. GIS analysis capabilities provide ways for modeling and synthesizing information that contribute to supporting decisions for resource management across a wide range of scales, from local to global. A GIS also provides a means for visualizing resource characteristics, thereby enhancing understanding in support of decision making (Johnson, 2009).

2.10.1. Application

A GIS is used for capturing, storing, querying, analyzing, and displaying geographically referenced data (Goodchild, 2000). The increased availability of large, geographically

referenced data sets and improved capabilities for visualization, rapid retrieval, and manipulation inside and outside of GIS demand new methods of exploratory spatial data analysis that are specifically tailored to this data-rich environment. Using GIS databases, more up-to-date information can be obtained or information that was unavailable before can be estimated and complex analyses can be performed. This information can result in a better understanding of a place that can help to make the best choices.

2.10.2. Watershed delineation

Delineation of a watershed means determining the boundary of the watershed. GIS uses DEMs data as input to delineate watersheds with integration of Arc SWAT or by hydrology tool in ArcGIS spatial analysis tool (Winchell *et al.*, 2008). DEMs provide good terrain representation from which watersheds can be derived automatically using GIS technology.

2.10.3. Weighted overlay analysis

Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from water supply (Yang, 2003). To prioritize the influence of these factor values, weighted overlay analysis uses evaluation scale from 1 (represents the factors have equal importance) to 9 (represents the most suitable factor). Weighted overlay only accepts integer raster as input, such as a raster of land cover, soil types, slope, and Euclidean distance (the straight-line from the center of the source cell to the center of each of the surrounding cells) distance output to find suitable land for irrigation.

2.10.4. Mapping

The main application in GIS is mapping where things are and editing tasks as well as for map based query and analysis (Campbell, 1984). The map represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive

text, and a symbol legend. GIS mapping can be an effective tool to organize, retrieve, and present spatial data for irrigation districts.

2.10.5. Digital Elevation Model (DEM)

DEMs are point elevation data stored in digital computer files. These data consists of x, y grid locations and point elevation or z variables. They are generated in a variety of ways for a different map resolutions or scales. Under an agreement with the National Aeronautics and Space Administration (NASA) and the Department of Defense's National Geospatial intelligence Agency (NGA), the US Geological Survey (USGS) distribute elevation data from the Shuttle Radar Topographic Mission (SRTM). Shuttle Radar Topography Mission obtains elevation data on a near-global scale with a radar system that flew onboard a space shuttle. For most parts of the world, this data set provides a dramatic improvement in the availability of high-quality and high-resolution elevation data (Jarvis *et al.*, 2004). Digital Elevation Model is a commonly used digital elevation source and an important part of using for watershed characterization. Many agencies provide DEM data with 90-m, 30-m and 20-m resolutions.

2.10.6. Satellite imagery

Remotely sensed satellite data are familiar to GIS users. The utility of different remote sensing data from different satellites have been demonstrated in many fields such as agriculture, cartography, civil engineering, environmental monitoring, forestry, geography, water resources management, land resources analysis and land use planning.

The use of satellite images in any of fields mentioned above, demands the knowledge of the different bands that each sensor system onboard satellites use to take the imagery and how these bands of the electromagnetic spectrum interact with land surface features and with that of the atmosphere (Lemlem, 2007). All types of satellites vary with their sensors, flight height, bands, and spatial resolution, spectral resolution, etc. The spatial resolution of a satellite image relates to the ground pixel size. For example, a spatial resolution of 20 meters means that each pixel in the satellite image corresponds to a ground pixel of 400 square meters. The pixel value,

also called the brightness value, represents light energy reflected or emitted from the earth's surface (Lillesand and Kiefer, 2000).

As there are many satellites in the space providing remote sensing data, their application will vary with their way of data acquisition. The most popular satellites are the Landsat and SPOT. Landsat operated by the National Aeronautics and Space Administration with the cooperation of the U.S. Geological Survey since early 1970s till 2003, have produced the most widely used imagery worldwide with 60, 30 and 15m spatial resolutions (Blundell and Opitz, 2006).

2.11. SWAT Model

SWAT requires specific information about weather, soil properties, management practices, vegetation, and topography of the watershed to be studied. It is a semi-distributed physically based model which uses the physical process associated with sediment movement and water movement, crop growth and nutrient cycling. The watershed divided in to sub watersheds using SWAT based upon drainage areas of the tributaries to simulate hydrological processes. The sub-watersheds are further divided into hydrologic response units known as HRUs, which consists of homogeneous land use, management, soil, and slope (topographical) characteristics.

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The Gidabo River catchment is one of three medium-sized rivers discharging into Lake Abaya. The Gidabo River catchment is bordered by the catchment of Lake Hawassa to the North, River Bilate to the West, River Gelana to the South and Genale-Dawa Rivers to the East.

Geographically the watershed is located between 38.02°-38.65°E longitudes and 6.14°-6.92°N latitude with a drainage area of 3180.49 km². The eastern part is highland having a peak of 3213 m.a.s.l at Gelala Mountain and the western part is lowland where the lowest altitude is about 1171 m a.s.l at lake Abaya.

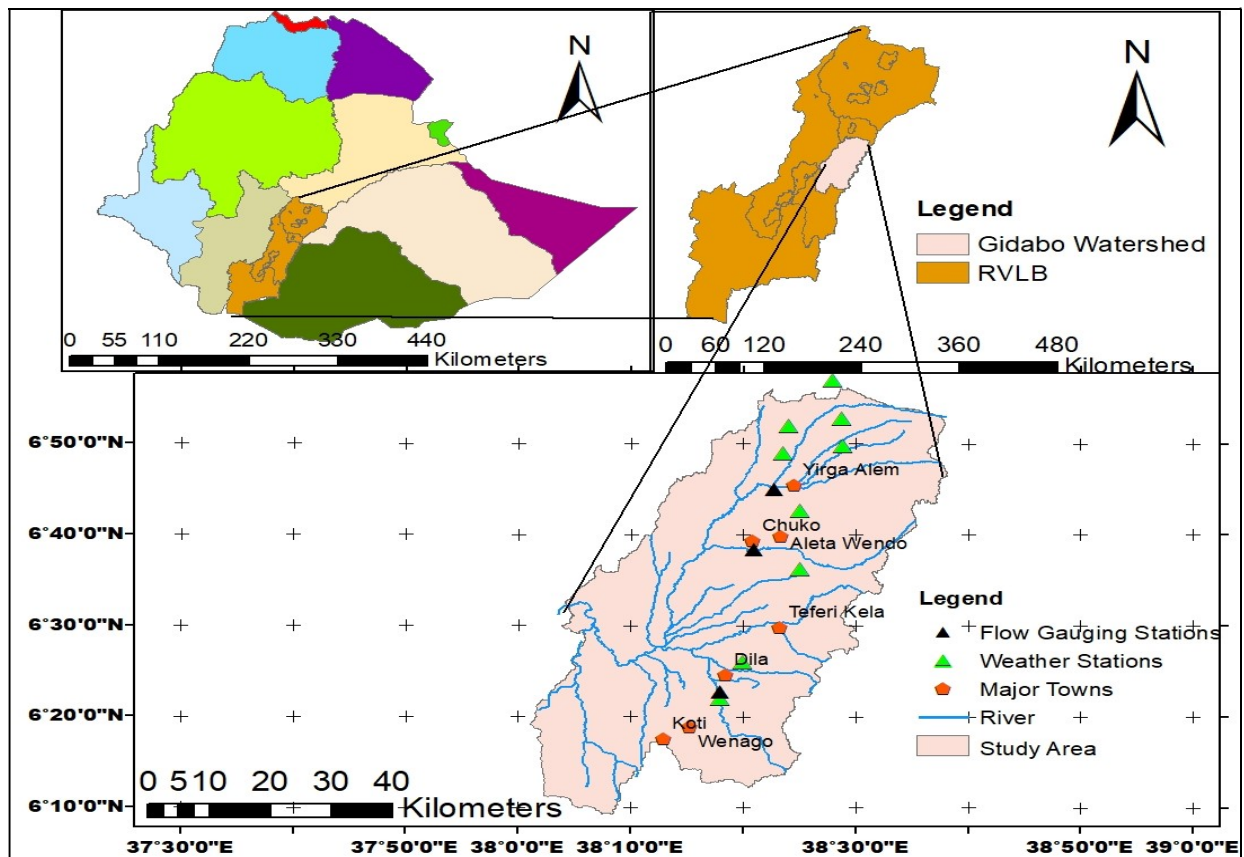


Figure 1: Major River basins of Ethiopia and Location map of the study watershed.

3.1.2. Agro-ecology

According to MoA (2000) classification, agro-ecology of Ethiopia is classified as: Wurch, Dega, Weyna-dega, Kolla, and Bereha. Similarly, the landform in Gidabo River catchment also shows variations in agro-ecology as Wurch, Dega, Weyna-dega and Kola that constitute 0.67%, 13.40%, 64.65% and 21.28% of the total study area respectively (Table 2). This agro-ecological variation in landforms has a significant influence on cropping pattern of the catchment. The dominant crops grown on the study area are inset, coffee, chat, wheat, maize, tomato, vegetables and agrofosretry. Both rainfed and traditional irrigation agriculture have been practiced within the watershed and from these maize and tomato are the two major crops that have been produced using small scale surface irrigation (GZAO, 2017 and SZAO, 2018).

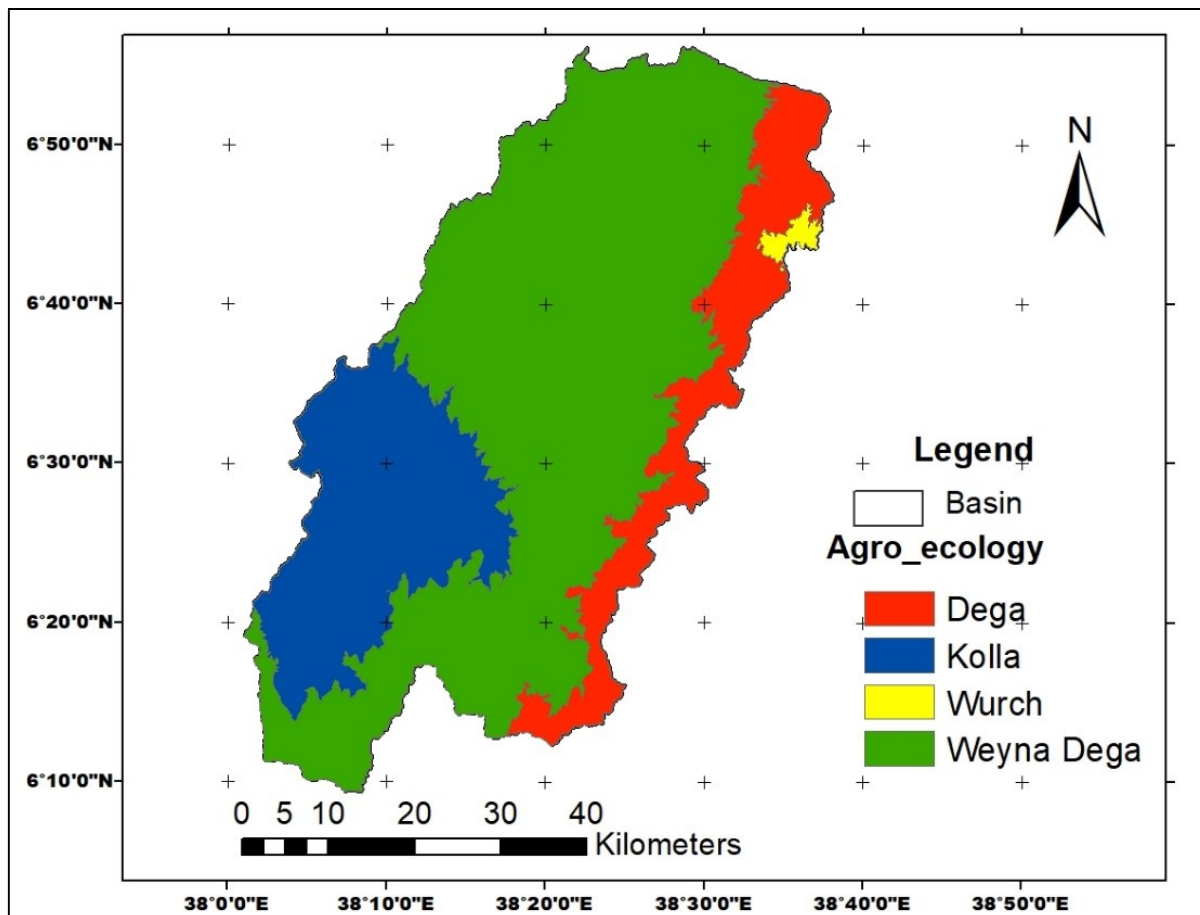


Figure 2: Agro-ecology classification map of the Study Area

Table 2: Agro ecological zone of the study area

ID	Agro ecological zone	Their Elevation Range (m.a.s.l)	Area Coverage in (km ²)	Area Coverage in (%)
1	Wurch	3200-3700	21.49	0.67
2	Dega	2300-3200	426.07	13.40
3	Weyna Dega	1500-2300	2056.06	64.65
4	Kolla	500-1500	676.87	21.28
	Total		3180.49	100

As indicated in the Table 2, the study area is classified in to four agro ecological zones. As the result shown in Figure 2, above most of the study area specially North-Western, central and southern parts were found under Weyna dega agro ecological zone which covers 2056.06 km² of the total area which is found in the elevation ranges from 1500-2300 m.a.s.l. Kolla, Dega and Wurch covers 676.87 km², 426.07 km² and 21.43 km² areas respectively.

Topography: - The low land area is situated in the Western part joins Lake Abaya at the outlet. High elevation values are observed in the Eastern and North Eastern part of the watershed. There is a high elevation change between the upstream and downstream of the watershed with the altitude range of 1171 to 3213 m.a.s.l (from low lands in the west to the highlands in the east and the altitude increases from west to east.

3.1.3. Climatic Conditions

The climate is highly variable in the Gidado River Basin and gradually changes from semi-arid at the rift floor to humid in the mountains/highlands. In the highlands and escarpment bounding the rift floor, rainfall exceeds 1600 mm/year, whereas the lowest elevation of the rift floor receives much less rainfall, often below 800 mm/year (average of the period 1990-2014). Precipitation is characterized by a bimodal pattern with a short during March to May and a subordinate long/peak in July to October. The diurnal variation of temperature in the basin is more visible than its seasonal variation. The average monthly temperature varies from 23.48 to 32 °C (27.7°C) in the lowlands and 7.12–14.57 °C (11°C) in the high elevation plateau as shown in Figure 4 below (since 1990 to 2014).

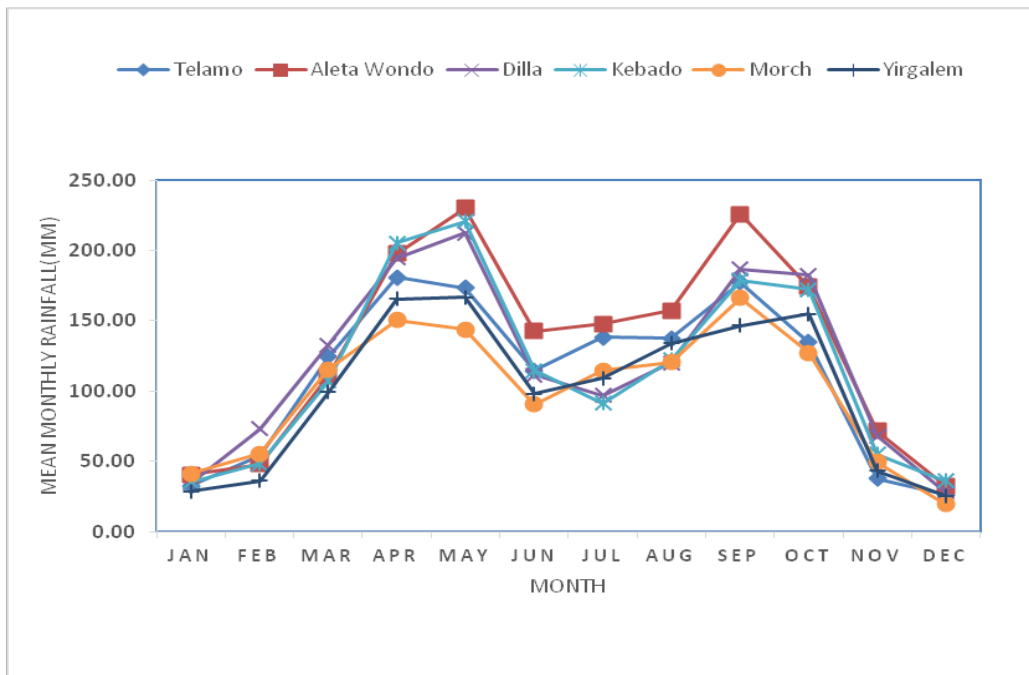


Figure 3: Average monthly rainfall pattern of stations in the study area (1990-2014)

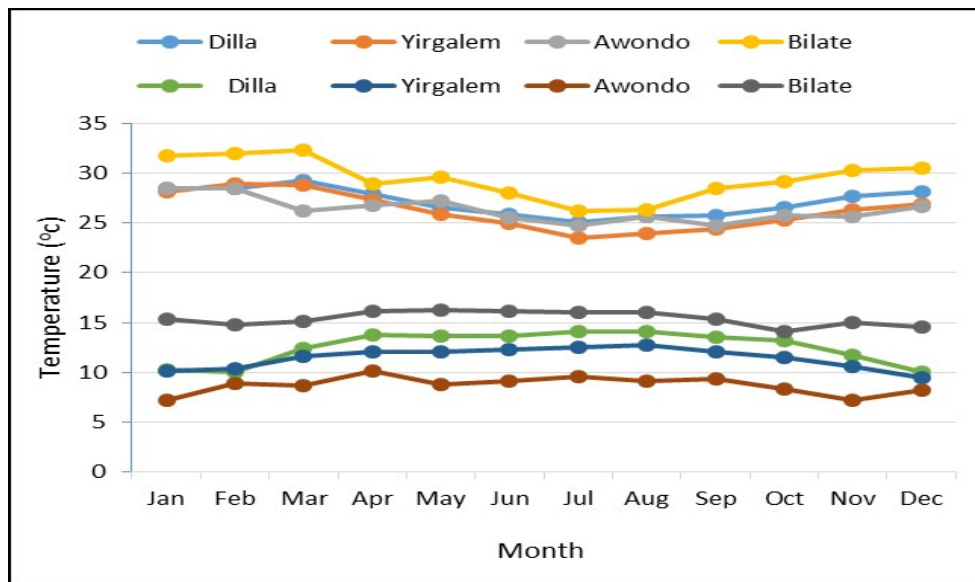


Figure 4: Monthly max and min temperature (1990-2014)

3.2. Data Sources and Materials

In this study various types of data, software and materials were utilized to achieve the objectives.

GPS: GPS was used to collect geographic coordinate values at field. The geographic coordinate values were used as ground control points to locate field data on satellite images for supervised classification and to identify outlet of catchment.

Software Used: ERDAS IMAGINE 2014 was used for land use land cover type classification, ArcGIS10.3 was used for watershed delineation, to analyze soil map, land use land cover map and slope map of the watershed, and SWAT2012 (ArcSWAT10.319) integrated with Arc GIS for watershed delineation analyzing the HRUs, and sensitive parameters. SWAT CUP for calibration, validation, and sensitivity analysis of simulations. CROPWAT8.0 model was used to compute irrigation and crop water requirement, Dew02, PcP STAT was used to convert the daily climatic and hydrological time series data in to mean monthly basis. AHP for ArcGIS10.x extension was used to compare all the criteria using pair-wise comparison matrices and assign weights for each layer. LocClim model was used to extract temperature and sunshine hour data.

3.2.1. Landsat image data

Land use land cover (LULC) map of the study area was prepared Landsat 8 satellite image with path168 and rows 55 &56 with spatial resolution of 30m. The satellite image of the area was downloaded from USGS website (<https://www.earthexplorer.usgs.gov/> Feb 19, 2014). The image was used for the preparation of land LULC based on Supervised classified technique in ERDAS Imagine 2014 software included three bands (4, 3 & 2) using a ground truth data points collected from field observation and Google earth. The LULC classification of the watershed consists of farmland/agricultural land, evergreen and mixed forests, grassland, shrub land, settlement, degraded land/bare land, water body and wetland.

3.2.2. Digital Elevation Model (DEM)

DEM of 30m * 30 m spatial resolution was downloaded from USGS Earth Explorer website (<http://dds.cr.usgs.gov/srtm/>). It was used to delineate a watershed and to derive slope maps and elevation of the study area for irrigation suitability analysis by using ArcGIS. The average elevation of the study area above mean sea level is 2777.5m.

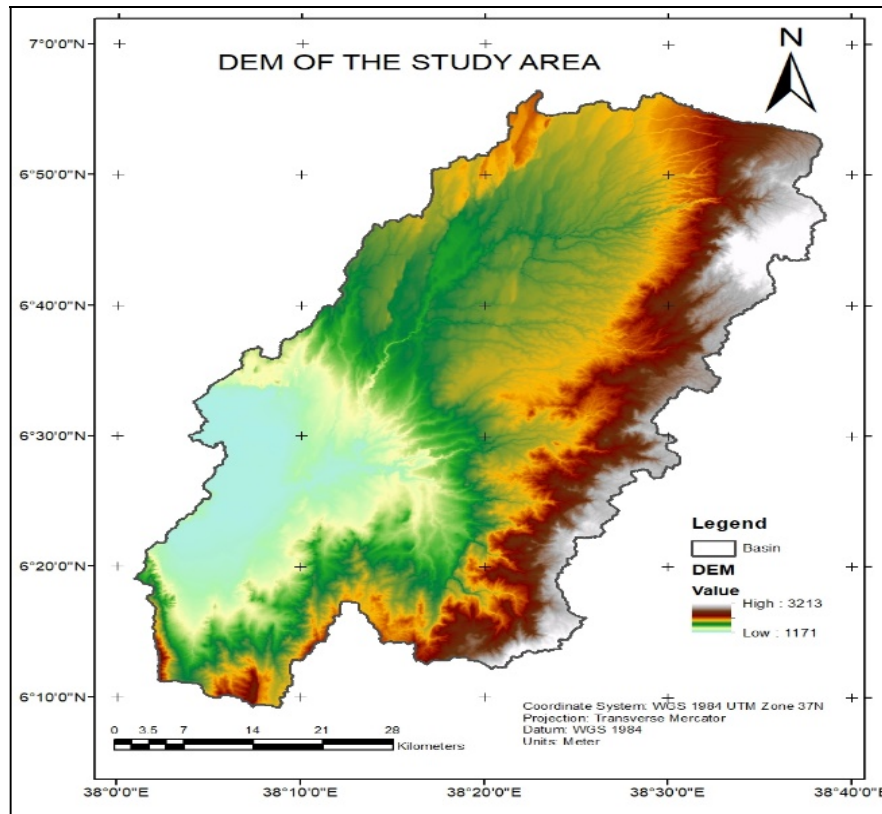


Figure 5: DEM of the Study Area

3.2.3. Soil data

Soil map obtained from MoA for rift valley lakes basin was used to identify the soil distribution within the watershed. According to FAO (1976 and 1997) the basic soil physical properties used for evaluation of soil suitability for surface irrigation were soil drainage, soil texture, and soil depth. In the study area six types of soil and four textural classes were identified and analyzed based on the FAO soil classification (Table 9).

3.2.4. Meteorological data

Climatic data which are very important for this study were collected from National Meteorological Agency (NMA) of Ethiopia for 25 years (1990-2014). These data were used to estimate mean monthly rainfall and important climatic parameters of the study area and then used to calculate irrigation water requirements by using CROPWAT8.0 software for some of the crops which are selected in the study area like tomato and maize. The missing data and data length of stations is also shown in the appendix Table-25.

3.2.5. Stream flow data

Hydrometric discharge measuring stations within the Gidabo River Catchment are five in number. Stream flow data for these gauging stations was collected from Hydrology Department of the Ministry of Water, Irrigation and Electricity (MoWIE) of Ethiopia. These stations are the Aposto and Meissa both on Gidabo River, Kola River near Aleta Wondo, Sala and Bedessa Rivers near Dilla are the hydrometer stations in the Catchment. This study was focused on three gauged catchments in the study area named as Aposto, Kola, and Bedessa. Their missing values and date of length are shown in appendix Table-25. Aposto catchment has a terrain elevation ranges between 1646 and 3213 m.a.s.l which includes the origin of Gidabo River, Soka Sonicha mountain range (with the most prominent being the Gelala mountain). Kola catchment is the smallest gauged catchment which has a drainage area of 189 km². Its altitude ranges between 1744 and 3167 m.a.s.l. The third gauged catchment selected for this study was Bedessa with a drainage area of 229 km² and had relatively lower elevation (1455-2060 m.a.s.l). The stream flow data were used to assess both water resources potential of the gauged and un-gauged sites for irrigation purpose.

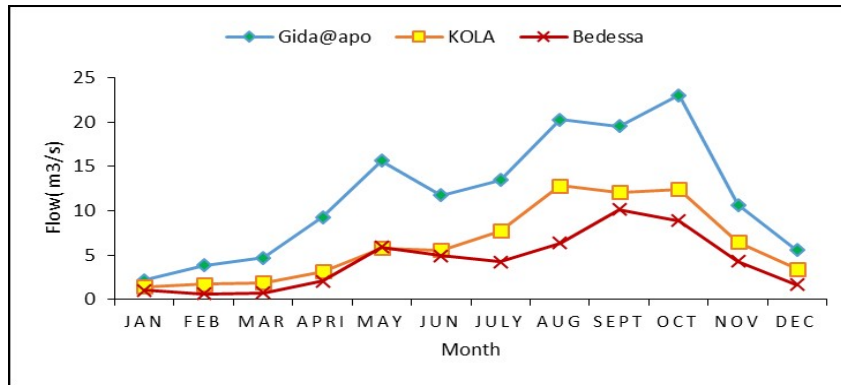


Figure 6: Mean monthly runoff at River gauging stations (1990-2014).

3.3. Methodology

This portion described the method which was used in this research. This study focuses on the determination of surface water potential and irrigable land assessment for surface irrigation in the ArcGIS10.3 with the combination of ArcSWAT systems starting from the data collection up to the final result of the study is presented as follows.

3.3.1. General Framework of the Study

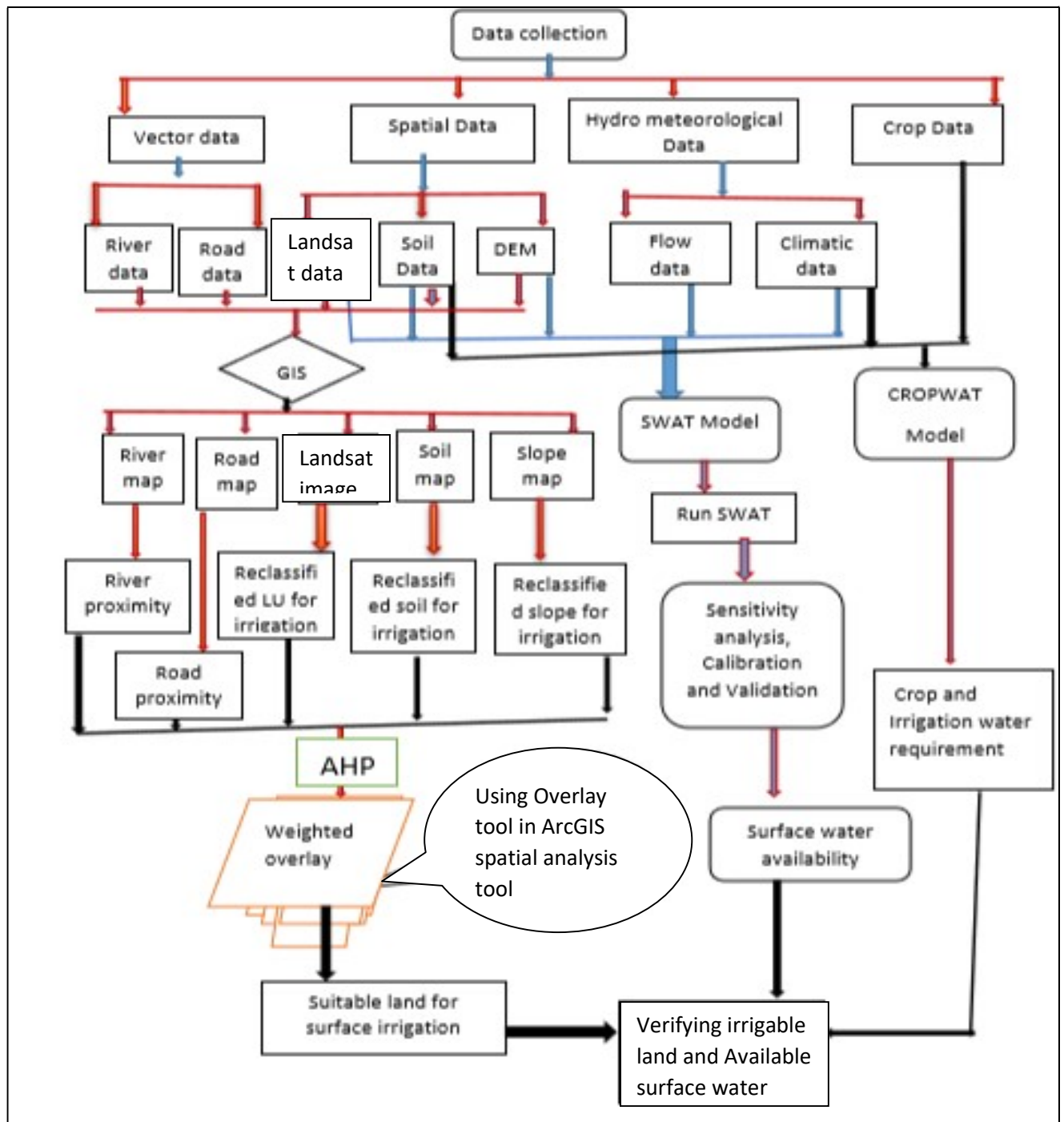


Figure 7: Research design or Flow chart

3.3.2. Land use land cover classification schemes

In order to clearly classify LU/LC in the study area, determination of type and size of LU/LC classes is important. Accordingly, based on the previous knowledge of the study area and in the current brief reconnaissance survey, a classification scheme developed as LULC class.

Farm/Cultivated land: - Areas used for crop cultivation is annuals which covers 15.14% (479.63 km²) of the total area and exists in all parts of the watershed.

Grass land: Land area covered by open grass used for grazing purpose or pasture, as well as bare lands that have little grass or no grass cover. This land unit is the second dominant land cover in the watershed, covers an area of about 23.84% (734.36km²) of the total area.

Shrub/bush land: - An area dominated with shrubs, bushes, and small trees, mixed with some grasses. It mostly found in the Northern part and in some extent south-west part of the study area. It covers 6.72 % (213.78 km²) of the total area of the watershed.

Forest land: - The land covered with dense trees which includes ever green forest land covers 18.81% (598.13km²) of the total area.

Built up: - It consists: the settlement and road in the study area. It covers about 4.55% (144.64km²) of the total area and the remaining 7% of the area is covered with

Wet land: - This land unit mostly consists of wetlands (swampy areas). It is found near to Lake Abaya, around Yirgalem and Aleta Wondo. It covers an area of 2.40 % of the total area

Barren land: - Area of thin soil, sand, or rock, almost has no vegetation

3.3.3 Image pre-processing and classification

Preprocessing- Data preprocessed in ERDAS imagine 2014 for geo-referencing and sub-setting of the image on the basis of Area of Interest (AOI). The main objective of image classification is to place all pixels in an image into LU/LC classes in order to draw out useful thematic information.

Supervised Classification: Supervised classification is usually appropriate when we want to identify relatively few classes, when we have selected training sites that can be verified with ground truth data, or when we can identify distinct, homogeneous regions that represent each class. Supervised classification is much more accurate for mapping classes, but depends heavily

on the cognition and skills of the image specialist. The strategy is simple; the specialist must recognize conventional classes in a (real and familiar) or meaningful classes in a scene from prior knowledge, such as personal experience with what's present in the scene, or more generally, the region it's located in, by experience with thematic maps, or by on-site visits. As a rule, the classifying person also locate specific training areas on the image either a print or a monitor display to identify the classes. The resulting training sites are areas representing each known land cover category that appear homogenous on the image (as determined by similarity in tone or color within shapes delineating the category). The maximum likelihood algorithm assigns each pixel to the class with the highest likelihood based on mean vectors and covariance matrixes of the sub classes. In this study nine LU/LC classes were identified by supervised classification; the researcher has collected about 381 ground truth points randomly. Based on this classification, nine land use/ land cover classes were identified by referencing to 150 ground truth points.

Image classification was done in order to assign different spectral signatures from the Landsat datasets to different LULC on the basis of reflectance characteristics of the different LULC types. Different color composites also used to improve visualization of different objects on the imagery and the recommended standard of accuracy in the identification of LU/LCC mapping from the remote sensor data should be more than 85%.

Accuracy assessment:-To validate and crosscheck the result of the Landsat Image classification with known ground truth data, accuracy assessment was checked for the signature values of the classified images by calculating the confusion matrix in ERDAS IMAGINE2014 software. The accuracy is essentially a measure of how many pixels in the ground truth region of interests (ROIs) were classified correctly. Items calculated include; overall accuracy, kappa coefficient and confusion matrix. The overall accuracy was calculated by summing the number of pixels classified correctly and dividing by the total number of pixels.

$$\text{Overall accuracy} = \frac{\text{Total number of corrected pixels}}{\text{Total number of pixel}} \dots\dots\dots (3.1)$$

Kappa coefficient represents strong agreement between classified land cover classes and observed land cover/use (Ephrem, 2008). It lies between 0 and 1, where 0 represents weak agreement and 1 represents strong agreement. According to Rahman *et.al* (2006), kappa

values can be classified into three: the value greater than 0.8 represents strong agreement, between 0.4 and 0.8 represents moderate agreement and a value below 0.4 represents poor agreement. Equation 3.2 gives mathematical relationship for calculating kappa coefficient.

$$Kappa (K) = \frac{P_o - P_e}{1 - P_e} \dots\dots\dots (3.2)$$

Where,

P_o = is the proportion of correctly classified classes

P_e = is the proportion of correctly classified classes expected by chance

3.3.4. Data pre-processing and checking

Collected data can contain errors due to failures of measuring device or the recorder. So, before using the data for specific purpose, the data have to be checked and errors have to be removed. The analysis was extended to hydrological and meteorological data to prepare input data for water resources assessment and irrigation water requirement estimation using the CROPWAT model.

i) Consistency of stream flow and rainfall data: To prepare the stream flow and rainfall data for further application, their consistency was checked using double mass curve analysis. A plot of accumulated rainfall data at site of interest against the accumulated average at the surrounding stations was used to check consistency of rainfall data.

ii) Filling missing rainfall data: Different methods (Normal ratio method, inverse distance and Arithmetic mean method) are available for filling missed recorded data of the stations. According to Dingman (2002) normal average annual precipitation of adjacent stations differs by more than 10% of the normal average rainfall from the missed data stations. Thus, in this study missing records of the rainfall stations were estimated by using the normal ratio method (NRM). The NRM can be computed using the following equation:

$$P_x = N_x / M \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots + \frac{P_m}{N_m} \right] \dots\dots\dots (3.3)$$

Where; P_x is missed precipitation data, P₁, P₂...P_m are the precipitation values recorded in neighboring stations , N_x is normal average precipitation of stations x, : N₁, N₂... N_m represents normal average rainfall of each neighboring stations at (1, 2, 3, and x) respectively. M is the number of surrounding gauge stations. The monthly maximum and minimum

temperature values at stations of study area will be averaged into maximum and minimum long term monthly values. These values will be used as input data for evapotranspiration computations. Other climatic data such as sunshine duration, relative humidity and wind speed data of study area stations also will be averaged into long term mean monthly values and used for evapotranspiration calculation.

Consistency of rainfall:- The consistency of rain fall data was checked using double mass curve analysis through plotting the graph of cumulative rainfall collected against the cumulative average records collected at the selected stations in the same periods. By adjusting the consistency value of proportionally, double mass curve plot was made for all of the six stations. As it can be shown in Figure -8, all the stations were found to be consistent and the correlation coefficient of the annual cumulative rainfall of each station with average annual cumulative rainfall values of all the three stations is well.

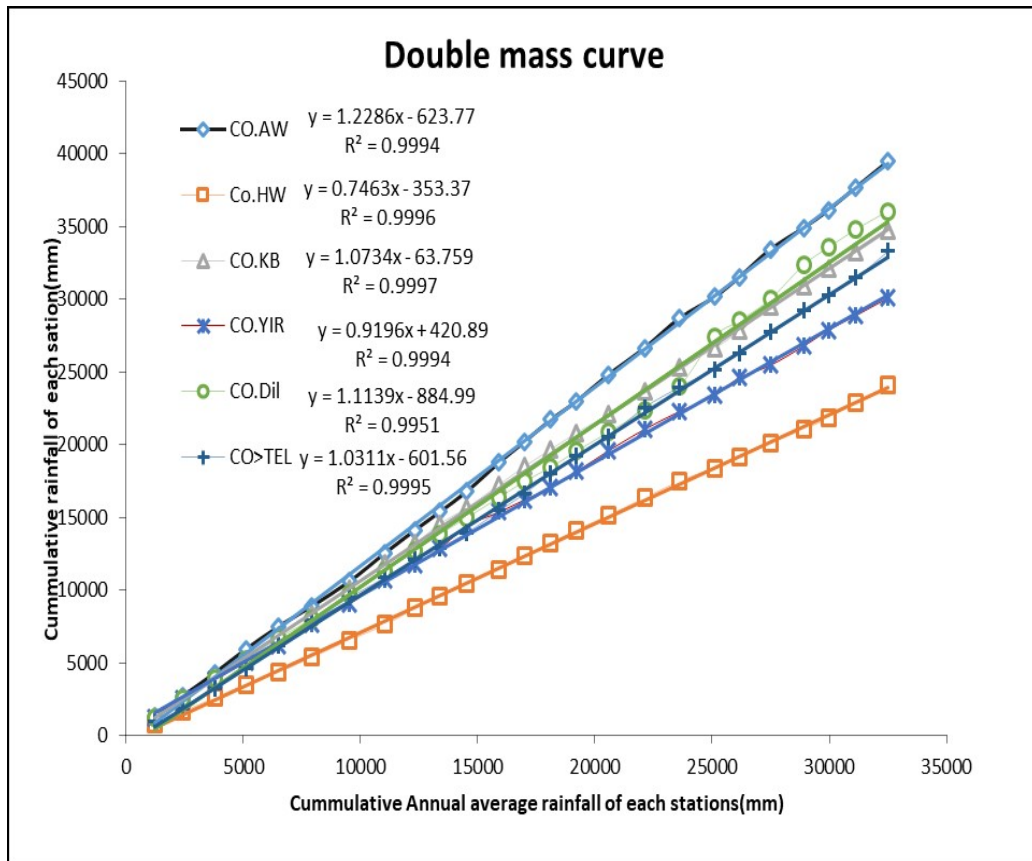


Figure 8: Double Mass Curves for the Stations

3.3.5. Watershed delineation

The watershed and sub-watershed delineation was performed using DEM with ArcSWAT model watershed delineation function. The steps for watershed delineation process includes, first the SWAT project set up was created, stream definition, flow accumulation, and manually adds outlet, watershed outlet selection, watershed delineation, and finally calculation of sub-basin parameters was performed. Once, the DEM setup was completed and the location of outlet was indicated on the DEM, the model automatically calculates the flow direction and flow accumulation. Consequently, stream networks, sub watersheds, and topographic parameters were calculated using the respective tools. This was done by (importing DEM data, computing flow direction, creating watershed outlets, delineation of main and sub-watersheds).

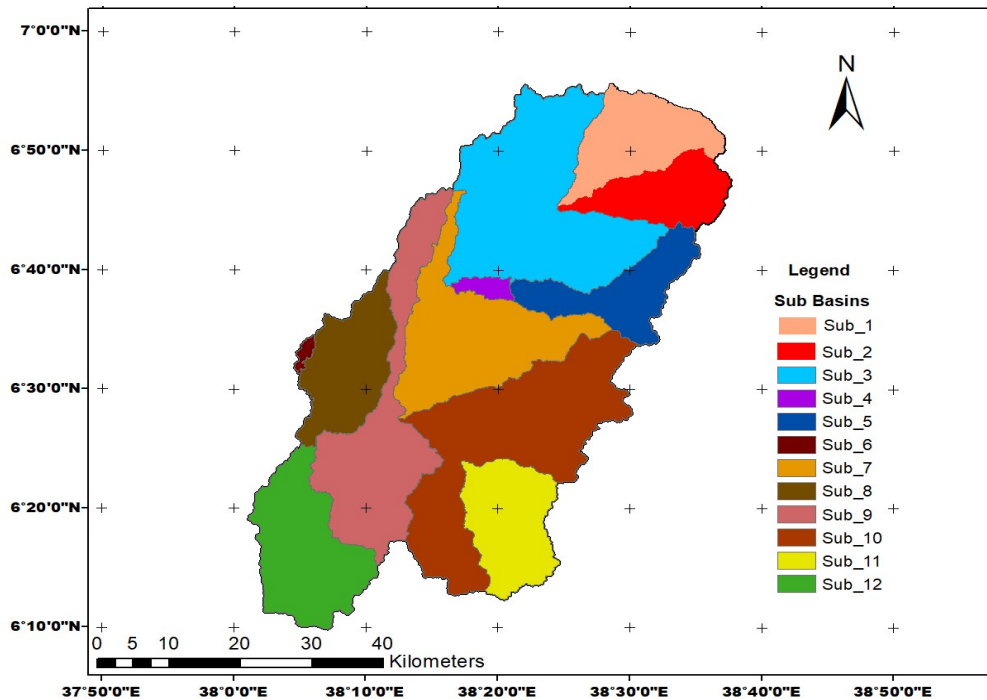


Figure 9: Sub watershed map of Gidabo river catchment

3.4. Factors Determining Surface Irrigation Potential

Identification of suitable sites for surface irrigation was taken by considering the slope, soil, land cover/use and distance between water supply and distance to roads as factors. The individual suitability of each factor was first analyzed and finally weighted to get potential irrigable sites.

Slope suitability: - The slope map was derived from its available DEM with (30*30 resolution) by application of spatial analysis tools (surface analysis) in ArcGIS. The slope derived from the DEM was classified in to four suitability classes (S1, S2, S3, and N) depending upon FAO (1976 and 1996) for surface irrigation development in the aid of the “Reclassification” tool function in ArcGIS. According to FAO, the slope suitability factor ratings identified as 0-2 % is S1, 2-5% is S2, 5-8% is S3 and >8 % is classified as N (not) suitable class. Once the slope was classified accordingly, the area of each slope was calculated in the attribute table and the geographical location of each slope suitability map was identified using ArcGIS tools. The geographical location of each slope is shown in Figure 11.

Soils: The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified which includes drainage, texture, depth, salinity, and alkalinity (Fasina *et al.*, 2008). Major types of soils and textures were identified and analyzed in the study area. The area coverage, depth, drainage and texture of each soil were manipulated in the attribute table after converting in to polygon format.

Soil depth: - refers to the thickness of the soil materials. Soil depth provides structural support, nutrients, and water for plants. Soil depth, soil layering, and depth to an estimated water table are also major factors that must be considered when determining the amount of available water a soil profile can hold (Jamshid, 2003). Soil depth was considered as one of the major factors that determine the selection of surface irrigation potential and crops within the study area.

Based on FAO (1979) the soil depth map of the study area was grouped in to the following suitability classes of S1, S2, S3 and N for surface irrigation in Table 3, and it is presented graphically in Figure 13. The soil depth of the study area was varied from place to place. It was ranging from less than 30 centimeters to greater than 120 centimeters.

Table 3: The FAO guideline which was used to classify the soil depth of the study area

Factors	Factor rating			
	S1	S2	S3	N
Soil depth(cm)	>120	90-120	30-90	<30

Source: FAO (1979)

Soil Drainage: - Permits normal plant growth. Evaluation of the soil drainage requirement is a critical element in selecting land for irrigation, particularly with diversified upland crop production (FAO, 1997). Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. According to FAO evaluation techniques used for evaluation of permeability of soil properties of the land, soil drainage of the area can be classified as MW (moderately well drained), IP (imperfectly drained) and P (poorly drained). The soil texture can determine the permeability of the soil for water in the study area. The soil drainage properties of the study area was classified in to moderately well, imperfectly and poorly drained as shown in Table 11, and Figure 14.

Overall soil suitability: - The vector layers of the soil suitability factors (soil texture, soil depth and soil drainage) were converted to raster layer using conversion tool for weighted overlay analysis. Using overlay tool in Arc GIS10.3, weighted overlay analysis of three determinants reclassified raster soil map (soil drainage, texture and depth) were performed to determine their suitability for surface irrigation.

Then the new value was reassigned for each soil factor and the values were given based on the common evaluation scale from 1-5 by 1 in the weighted overlay analysis dialog box. Of which the value 1 represents the highly suitable, 2 for moderately suitable, 3 for marginally suitable, 4 and 5 are for not suitable class. High percent of influence was given for soil depth during the weighted overlay analysis, since soil depth was the determinant factor in evaluating soil of an area for agricultural development specially irrigated agriculture and it provided structural support, nutrients, organic matter and water.

Table 4: Soil suitability classification result for surface irrigation

Factors	Suitability class			
	S1	S2	S3	N
Soil texture	Sic-C, CL-C, L-CL	ScL	-	-
Soil depth	> 120	90-120	30-90	< 30
Soil drainage	Well	Moderately well	Imperfect	Poor

Source: FAO, 1997

C= Clay, CL= Clay Loam, SCL = Sandy clay Loam, Sic-C= silt clay

S1= highly suitable, S2 = moderately suitable, S3= marginally/less suitable, N= Not suitable

Lithic Leptosol is limited by shallow soil depth (10 cm) which is unfavorable for crop growth and surface irrigation method. Therefore, an area covered by this soil was classified as N (not suitable class).

Land use land cover classification:- Land cover/use of the study area is also the factor, which was used to evaluate the land suitability for irrigation. LULC map of the watershed was derived from satellite image. The image was used to develop the LULC map and potential irrigable land of the Gidabo River catchment. It influences on the cost of irrigation practice to prepare the land for agriculture. The types of LULC of the Gidabo River catchment was ranked based on their importance for surface irrigation potential, costs to remove or change for cultivation and environmental impacts under the watershed. After rank was given for the LULC types, reclassified map of the Gidabo River catchment was developed. It was reclassified into four suitability classes and given value from 1 to 4. 1 represents very suitable, 2 suitable, 3 marginally suitable and 4 unsuitable.

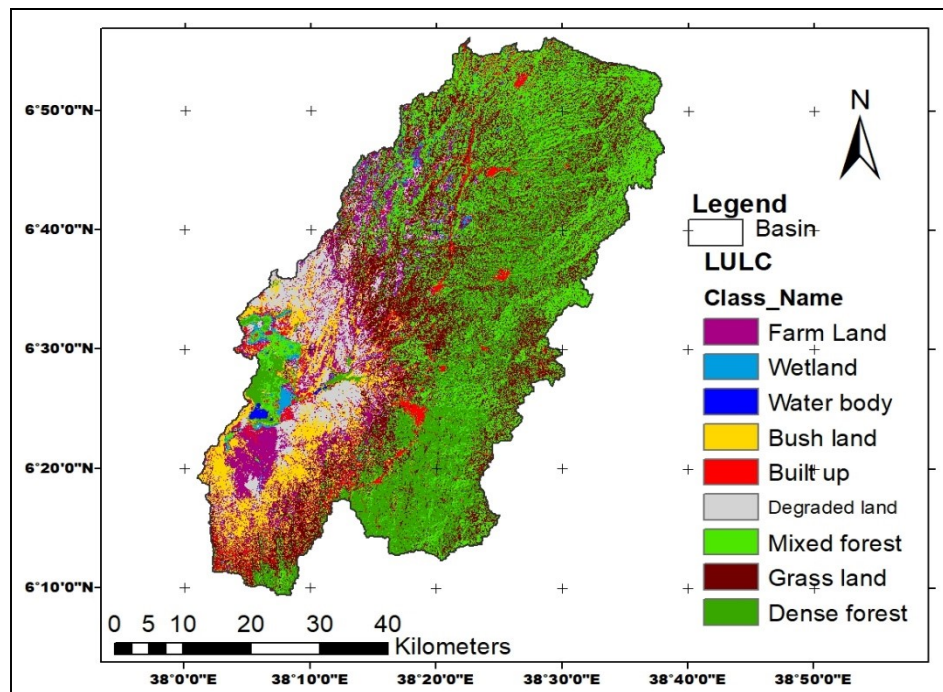


Figure 10: LULC classification Map

Euclidean Distance: - Euclidean distance is the straight line distance between two points on a plane, also known as “distance as the crow flies”. It describes each cell’s relationship to a source or a set of sources. It consists in generating a raster from a vector layer or another raster

that indicates the existing distances from the figure to the rest of the field in a visual and colorful way. It indicates the space that exists from a certain distance to another distance and so on until a maximum distance is indicated. The Euclidean distance output raster contains the measured distance from every cell to the nearest source. The distances are measured 'as the crow flies' in the projection unit of the raster and are computed from cell Centre to cell Centre. This tool was used when creating the irrigation suitability map (Esri, 2016).

Distance from water supply and road: - To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from watershed outlets was calculated using DEM of 30m ×30 m cell size and reclassified and distance to road is also determined similarly. Then, reclassified distances were used for weighted overlay analysis together with other factors which are shown in the Figure 17 and 18 respectively.

3.5. Saaty's Analytical Hierarchical Process (AHP)

The Analytic Hierarchy Process (AHP), introduced by Saaty (1980), is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. The AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. The higher the weight, the more important the corresponding criterion is.

The application of AHP process involves the following steps.

1. Criteria or factors contributing to the set of suitable are identified;
2. The relative importance of each factor to each other factor, i.e. between pairs of criteria this is usually done by domain and experts' opinions, and
3. The consistency of the overall set of pair wise comparisons is assessed using its consistency ratio (CR).

Consistency Ratio: - The final step of AHP pairwise comparison is to calculate a consistency ratio (CR). This is done to identify the degree of consistency in assigning values to the variables in the pairwise comparison matrix (Suh and Brownson, 2016). The formula to reach the consistency ratio is: $CR = CI / RI$

Where CI is the consistency index and RI is the random consistency index (Uyan, 2013). The consistency index is obtained using the formula $CI = \lambda_{max} - n / n - 1$

Where λ_{max} is the eigenvalue of the pairwise comparison matrix and n is the number of variables (Uyan, 2013). The random consistency index is uniform, and based on the number of variables in the comparison matrix (Carrión et al., 2008 & Sindhu et al., 2017). This is shown in appendix Table 24. Thus RI is equal to 1.12 when n is 5

Table 5 shows that the procedure of assigning weightage for each parameter and classes within the parameter based on the importance of it. The value 9 in the table shows higher important while 1/9 shows the least important while 1 shows the equal weight of a parameter or a class. Based on these weightage criteria each parameter in the study has been classified.

Determination of criterion weights: AHP is used to determine criterion weights. A pair-wise comparison matrix is created to express the relative importance between each two criteria. The comparison matrix is basically a list of criteria, which are weighted depending of their respective importance. The matrix values, which could be 1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8 or 9, represent the relative degree of importance of one criterion against another. A bigger matrix value means the first criterion is more important than the second one and vice versa. Value 1 means the two compared criteria have equal importance. Value 9 represents absolute importance and 1/9 the absolute triviality (Saaty and Vargas, 1991).

Table 5: Continuous rating scale of saaty’s Analytical Hierarchical process (1980)

Intensity of importance								
1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very Strong	Strong	Moderate	Equally	Moderate	Strong	Very strong	Extremely
Less important ←					→ More important			

Note 1/8, 1/6, 1/4, 1/2, 2, 4, 6 and 8 can be used if more number of classes or criterion are used.

3.6. Weighing of irrigation suitability factors to find potential irrigable lands

To find suitable site for surface irrigation, overlay analysis was set in Arc tools box and tools from spatial analysis tool sets after weighting the criteria using AHP tool. Then, after their

individual suitability was assessed, the irrigation suitability factors which were considered in the study, such as slope, soil factors (Soil depth, drainage and texture), land cover /use and distance (from Rivers and roads) were used as the input for irrigation suitability model to find the suitable land for surface irrigation. The weighted overlay tool overlays several raster using a common measurement scale and weights each according to its important (ESRI). The result of overlay analysis has been classified into four classes as highly; moderate, marginally suitable and not suitable (Figure 18). The reclassification values of each factors considered are discussed in section 4.3.

3.7. Assessment of Surface Water Availability

The availability surface water of the watershed was investigated by using the simulated value of stream flow from SWAT model output. The stream flow (discharges) of Gidabo River at Aposto, Kola and Bedessa rivers near Aleta Wondo and Dilla respectively were obtained from Ethiopian Ministry of Water, Irrigation and Electricity which were used for flow calibration and validation using SWATCUP after sensitivity analysis was performed.

3.7.1. SWAT model description

SWAT the acronym for Soil and Water Assessment Tool a river basin, or watershed scale model develop by Dr Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT is operates on a daily time step and designed to predict the impact of land management practices on sediment, agricultural chemical and water yields in large complex basins with varying land use, soils, and management conditions over long periods of time series (Neitsch *et al.*, 2005). The model has been widely applied to the different size of the watershed and applications all over the water resources, including the effects of climate and soil erosion (Neitsch et al., 2011). It is a long-term, continuous simulation of the watershed models. For modeling purposes, the watershed is delineated and divided into sub watershed. The sub watershed is further divided into hydrologic response units (HRUs) based on land use, soil, and slope classes 5%, 15%, and 15% respectively used for classification. By using these data SWAT classified the watershed into ninety eight HRUs. The model estimates relevant

hydrologic components such as surface runoff, evapotranspiration, groundwater flow, sediment yield and other components for each HRU unit.

The SWAT system is embedded within geographic information system (GIS) that can integrate various spatial and environmental data including soil, LULC, climate and topographic features. Overall, this study concerns the application of the latest version of SWAT2012.10_319 model integrated with Arc GIS10.3 techniques was used to simulate hydrology of Gidado watershed.

3.7.2. Arc SWAT model set up

Digital Elevation Model (DEM): describes the elevation of any point in a given area at a specific spatial resolution as a digital file. It required by SWAT to delineate the watershed into a number of sub watershed and used to analyze the drainage pattern of the watershed as slope, stream length and width. Before the DEM data was loaded into ArcSWAT interface, it was projected into the projected coordinate system, using Arc toolbox operation in ArcGIS10.3.

Watershed delineation: Watershed Delineator tool in ArcSWAT2012 allows the user to delineate the watershed and sub watershed using digital elevation models of the study area.

This tool uses and expands ArcGIS10.3 and Spatial Analyst extensions (Neitsch et al., 2005). Flow direction and accumulation are the concepts behind the definition of the stream network of the DEM in SWAT model. The user determined the origin of streams with a threshold area was required to form the origin of a stream at last to form sub watersheds. Winchell et al. (2007) the size, number of sub watersheds and stream network depend on threshold area. The monitoring point was added manually and selected for finalizing the sub watershed delineation. Finally, the Gidabo watershed was delineated at an outlet point of Lake Abaya. The study area was delineated as 3180.49 km² and 12-sub watersheds are formed for the whole study area.

3.7.3. Weather Data definition

The PcP Stat was used to calculate the weather stations statistics needed to create user weather station files for SWAT which requires daily input values of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed to generate weather station statistics. Among the stations used for this study, Dilla station is synoptic station in

which all types of climatic data, (Precipitation, Temperature (max, min), humidity, solar radiation, and wind speed) were available. But in other stations humidity and solar radiation were not available. Hence, Dilla station was used for generating the remaining weather data.

3.7.4. SWAT Model Simulation

Model simulation is used to identify the differences between measured data and simulated results. Location table of weather data, daily precipitation data files, maximum and minimum air temperatures, wind speed, relative humidity were loaded to link them up with the required files already created for the purpose. The model was initially run on monthly basis using default parameter values. The result from simulation cannot be directly used for further analysis. But, the ability of the model to predict the stream flow should be evaluated through sensitivity analysis, model calibration, and model validation (White and Chaubey, 2005).

3.8. Model Parameters, Sensitivity Analysis, Calibration and Validation

It is a computer program for integrated various sensitivity analysis, calibration and validation programs for SWAT model. Several techniques are used to analysis calibration and validation of the model. For this study Sensitivity analysis, calibration, and validation were implemented by the automated SWAT Calibration and Uncertainty Program software (SWAT-CUP) using the commonly applied Sequential Uncertainty Fitting algorithm (SUFI2) (Abbaspour, 2007).

3.8.1. Parameters and Sensitivity analysis

The simulated and observed value for the flow may differ, in order to minimize this variation it is essential to determine the parameters which affect model simulation. To check these model parameters are to be known and its effect should be evaluated via sensitivity analysis. It was done for the entire period (1990-2014), which includes three years warm-up period (January 1, 1990 to December 31, 1992) which allows the model to cycle multiple times to minimize the effect of the user's estimates of initial state variables such as soil and water content and surface residue (Zhang *et al.*, 2007). For this study, sixteen parameters were used for analysis (Neitsh *et al.*, 2005) Table 6.

Table 6: The common parameters in SWAT model for sensitivity analysis

No	Parameter	Definition	Range
1	Alpha_Bf	Base flow alpha factor (days)	0 - 1
2	Gw_Delay	Groundwater delay (days)	0 - 500
3	Gw_Revap	Groundwater "revap" coefficient	0.02 -0.2
4	Gwqmn	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0 - 5000
5	Revapmn	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0 - 500
6	Ch_K2	Effective hydraulic conductivity (mm/hr)	0 - 500
7	Ch_N2	Manning's nvalue for main channel	0 - 0.3
8	Epc0	plant water uptake compensation factor	0 - 1
9	Esco	soil evaporation compensation factor	0 - 1
10	Sol_BD	Soil bulk density	0 – 0.3
11	Sol_Awc	soil available water capacity	0 - 1
12	Sol_K	hydraulic conductivity of saturated soil	0 - 2000
13	Sol_Z	Depth from soil surface to bottom layer (mm)	0 - 3500
14	Cn2	curve number	35 -98
15	Surlag	runoff delay coefficient	0 - 10
16	Slope	Average slope steepness (m/m)	0 - 999

Sensitivity analysis indicates how the changes in parameter values affect the overall change in the output of the model. This can be done by using default sensitivity analysis, where only one parameter is changed or more complex arrangements that explore the relationships between multiple parameters. The sensitivity analysis was done by using SWAT-CUP, in which observed flow data, simulated flow data and the sensitive parameter in relation to flow with the absolute lower and upper bound were used as inputs.

3.8.2. Model Calibration and Validation

Model calibration is a means of adjusting the model parameters to match the simulated results with the observed data as much as possible thereby reducing the prediction uncertainty. It is

performed by carefully selecting values for model input parameters by comparing model prediction (output) for a given set of assumed conditions with observed data. After selection of sensitive input parameters, the SWAT model was calibrated for stream flow of the watershed at its sub-outlets of the watershed. Multi-site calibration and validation was used to assess the performance of the SWAT model. The calibration was done by changing the parameters sequentially for obtaining optimum agreement between observed and simulated stream flow. Flow calibration was performed using observed data for a period of 12 years from 1993-2004. After each calibration, checking of the statistical model performance indicator (R^2 , NSE and PBIAS) values and calibrated at least until the minimum recommended values were fitted by the model. That is $R^2 > 0.6$, $NSE > 0.5$, and $PBIAS < \pm 25$ for stream flow (Moriasi et al, 2007). Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. The calibration process continued until simulation of validation period of stream flow accepted for the model performance. The average monthly stream flow data of eight years period from (2005- 2012) were used for model validation process in this study.

3.8.3. Model Performance Evaluation

Several statistical approaches were used to check the model performance, with coefficient of determination (R^2), Nash-Sutcliffe simulation efficiency (NSE) and percent bias (PBIAS). Model prediction is considered unacceptable or poor if the R^2 and NSE values are less than or very close to zero while perfect if the values are one (Alansi *et al.*, 2009). These parameters are important to investigate and determine the accuracy of SWAT model simulations in this study.

Coefficient of determination (R^2): provides a measure of how well observed outcomes are replicated by the model. It describes the proportion of the total variance in the observed data i.e. described by the model. The range of R^2 lies between 0 (which indicates the model is poor) and 1 (which indicates the model is perfect), with higher values indicating less error variance, and typical values greater than 0.6 are considered acceptable (Moriasi *et al.*, 2007). It is calculated:

$$R^2 = \frac{[\sum_{i=0}^n (Q_{Obs} - \bar{Q}_{Obs}) * (Q_{Sim} - \bar{Q}_{Sim})]^2}{\sum_{i=0}^n (Q_{Obs} - \bar{Q}_{Obs})^2 \sum_{i=0}^n (Q_{Sim} - \bar{Q}_{Sim})^2} \dots\dots\dots(3.4)$$

Where n is the number of observations during the simulation period,

Q_{Obs} is the observed flow data,

Q_{Sim} is the simulated flow value with the respected time,

\bar{Q}_{Obs} and \bar{Q}_{Sim} are the arithmetic means of the observed and simulated values.

If, $R^2 = 0$, none of the variances in the measured data is replicated by the model predictions.

$R^2 = 1$, indicates that all of the variances in the measured data is replicated by the model predictions

The Nash Sutcliffe simulation efficiency: - NSE measures the efficiency of the model by relating the goodness-of-fit of the model to the variance of the measured data. (NSE) indicates that how well the plots of observed versus simulated data fits the 1:1 line. NSE is computed using the following equation:

$$NSE = 1 - \frac{\sum_{i=1}^n (Q_{Obs} - Q_{Sim})^2}{\sum_{i=1}^n (Q_{Obs} - \bar{Q}_{Obs})^2} \dots \dots \dots (3.5)$$

Where n is the number of observations during the simulation period,

Q_{Obs} is the observed flow data,

Q_{Sim} is the simulated flow value with the respected time,

\bar{Q}_{Obs} is the arithmetic means of the observed flow.

The value of NSE ranges from negative infinity to one (perfect). NSE value < 0 indicates the mean observed value is a better predictor than the simulated values, which indicates unacceptable performance. While NSE values greater than 0.5, the simulated value is a better predictor than means measured value and generally viewed as acceptable performance (Santhi et al., 2001).

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than the observed values. PBIAS is expressed in percentage; the lower absolute value of the PBIAS is the better will be the model performance.

$$PBIAS = \frac{\sum_{i=1}^n (Q_{Obs} - Q_{Sim})}{\sum_{i=1}^n (Q_{Obs})} * 100 \dots \dots \dots (3.6)$$

Where n is the number of observations during the simulation period,

Q_{Obs} is the observed flow data,

Q_{Sim} is the simulated flow value with the respected time,

The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate

model overestimation bias (Moriasi et al., 2007). According to Moriasi et al. (2007), the following evaluation statistics were recommended to evaluate the model performance.

Table 7: Model parameters performance

	Performance rating			
	Unsatisfactory	Satisfactory	Good	very good
R ²	<0.5	0.5-0.6	0.6-0.7	0.7-1
NSE	<0.5	0.5-0.65	0.65-0.75	0.75-1
PBIAS	PBIAS ≥ ±55	±30 ≤ PBIAS < ±55	±25 ≤ PBIAS < ±30	±25 < PBIAS < ±25

3.9. Transferring Calibrated Parameters of Gauged to Ungauged Watersheds

After thorough calibration and validation of SWAT model for gauged rivers in the watershed, the final calibrated parameters were used to predict discharge of ungauged rivers in the watershed, which had similar LULC, slope, and soil characteristics as that of gauged rivers watershed.

Spatial proximity: Regionalization based on spatial proximity approach was used the calibrated parameter values from the geographically closest gauged watershed. The underlying assumption here is that neighboring watersheds should behave similarly because of similar climatic and physical characteristics. The physical similarity method transfers the whole set of parameter values from a physically similar watershed whose characteristics (climatic and physical) are similar to those of the target ungauged watershed (Vaze et al., 2011). So the assumption is made that watersheds are highly uniform with respect to climatic and topographic properties.

Therefore, calibrated model parameter values from gauged watersheds can be derived and applied at the ungauged watersheds in order to predict the discharge regime. The studies have shown that choosing the donor watersheds based on spatial proximity to the ungauged watershed alone is by far the most credible approach (Merz & Blöschl, 2004; Zhang & Chiew, 2009).

3.10. Computing irrigation water requirements

In this study, two crops (maize and Tomato) were selected for estimation of irrigation water requirement on monthly basis and their cropping pattern data (Planting dates, harvesting dates, rooting depth, crop coefficients and cropping calendar appendix Figure 4 and 5) were obtained

from Sidama, Gedieo and Borena zones agricultural offices. In the identified potential irrigable sites, gross irrigation water requirement was estimated by considering the overall application efficiency of 60 % for surface irrigation (FAO, 1998 and water conveyance efficiency of 80 % which were assumed from since there will be continuous supply of irrigation water with no substantial change in according to FAO irrigation and drainage paper no 24, (FAO, 1992). For estimating irrigation water requirement, ETO values were estimated using Penman Monteith method by CROPWAT8.0 (FAO 1992). The climatic data required for estimation of ETO were mean monthly maximum and minimum temperature (°C), relative humidity (%), wind speed (km/day or m²/s), and sunshine hours. The ETO was calculated:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \left(\frac{900}{T + 273} \right) U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \dots\dots\dots (3.7)$$

Where: ETO=reference evapotranspiration (mm/day); Rn=net radiation at the crop surface(MJM²d⁻¹); G= soil heat flux density(MJM⁻²d⁻¹); T=mean daily air temperature at 2m high(°C); U2= wind speed at 2m high(m/s); es= saturation vapore pressure (kPa); actual vapor pressure (kPa); Δ= slope vapore pressure curve (kPa °C⁻¹); γ= psychromic constant (kPa °C⁻¹); es - ea= saturation vapore pressure deficit (kPa).

$$ET_c = K_c * ET_o \dots\dots\dots (3.8)$$

$$IWR = ET_c - P_{ef} \dots\dots\dots (3.9)$$

Where: ETc is crop evapotranspiration or crop water requirement (mm/day). IWR is irrigation water requirement (mm), and P_{ef} is effective rainfall (mm). Effective rain fall (P_{ef}) is the portion of a rain, falling during the growing period of the crop which is available to meet the consumptive water need or the evapotranspiration requirement of the crop. It is calculated using CROPWAT version 8. Consequently, gross irrigation requirement for the selected crops was computed using the formula:

$$GIWR = \frac{1}{E} * NIWR * A_{crop} \dots\dots\dots (3.10)$$

Where: GIRW =Gross irrigation water requirement is the amount of water to be extracted (by diversion) and applied to the irrigation scheme in (m³/month). NIWR=Net irrigation water requirement, A_{crop}=Potential irrigable area to be cultivated with selected crop (ha)

The overall irrigation efficiency (E in %) expresses the percentage of the quantity of water used efficiently for the growth of the crop in the field to the quantity of intake water from the water

source. A portion of the intake water is lost during transport through the canals and in the fields by the evaporation, infiltration and so on. The remaining part is stored in the root zone and used by the crop. Irrigation efficiency is estimated by using the following formula:

$$E = \frac{E_c * E_a}{100} \dots\dots\dots (3.11)$$

Where: E= Over all Irrigation efficiency (%), Ec= Conveyance efficiency (%), Ea= Field application efficiency (%).

4. RESULTS AND DISCUSSIONS

4.1. Identification of Suitable Areas for Surface Irrigation

Potential irrigable land was obtained by creating irrigation suitability model analysis which involved weighting of values of all data sets, land characteristics dataset and distance from the water supply and road. The main and tributary rivers are referring to the main and sub-watersheds obtained by watershed delineation.

4.1.1. Slope Suitability

According to the slope classification result, the land having slope range below 2 % was classified as highly suitable while the slope range $> 8\%$ categorized as unsuitable class for surface irrigation. This type of land classification is very common and widely used in many researches and also recommended by FAO guidelines (FAO, 1976 and 1996).

The suitability result indicated that 5.30% of the land was highly suitable, 17.17 % moderately suitable, 15.51% marginally suitable and majority of the study area in terms of slope 62.02% was not suitable class for surface irrigation development.

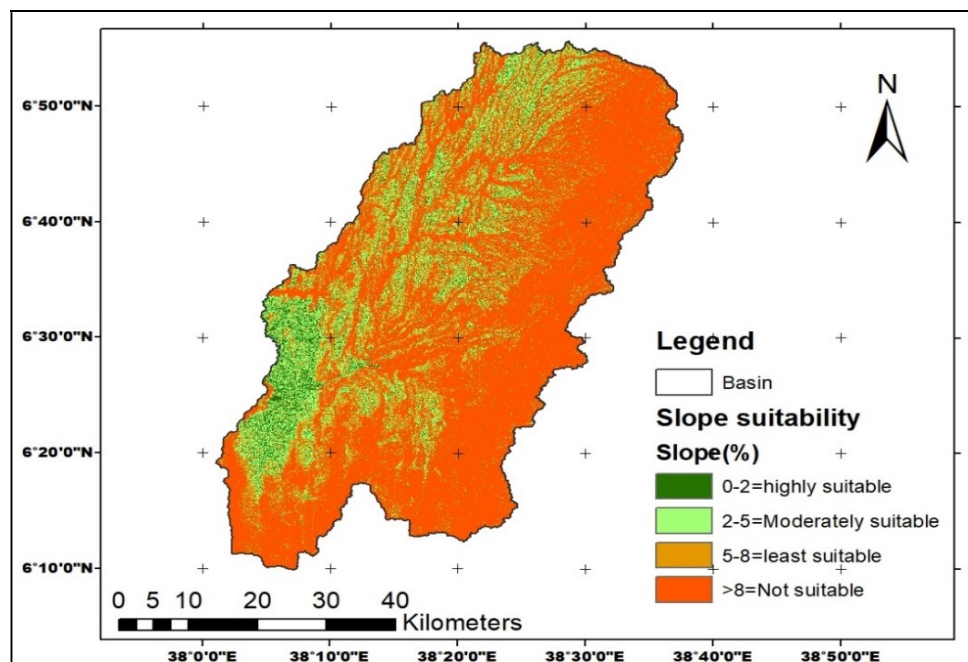


Figure 11: Map showing the suitability of study area based on slope

Table 8: Slope suitability range of the study area for surface irrigation

Slope range (%)	Area (Km ²)	%	Description
0-2	168.70	5.30	Highly suitable(S1)
2.0001-5	546.22	17.17	Moderately suitable(S2)
5.0001-8	493.33	15.51	Marginally suitable(S3)
>8	1972.24	62.02	Not suitable(N)
Total	3180.49	100	

Source FAO (1996), Slope suitability classification for surface irrigation

As shown in the Table 10, most of the catchment area is not suitable for the development of surface irrigation and it covers 77.53% (2465.55 km²), of the total area. The remaining 22.81% (714.92 km²) of area is suitable for surface irrigation development.

4.1.2. Soil suitability

According to FAO (1976 and 1997) the basic soil physical properties used for evaluation of soil suitability for surface irrigation were soil drainage, soil texture, and soil depth. The soil suitability was implemented, using FAO (1997). The land suitability of the river catchment with regard to soil has been established by evaluating the soil suitability parameters such as soil texture, depth and soil drainage suitability through overlay analysis.

Soil texture Suitability: In this study six types of soil were identified and analyzed. The area coverage, depth, drainage and texture of each soil were manipulated in the attribute table after converting in to polygon format.

Table 9: Major soil textures and their suitability classification

Soil Type	Texture	Area(km ²)	%	Suitability
Eutric Leptosols (LPe)	L	235.3	7.40	S3
Lithic Leptosols (LPq)	Cl-L	840.46	26.43	S2
Haplic Luvisols (LVh)	S-Cl-L	365.21	11.48	S3
Chromic Luvisols (LVx)	S-Cl-L	763.76	24.01	S3
Humic Nitosols (NTu)	Cl	159.74	5.02	S1
Eutric Vertisols (VRe)	Cl	816.02	25.66	S1
Total		3180.49	100	

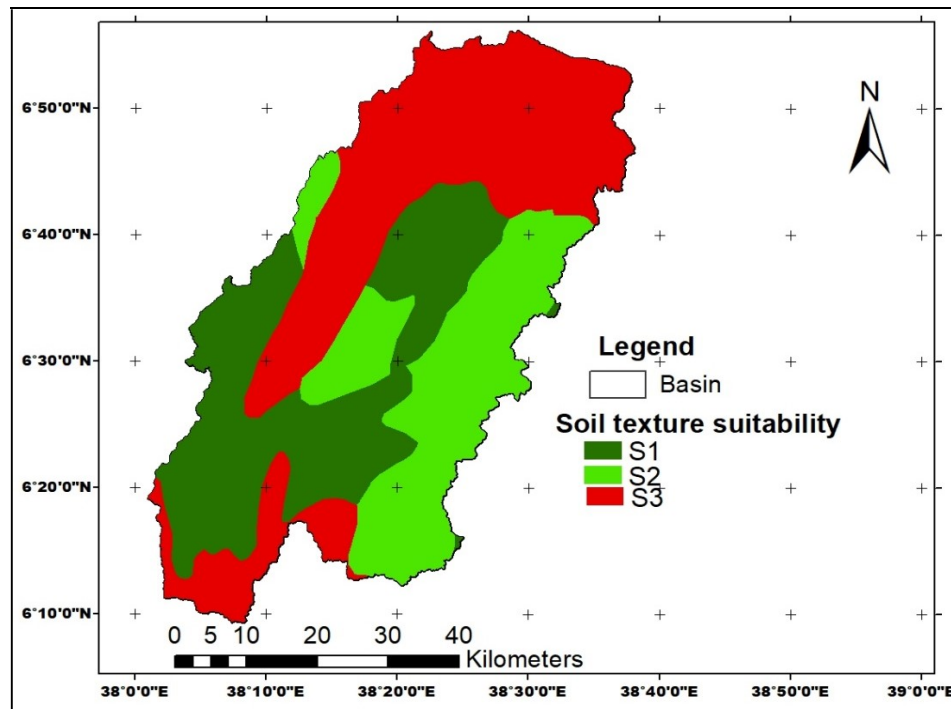


Figure 12: Soil texture suitability map of the study area

Based on the FAO guidelines for soil evaluation, the soil texture of the study area was evaluated and classified in S-CI-L (sandy clay loam), CI (clay), and CI-L (clay loam and L (loam) as shown in soil texture suitability classification results in Table 9.

This analysis indicated that the study area was classified into three irrigation suitability classes based on soil texture suitability as a factor: Humic Nitisols and Eutric Vertisols have clay soil texture characteristics, which accounts 30.68% of the total area, was classified as highly suitable (S1) for surface irrigation. Haplic and Chromic Luvisols were sandy clay loam texture and Eutric Leptosols (Loam) were classified as S3 (marginally suitable class). And Lithic Leptosols shares clay loam texture and was classified as S2. In general, about 26.43% of the land in the study area can be categorized as moderately suitable (S2 class) for surface irrigation. These soils are classified as S2 because of the presence of the factors limiting the land for the specified use (FAO, 1979).

Soil depth reclassification: - Based on FAO (1979) the soil depth map of the study area was classified in to the four suitability classes as S1, S2, S3 and N for surface irrigation as shown in the Figure 13.

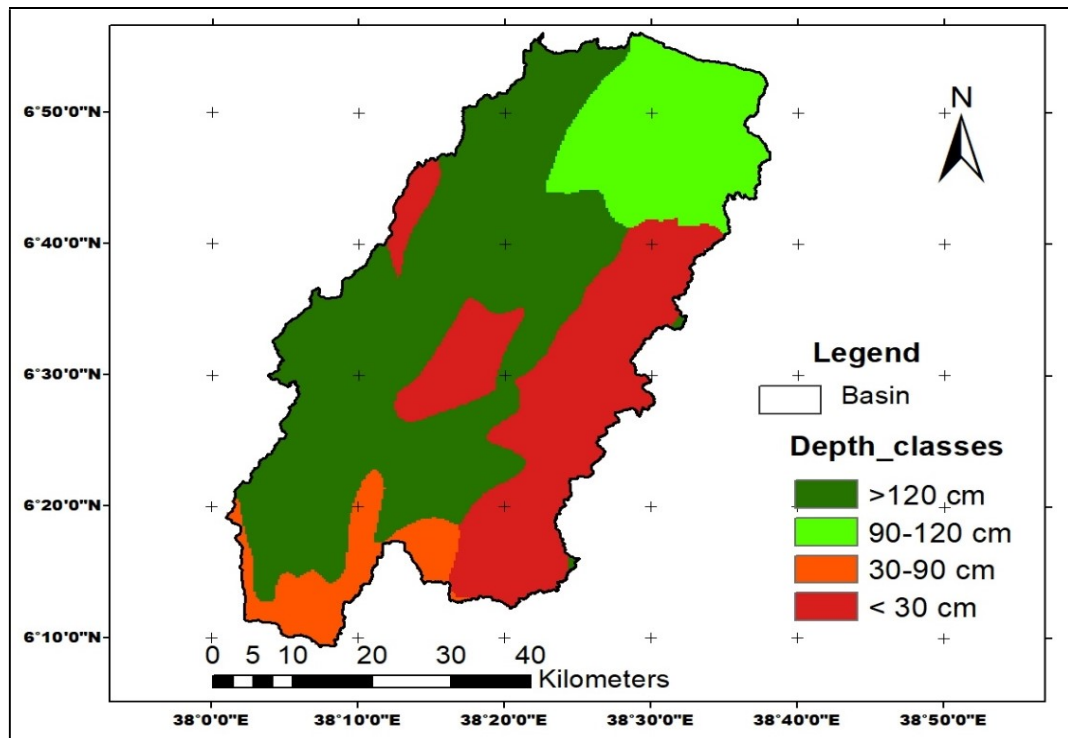


Figure 13: Soil depth suitability of study area

The soil depth of the study area was varied from place to place. It was ranging from less than 30 centimeters to greater than 120 centimeters.

Table 10 : Soil depth suitability classification for surface irrigation

Soil depth (cm)	Area(km ²)	%	Description
>120	1598.93	50.27	Highly suitable (S1)
90-120	525.80	16.53	Moderately suitable (S2)
30-90	235.3	7.40	Marginally suitable (S3)
<30	820.46	25.80	Not suitable (N)
Total	3180.49	100	

Source: FAO (1979)

As shown in the (Table 10) most of the study area was highly suitable (S1) for soil depth as it accounts 50.27%. 16.53% of the land came under moderately suitable for surface irrigation and 7.40% was classified as marginally suitable (S3). However, the rest was classified as not suitable it covers 25.80% of the land.

Soil drainage and its suitability: - According to FAO standard guidelines (1997), soil drainage of a Gidado sub basin was classified in to three classes. These are moderately well drained (MW), imperfectly drained (IP), and poorly drained (P). Consequently, suitability map of soil drainage within the study area was developed as it can be seen in the Figure 14 below. About 40.68% of the area have a moderately-drained soil which is suitable for surface irrigation, 33.67 % and 25.66% of the soils in the area were categorized under imperfectly and poorly drained class respectively for surface irrigation according to FAO guidelines.

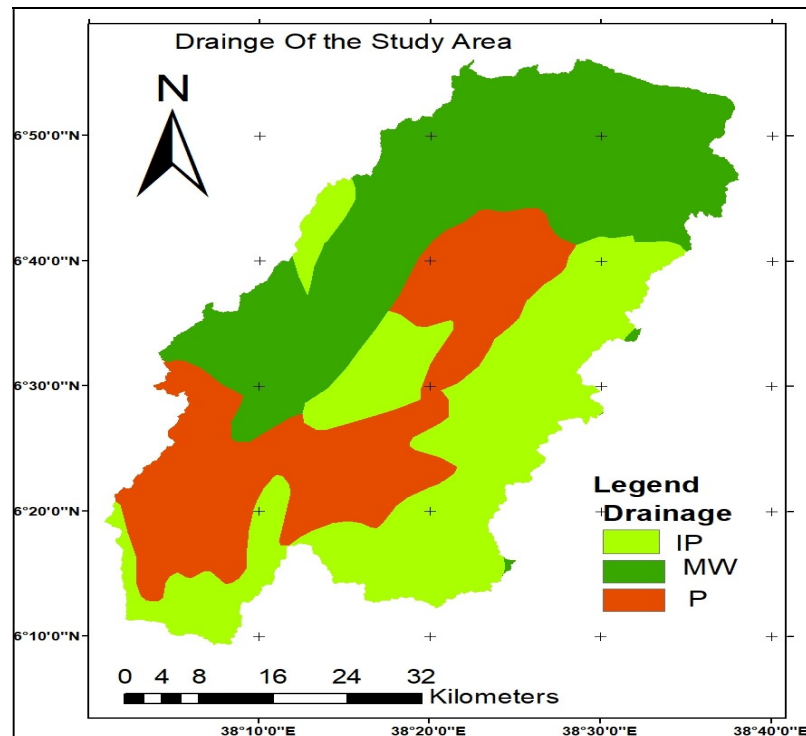


Figure 14: soil drainage suitability classification

Table 11: Factor rating for suitability of soil drainage

Drainage	Area(km ²)	% of the total	Rating factor
MW(Moderately drained)	1293.71	40.68	S2
IP(Imperfectly drained)	1070.76	33.67	S3
P(Poorly drained)	816.02	25.66	N
Total	3180.49	100	

The overall soil suitability: The results of soil suitability in the weighted overlay analysis revealed that about 5.83%, 59.09%, 26.74% and 8.34% of soils in the watershed were

categorized under highly, moderately, marginally and not suitable classes respectively with the combined effect of the three rasterized soil (drainage, depth and texture) suitability classes.

Table 12: Soil suitability of surface irrigation in the weighted overlay analysis

S/N	Area (km ²)	% of area	Suitability
1	185.34	5.83	Highly suitable
2	1879.35	59.09	Moderately suitable
6	850.46	26.74	Marginally suitable
4	265.34	8.34	Not suitable
Total	3180.49	100	

Generally, in the weighted overlay analysis 64.92 % of the soil in the study area was classified as suitable for surface irrigation and the rest 35.08 % of the total area was not suitable for surface irrigation development Table 12. The areal distribution of the overall soil suitability map of the watershed is shown in Figure 15.

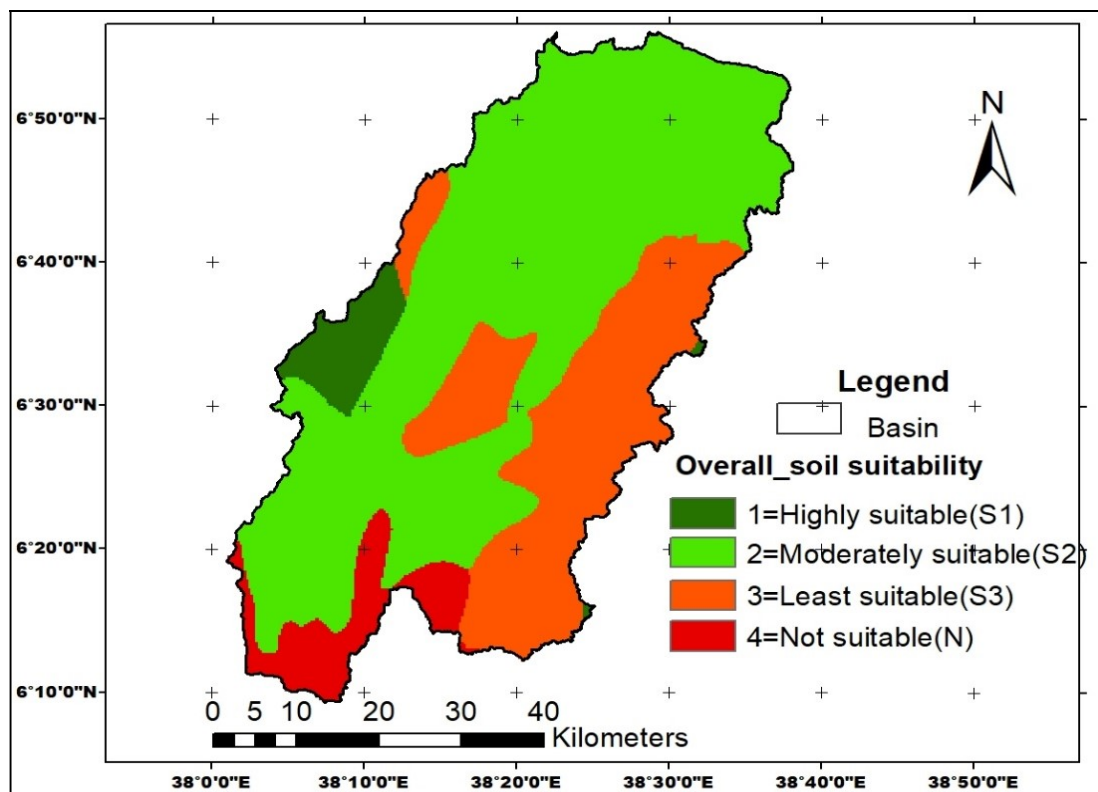


Figure 15 : The overall soil suitability map

4.2.3. Land use/cover suitability investigation

Table 13: Land use/land cover, SWAT codes and their areal coverage in the watershed

Land uses	SWAT Code	Area(km ²)	% in watershed area	Rate
Forest-Evergreen	FRSE	598.13	18.81	N=4
Forest-Mixed	FRST	793.21	24.94	S3=3
Range-Bush	RNGB	213.78	6.72	S3=3
Range-Grasses	RNGE	734.36	23.09	S2=2
Agricultural Land	AGRL	479.63	15.10	S1=1
Residential	URBN	144.75	4.55	N=4
Barren	BARR	211.87	6.66	N=4
Water	WATR	2.36	0.07	N=4
Wetland	WETN	2.40	0.08	N=4
Total		3180.49	100	

From the Table 13 the land use/cover suitability analysis was classified as highly, moderately, marginally and not suitable classes for irrigation.

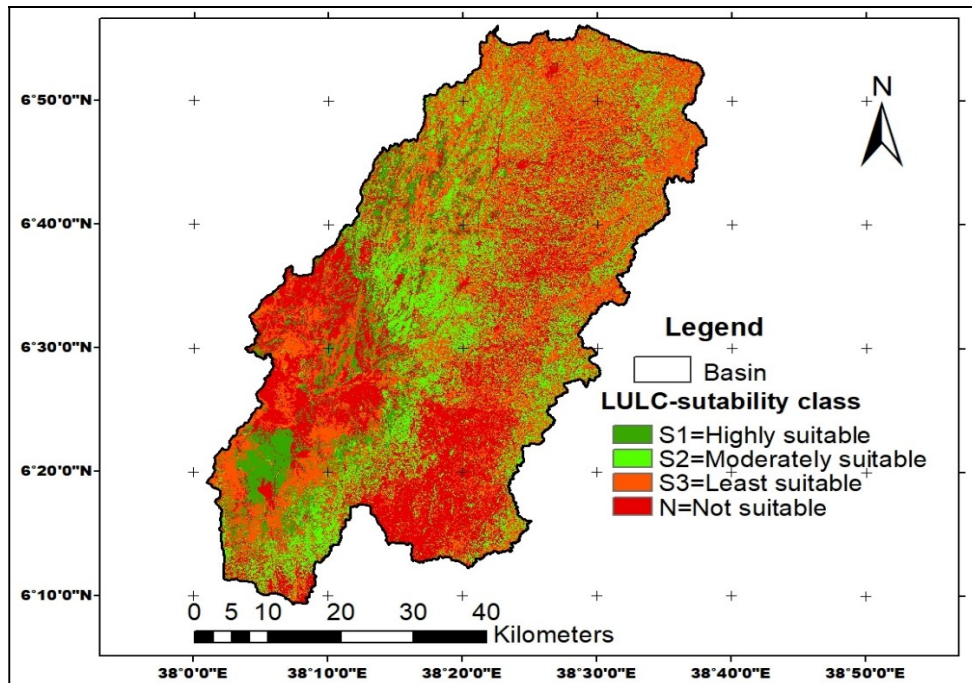


Figure 16 : LULC classification

Table 14: Landsat 2014; Error matrix of LULC classification in the study area

Classified Data	FEG	FM	RB	RG	FL	RS	Br	W	WL	Row Total	Corrected sample	User accuracy (%)
Forest-Evergreen(FEG)	28	2	0	0	0	0	0	0	0	30	28	93.33
Forest-Mixed (FM)	3	25	2	0	0	0	0	0	0	30	25	90
Range-Bush(RB)	0	0	27	3	0	0	0	0	0	30	27	90
Range-Grasses(RG)	0	0	1	28	1	0	0	0	0	30	28	93.33
Farmland(FL)	0	0	0	0	26	0	4	0	0	30	26	86.67
Residential(RS)	0	2	0	0	0	25	0	0	0	27	25	92.59
Barren(Br)	0	0	0	0	4	0	20	0	0	24	20	83.33
Water(W)	0	0	0	0	0	0	0	11	2	13	11	84.62
Wetland(WL)	0	0	0	0	0	0	0	2	15	17	15	88.24
Column Total	31	29	30	31	31	25	24	13	17	231	205	
Producer Accuracy (%)	90.32	86.21	90	90.32	83.87	100	83.33	84.62	88.24			
	Overall Accuracy (%)=205/231=88.75%											
	overall Kappa value(%)=87.25%											

Table 14, showed that the overall accuracy is 88.75% and its Kappa value is 87.25%.this indicates that there is strong agreement between classified data from classified image and reference data from Google Earth data. User's accuracy ranged from 83.33% to 93.33% while producer's accuracy ranged from 83.33% to100%. Moreover, the measure of producer's accuracy reflects the accuracy of prediction of the particular category. The User's accuracy reflects the reliability of the classification to the user. User's accuracy is the more relevant measure of the classification's actual utility.

4.2.4. Reclassifying distance to perennial rivers and Roads

According to Seleshi G. *et al.*, (2016) and Victor, M.W. (2014), Irrigation areas should be located as close as possible to rivers (putting into consideration a buffer zone for protection of water resources) and close to the roads for accessibility, in terms of labor accessibility and movement of both farm input and output. Their suitability classification is shown below in the Table 15 and Figure 17.

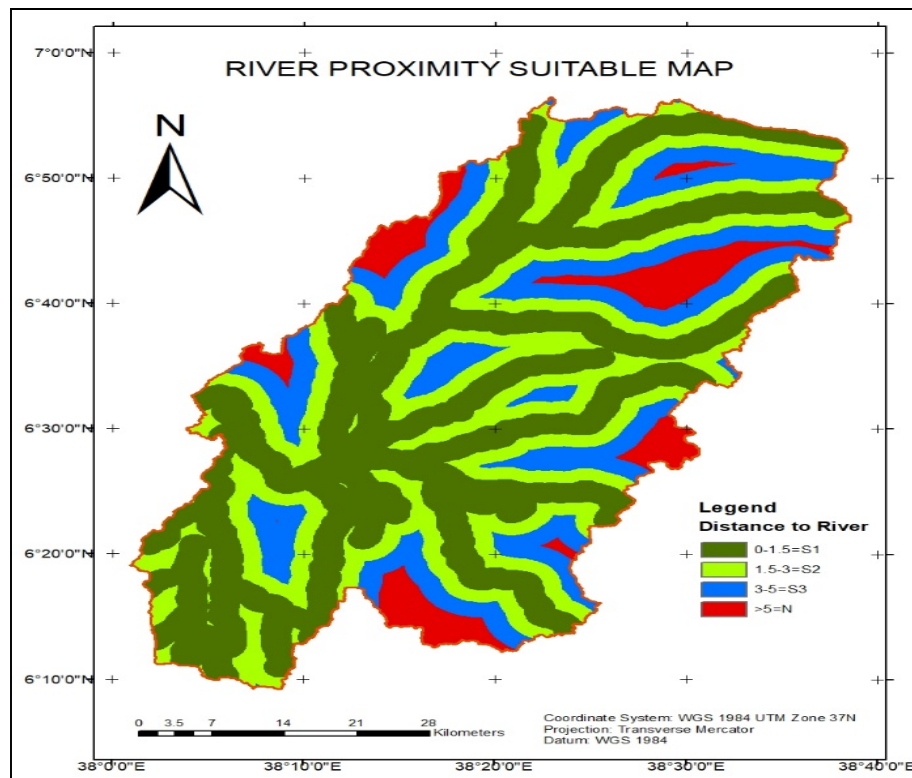


Figure 17 : Map showing the suitability of study area based on Distance to rivers

Table 15: Table showing criteria for classification of Distance to Perennial Rivers

Class range (km)	Weight	Description
0-1.5	1	Highly suitable
1.5-3	2	Moderately suitable
3-5	3	Marginally suitable
>5	4	Not suitable

Source: Seleshi G. *et al.*, (2016)

Reclassifying distance to Roads: - According to Seleshi G. *et al.*, (2016) and Victor, M.W. (2014), Irrigation areas should be located close to roads for accessibility, in terms of labor accessibility and movement of both farm input and output.

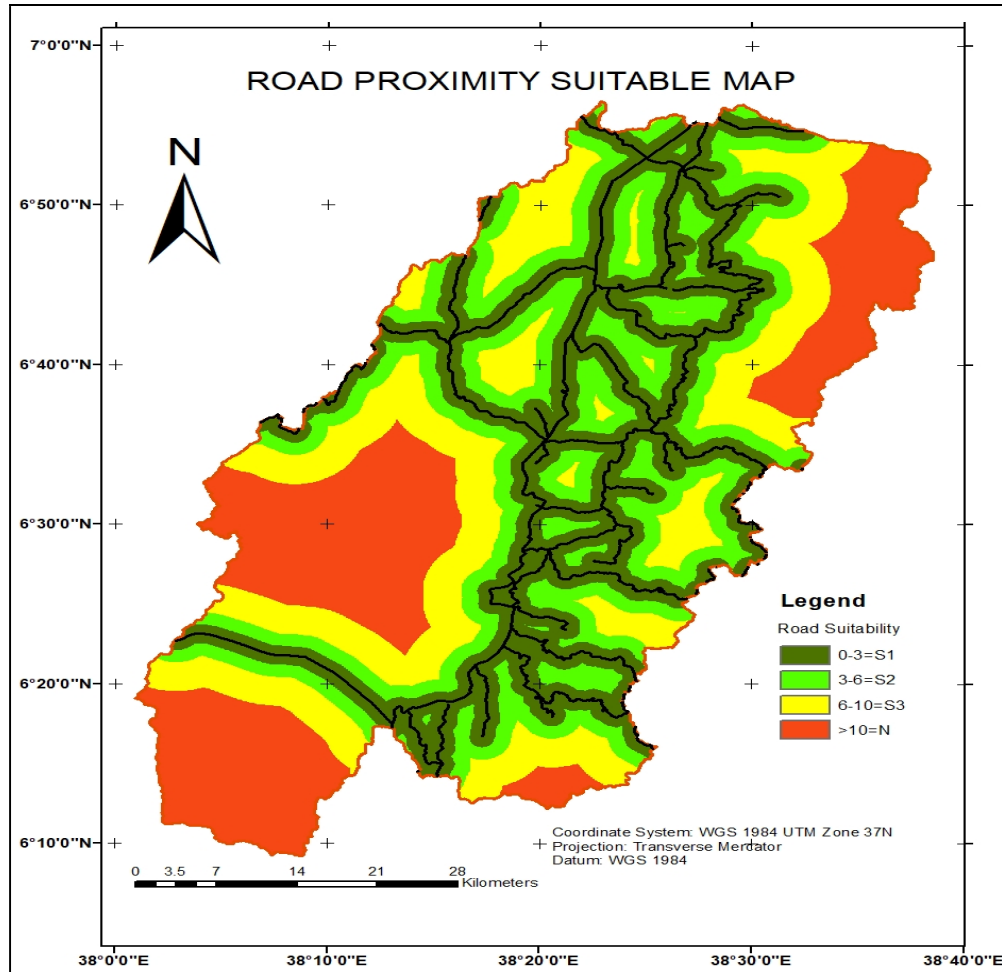


Figure 18 : Map showing the suitability of study area based on distance to river

Table 16: Showing criteria for suitability classification of Distance to Roads

Class range (km)	Weight	Description
0-3	1	Highly suitable
3-6	2	Moderately suitable
6-10	3	Marginally suitable
>10	4	Not suitable

Source: Seleshi G. *et al.*, (2016)

4.3. Weighting of factors and weighted overly the overall suitable areas for irrigation

The five factors ranging from soil to slope are listed in the first five columns and rows in Table 19. The column factors were compared with the factors in the rows for their significance to surface irrigation, then using the scoring of (Saaty, 1977) the pair-wise matrix Table 19 was prepared. Thus, the “river proximity” in the column is much more important for determining the suitability of a basin than the factor “land use” (in the row). Hence, I assigned the value of 5 at the intersection of “river proximity” in the column and “land use” in the row. Conversely, “land use” (in the column) of Table 19 is much less important than “river proximity” (in the row) and the reciprocal of 5 to the intersection of these two factors was assigned. Next, after completing the pair-wise comparison matrix, the weights of the factors are computed by normalizing the respective eigenvector by the cumulative eigenvector. Eigenvalue vector is the n th root of the product of rows (Podvezko, 2009).

The results in Table 18 show that the factor “slope” is the most important factor since all its values are greater than 1 in its row followed by “river proximity” that only has one value less than 1. The least important factor in considering surface water irrigation suitability is “road proximity” with all its row values less than 1 except 2. The judgment is subjective, weighting of decision factors is determined based on the importance of each factors and involves knowledge of those familiar with irrigation in the area. The factors slope, river proximity and soil were judged as very important because slope and river proximity are associated with a large initial investment and the remaining were considered were considered as important to least important.

Table 17: The pairwise comparison for irrigation suitability factors

Factors	Soil	LULC	River	Road	Slope
Soil	1	4	1/3	4	1/5
LULC	1/4	1	1/5	1/2	1/7
River Proximity	3	5	1	6	1/2
Road Proximity	1/4	2	1/6	1	1/7
Slope	5	7	2	7	1

The next step of AHP pairwise comparison is to normalize the matrix. This is performed by dividing each cell value by the sum of its column. The normalized value of each row is then

averaged to produce the priority vector. These priority vectors indicate the final weights of the variables.

Table 18: Normalized score table

Factors	Soil	LULC	River proximity	Road proximity	Slope	Average	wt %
Soil	0.105263	0.210526	0.09009	0.216216	0.100719	0.14456	14.46
LULC	0.026316	0.052632	0.054054	0.027027	0.251799	0.04639	4.64
River proximity	0.315789	0.263158	0.270270	0.324324	0.251799	0.28507	28.51
Road proximity	0.026316	0.105263	0.045045	0.054054	0.071942	0.06052	6.01
Slope	0.526316	0.368421	0.540541	0.378378	0.503597	0.46346	46.35
Sum	1	1	1	1	1		100

According to table 19; the maximum weight is given to the slope of the area because if it is too steep it incurs high cost to level the land and also the water cannot easily flow to the downward unless electrical system is used. Average for each parameter is determined then multiplied by 100 is weight of parameter.

Table 19: Pair-wise comparison matrix output generated by AHP

layer name	Soil	LULUC	River proximity	Road proximity	Slope	Weight %	CI	RI	CR
Soil	1	4	0.3333	4	0.2	14.46	0.058933	1.12	0.052619
LULUC	0.25	1	0.2	0.5	0.1428	4.64	0.058933	1.12	0.052619
River proximity	3	5	1	6	0.5	28.51	0.058933	1.12	0.052619
Road proximity	0.25	2	0.1667	1	0.1428	6.01	0.058933	1.12	0.052619
Slope	5	7	2	7	1	46.35	0.058933	1.12	0.052619
Average CR									0.052619

As it is shown in the Table 19, the CR value is 0.053 which is less the maximum allowable recommended Saaty's value (0.1) which was acceptable for weighting the factors to evaluate the physical land capability of the Gidabo watershed for developing irrigation suitability map. According to Saaty's technique, all the five factors, which were selected for the evaluation of irrigation potential in the basin, were weighted using pair wise comparison.

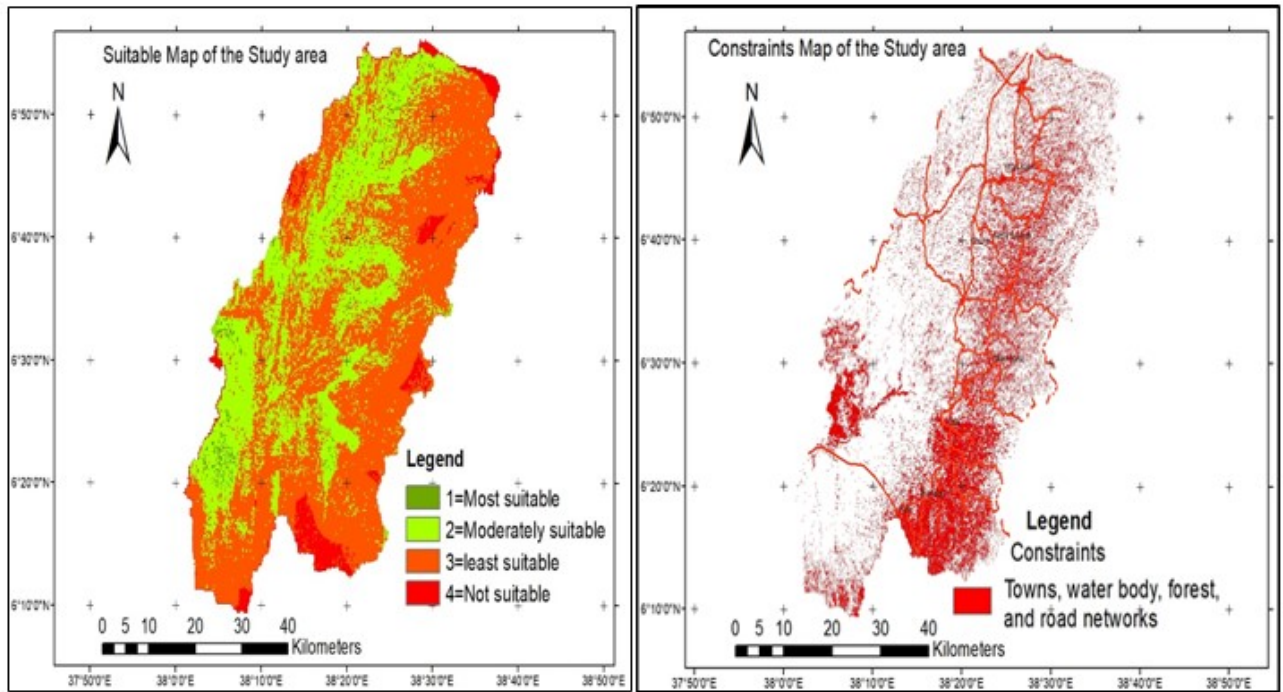


Figure 19 : Final suitability land and constraint map of Gidado river basin

As it can be seen in Figure 20, the weighted overlay analysis result was shown and tabulated in the Table 20. According to Abeyou W. *et al.*, (2015), a constraint map is a map which consists of water bodies, wetlands, urban areas, forest, and protected area. These areas were given a value of zero indicating that they ultimately limit the surface irrigation area suitability and are defined as permanently not suitable by the (FAO 1976, 1981) framework.

Table 20: Overall suitable sites and their area coverage in the sub basin

S.No	Area (ha)	Area (km ²)	Area (%)	Suitability class and description
1	13731.85	137.32	4.32	S1=Most suitable
2	100099.04	1000.99	31.47	S2=More suitable
3	182699.67	1827.00	57.44	S3=Less suitable
4	21518.63	215.19	6.77	N=Not suitable
Total	318049	3180.49	100	

Generally, the result of suitability analysis through weighted overlay of the rasterized maps of the land suitability parameters revealed that about 4.32% (13731.85 ha), 31.47 % (100099.04

ha), 57.44 % (182699.67 ha) of land in the study area were in the ranges of highly to marginally suitable classes respectively and 6.77 % (21518.63 ha) of the area categorized under not suitable class which was presented in Table 20.

4.4. Potentially irrigable lands in each sub-watershed

In the study, a suitable site of the area in each sub-watershed was identified and varying one to the other. Accordingly, the highest suitable area was identified in sub watershed_3 while sub watershed_6 has the least suitable area in the catchment. Area coverage of irrigation land suitability in each sub-watershed was presented in Table 21.

As described in Table 21, 113830.90 ha of an area identified was suitable for surface irrigation methods in the watersheds and the suitable land of each sub watershed was summarized.

Table 21: Irrigable suitable areas for each sub watershed for surface irrigation

Sub basins	Total Sub_area	Irrigable land(ha)	Rank
Sub_basin_1	20761.69	9703.02	7
Sub_basin_2	22702.09	6653.89	8
Sub_basin_3	54978.2	21485.9	1
Sub_basin_4	2191.7	1160.65	11
Sub_basin_5	18012	5290.70	9
Sub_basin_6	820.61	471.34	12
Sub_basin_7	36463	12865	5
Sub_basin_8	21357.9	10604.14	6
Sub_basin_9	37354	14226.25	4
Sub_basin_10	53374	14674	3
Sub_basin_11	21498	1198	10
Sub_basin_12	28536	15498	2
Total area	318049.19	113830.90	

As it has been seen in Table 21, sub watershed 3 is more suitable among others which have an irrigable area of 21485.9 ha from the total sub watershed area of 54978.2ha.

4.5. Sensitivity analysis of SWAT parameters

Parameter sensitivity analysis was done in order to determine the key parameters that are needed for calibration. Ten calibration parameters that affect flow were used in the sensitivity analysis Table 22. Global sensitivity analysis method was used and the parameters that were found to be most sensitive were used in the calibration process. The t-stat is a measure of sensitivity where larger in absolute values are more sensitive. The p-value determines the significance of sensitivity where values closer to zero are considered to be more statistically more significant (Abbaspour, 2007). According to the results obtained from the sensitivity analysis, the parameters were ranked depending on the values of t_stat and p_value.

Table 22: Sensitivity analysis of model parameters based on t_stat and p_value

Parameter	Description	T_stat	P_value	Rank
SOL_BD	Moist bulk density	-16.113	0.000	1
GW_DELAY	Ground Water Delay(Days) Threshold Depth of Water	7.939	0.000	2
SOL_K	Saturated hydraulic conductivity.	-6.632	0.000	3
CN2	SCS_CN for Moisture Condition	-5.631	0.000	4
GW_REVAP	Ground Water Evaporation Coefficient	2.246	0.026	5
REVAPMN.	Threshold depth of water in the shallow aquifer for "revap" to occur (mm).	-1.930	0.055	6
SOL_AWC	Available Water Capacity of the Soil Layer (Mm/Mm)	1.797	0.073	7
ALPHA_BF	Base Flow Alpha Factor (Days)	1.392	0.165	8
GWQMN(mm)	Threshold depth of water in the shallow aquifer required for return flow to occur	1.227	0.221	9
ESCO	Soil Evaporation Compensation Factor(unit less)	0.065	0.948	10

The result of the sensitivity analysis showed that 10 flow parameters were sensitive to the SWAT model. The most sensitive parameters were described in the rank order as they are presented in Table 24. The parameters, SOL_BD, GW_REVAP, SOL_K, CN2, were identified

to be highly sensitive. However, REVAPMN, SOL_AWC were identified as medium sensitive parameters. The remaining four parameters ALPHA_BF, GWQMN, GW_DELAY and ESCO were lower sensitive parameters.

4.5.1. Calibration

Measured flow data of twelve years from the period January 1, 1993 to December 31, 2004 were used for calibration and observed versus Simulated monthly flows in model calibration at three monitoring points are shown below in the Figure 20-22 for rivers such as, Gidabo, Kola and Bedessa respectively. As indicated in calibration figures plots are fitted 1:1 because of data qualities and measurement of weather and flow data.

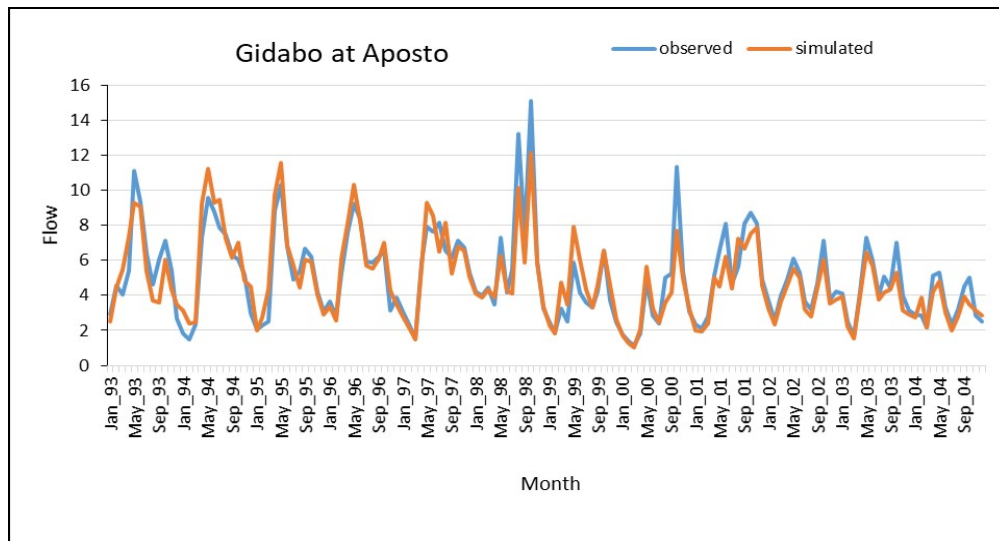


Figure 20 : Simulated versus observed monthly flows in model calibration of Gidabo River

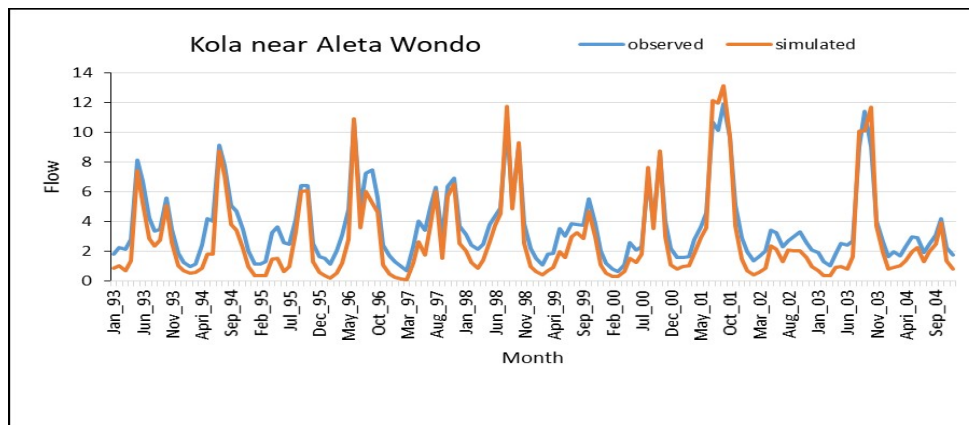


Figure 21 : Simulated versus observed monthly flows in model calibration of Kola River

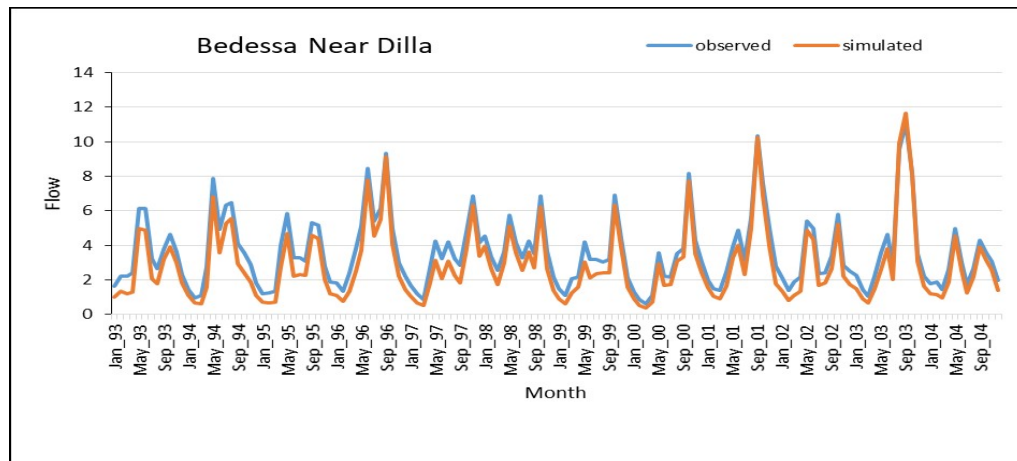


Figure 22 : Simulated versus observed monthly flows in model calibration Bedessa

The model was calibrated using monthly time step data of twelve years. As the model calibration result shown in Figures 20-22, there are some under and over estimations in the model output in some points but the overall result assured that the simulated flow is good to very good correlated with the measured/observed data with ($R^2 = 0.68, 0.73, 0.72$), ($ENS = 0.60, 0.63, 0.71$) and ($PBIAS = 12.2, -9.0$ and -14.0) for Gidabo, Kola and Bedessa respectively which shows the best performance of the model. The values indicated that Gidabo has a less performance as compared to kola and Bedessa.

4.5.2. Validation

As model calibration is not enough to say the model output is representing the study area, it has to be validated using an independent dataset. Therefore, it was validated using monthly time step isolated data to check its reliability. The model validation result shows that there are some under and over estimations in the model output as compared to the measured data but the overall validation result evidences there is a good correlation between the simulated model output and observed/measured data. Based on the model performance evaluation parameter numerical values of determination coefficient (R^2), Nash-Sutcliff's simulation efficiency (ENS) and percent bias (PBIAS) assured that the model shown a good performance during validation so as to able to simulate the runoff in the study area.

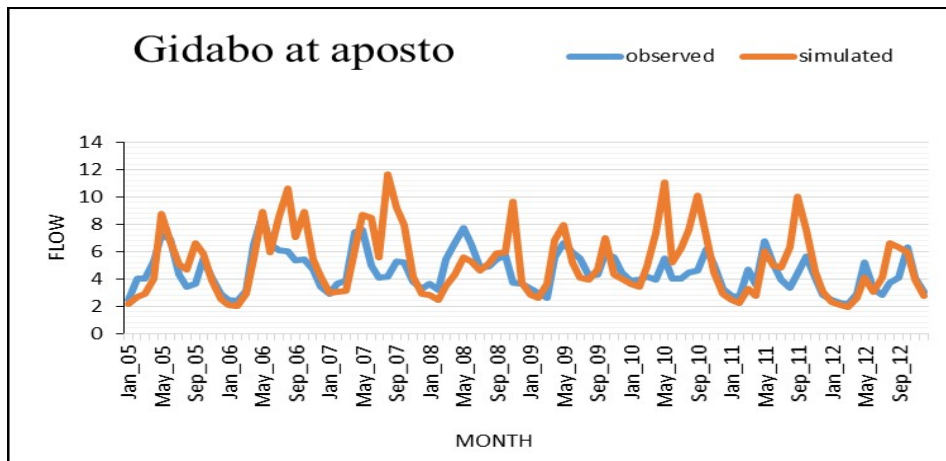


Figure 23 : Simulated versus observed monthly flows in model validation of Gidabo River

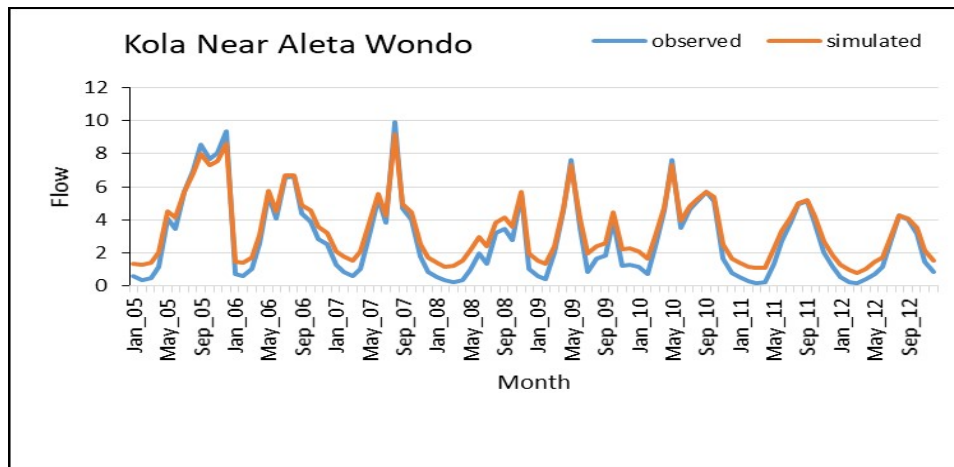


Figure 24 : Simulated versus observed monthly flows in model validation of Kola River

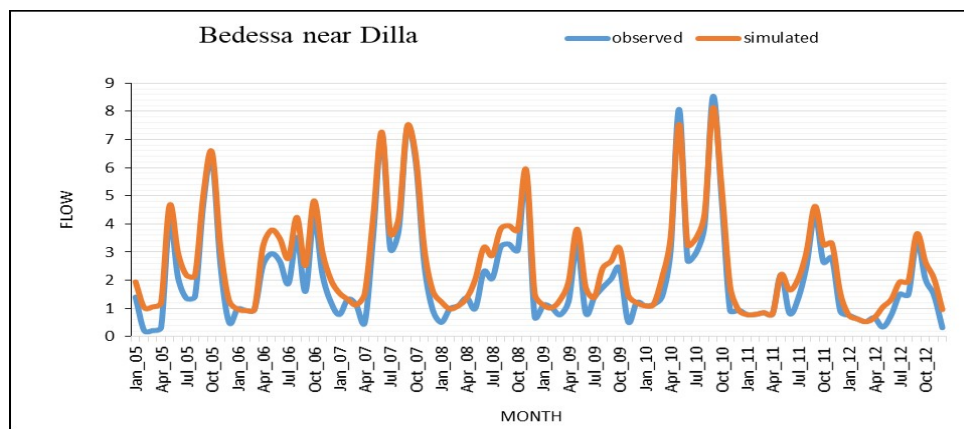


Figure 25 : Simulated versus observed monthly flows in model validation of Bedessa River

The model performance evaluation parameters determination coefficient (R^2), Nash-Sutcliff's simulation efficiency (NSE) and percent bias (PBIAS) with their allowable range and estimated numerical values during model calibration and validation are summarized in Table 23, below.

Table 23: Summary of model evaluation estimated numerical values

Criteria	Calibration (1993-2004)			Validation (2005-2012)			Performance rating
	Gidabo	Kola	Bedessa	Gidabo	Kola	Bedessa	
R^2	0.68	0.73	0.72	0.71	0.73	0.77	Good-Very good
NSE	0.60	0.63	0.71	0.72	0.65	0.64	Satisfactory-Good
PBIAS	12.2	-9.0	-14.0	5.5	-5.4	-9.8	Very good

As pointed out in Table 23, the model performance values for calibration and validation of the flow simulations were in the range of good to very good.

4.6. Assessment of Spatial and Temporal Distribution of Available Water

Surface water availability has been identified from the SWAT simulated outputs of stream flow in each sub-basin of the watershed. The mean minimum monthly surface water flow results of the sub watershed 1 to 12 indicated that $0.37\text{m}^3/\text{s}$ on February within sub basin six to a maximum of $20.82\text{m}^3/\text{s}$ on October within the sub basin ten. The area ranges from 820.61 to 54978.2 ha in the catchment. As shown in the Table 24 below, the mean monthly flow in the whole river basin was range from 49.96 to $122.20\text{ m}^3/\text{s}$ or 129.51-316.73MCM of water

Table 24: Average monthly simulated stream flow results in each sub-watershed (m^3/s)

Sub Basin	Months											
	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.11	2.41	3.58	6.62	10.26	8.46	6.33	6.14	7.50	10.30	7.11	4.33
2	3.74	3.14	4.26	8.81	12.70	8.83	6.54	6.86	8.84	11.40	7.00	4.85
3	9.74	8.29	8.99	12.88	17.09	14.37	13.54	14.55	16.48	18.50	14.33	11.72
4	0.67	0.64	0.69	1.32	1.66	1.08	1.04	0.67	0.64	0.69	1.32	1.66
5	3.66	3.15	3.58	5.13	6.82	5.78	5.35	5.66	6.36	7.16	5.45	4.41
6	0.46	0.37	0.39	0.49	0.65	0.60	0.58	0.59	0.63	0.73	0.63	0.54
7	7.13	6.12	6.65	9.37	12.13	10.26	9.91	10.47	11.84	13.14	10.21	8.50
8	4.32	3.62	3.84	5.03	6.53	5.79	5.71	6.00	6.59	7.42	6.06	5.15
9	4.47	4.38	5.11	10.05	12.29	7.66	7.56	8.98	11.57	12.00	6.93	5.32
10	10.97	9.57	10.88	15.67	20.22	16.75	15.91	16.55	18.67	20.82	15.94	13.04
11	5.07	4.39	5.07	6.88	9.00	7.85	7.21	7.41	8.13	9.35	7.35	5.98
12	4.70	4.51	5.95	10.33	12.18	7.96	7.42	8.68	10.73	11.16	6.73	5.32
Total	57.32	49.96	58.33	91.49	120.11	94.35	86.11	92.02	107.60	122.2	87.75	69.13

From the above table (Table 24), the minimum monthly values of available water distribution were observed within sub basin six followed by sub basin four throughout the year. The maximum values of available water distribution were observed within sub basin ten though out the year with its maximum value observed on the month of October. The temporal distribution of flow of the catchment on mean monthly basis is shown in the Appendices 5 Figure 2.

4.7. Gross irrigation water requirement

Gross irrigation requirements of each selected crops (Tomato and Maize) at identified potential irrigable lands were estimated using CROPWAT8.0 software. Each crop adopted in the area various in a real coverage, 40% of Tomato and 60% of Maize of the total irrigable sites. Table 25, describes monthly gross irrigation water requirements of Tomato and Maize resulted from monthly water demands of the full growth stage of Tomato and Maize that should be abstracted from the local cropping period.

Table 25: Gross irrigation requirements of the selected crops in (m³/s)

Sub_basin	Irrigable area(ha)	Crop Type	Monthly gross irrigation requirement(GIR) m3/s												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Sub_1	9703.02	Maize	4.93	3.21	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.24	1.54
		Tomato	3.09	2.12	1.41	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.57	2.07
Sub_2	6653.89	Maize	2.32	1.87	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	1.76
		Tomato	1.40	1.23	0.82	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	1.20
Sub_3	21485.9	Maize	6.23	4.90	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.65	4.53
		Tomato	3.37	2.99	1.99	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.23	2.93
Sub_4	1160.65	Maize	0.54	0.37	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.34
		Tomato	0.33	0.24	0.15	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.24
Sub_5	5290.7	Maize	2.48	1.70	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	1.54
		Tomato	1.52	1.11	0.70	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	1.07
Sub_6	471.34	Maize	0.28	0.21	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.19
		Tomato	0.16	0.13	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.13
Sub_7	12865	Maize	7.26	4.86	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.11	4.47
		Tomato	4.61	3.22	2.07	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.06	3.07
Sub_8	10604.1	Maize	6.80	4.93	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.17	4.19
		Tomato	4.43	3.33	2.13	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.11	2.89
Sub_9	14226.3	Maize	8.02	5.38	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.44	4.94
		Tomato	5.10	3.56	2.29	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.28	3.40
Sub_10	14674	Maize	8.28	5.55	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.54	5.10	

		Tomato	5.26	3.67	2.36	0.13	0.00	0.00	0.00	0.00	0.00	0.00	2.35	3.50
Sub_11	1198	Maize	0.68	0.45	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.42
		Tomato	0.43	0.30	0.19	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.29
Sub_12	15498	Maize	8.74	5.86	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.74	5.38
		Tomato	5.56	3.88	2.50	0.14	0.00	0.00	0.00	0.00	0.00	0.00	1.08	1.61

4.8 Irrigation Potential of River Catchments

Surface irrigation potential of the river catchments was obtained by comparing irrigation requirements of the identified suitable area and the available mean monthly flows in the river catchments based on the methods suggested by (FAO, 1997).

Table 26, represents gross irrigation requirements of the two crops commonly grown in each sub watershed (Tomato and Maize) and the available mean monthly flows obtained from SWAT simulation outputs in each sub watersheds. The analysis result revealed that the mean monthly flow of sub-watershed 1, 7, 8, 9 and 12 was less than the corresponding gross monthly irrigation requirements of crops in the month of January and February for sub watershed 1 and 7 and January, February and December for sub watersheds 8, 9 and 12. As a result, the critical command areas were calculated according to (Micheal, 2008) to grow these crops. From the Table 28, the minimum available flow in the month of January and February in Sub watershed_1 is 3.58 and 2.69 m³/s whereas the water requirement of the two crops 8.02 and 5.32 m³/s respectively giving a critical command area (that can be reliably irrigated using the available flow) of 4903.02ha.

Table 26: Comparison of GIWR and available stream flows at irrigable area

Sub basin	Irrigable area (ha)	Crop Type	Monthly gross irrigation requirement(GIR) m3/s											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sub_1	9703.02	CWR	8.02	5.32	1.93	0.08	0.00	0.00	0.00	0.00	0.00	0.00	2.81	3.61
		Flow	3.58	2.69	4.06	6.62	10.26	8.46	6.33	6.14	7.50	10.30	7.11	4.33
Sub_2	6653.89	CWR	3.72	3.10	1.13	0.05	0.00	0.00	0.00	0.00	0.00	0.00	2.33	2.96
		Flow	3.74	3.14	4.26	8.81	12.70	8.83	6.54	6.86	8.84	11.40	7.00	4.85
Sub_3	21485.9	CWR	9.60	7.89	2.80	0.12	0.00	0.00	0.00	0.00	0.00	0.00	5.87	7.46
		Flow	9.74	8.29	8.99	12.88	17.09	14.37	13.54	14.55	16.48	18.50	14.33	11.72
Sub_4	1160.65	CWR	0.66	0.59	0.21	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.57
		Flow	0.67	0.64	0.69	1.32	1.66	1.08	1.04	1.28	1.65	1.72	1.03	0.80
Sub_5	5290.7	CWR	3.50	2.81	0.97	0.08	0.00	0.00	0.00	0.00	0.00	0.00	2.11	2.62
		Flow	3.66	3.15	3.58	5.13	6.82	5.78	5.35	5.66	6.36	7.16	5.45	4.41
Sub_6	471.34	CWR	0.44	0.34	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.31
		Flow	0.46	0.37	0.39	0.49	0.65	0.60	0.58	0.59	0.63	0.73	0.63	0.54
Sub_7	12865	CWR	11.87	8.08	2.85	0.12	0.00	0.00	0.00	0.00	0.00	0.00	5.17	7.54
		Flow	7.13	6.12	6.65	9.37	12.13	10.26	9.91	10.47	11.84	13.14	10.21	8.50
Sub_8	10604.1	CWR	11.24	8.26	3.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	5.29	7.08
		Flow	4.32	3.62	3.84	5.03	6.53	5.79	5.71	6.00	6.59	7.42	6.06	5.15
Sub_9	14226.3	CWR	13.13	8.94	3.16	0.13	0.00	0.00	0.00	0.00	0.00	0.00	5.71	8.34
		Flow	4.85	4.38	5.11	10.05	12.29	7.66	7.56	8.98	11.57	12.00	6.93	5.32
Sub_10	14674	CWR	10.76	9.22	3.26	0.13	0.00	0.00	0.00	0.00	0.00	0.00	5.89	8.60
		Flow	10.97	9.57	10.88	15.67	20.22	16.75	15.91	16.55	18.67	20.82	15.94	13.04
Sub_11	1198	CWR	1.11	0.75	0.27	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.70
		Flow	5.07	4.39	5.07	6.88	9.00	7.85	7.21	7.41	8.13	9.35	7.35	5.98
Sub_12	15498	CWR	14.30	9.74	3.44	0.14	0.00	0.00	0.00	0.00	0.00	0.00	4.82	6.99
		Flow	4.90	4.51	5.95	10.33	12.18	7.96	7.42	8.68	10.73	11.16	6.73	5.32

The critical command/potential area for sub-watersheds 1, 7, 8, 9 and 12 was found 4903.02ha, 8332, 4419.14, 6426.25 and 6476ha respectively is shown in table 30, and their respective gross irrigation water requirement is also shown. However, for the other watersheds, since their monthly flows are greater than the irrigation requirements of the two crops, the identified potential irrigable area was taken as their irrigation potential (MoWR, 2002). Therefore, the irrigation potential of the river catchments in the study area are obtained and ranked (Table 27).

Table 27: Summary of irrigation potential of the river catchments and their ranking

Sub basins	Suitable	Rank
Sub_basin_1	4903.02	8
Sub_basin_2	6653.89	4
Sub_basin_3	14385.9	2
Sub_basin_4	1160.65	11
Sub_basin_5	5290.70	7
Sub_basin_6	471.34	12
Sub_basin_7	8332	3
Sub_basin_8	4419.14	9
Sub_basin_9	6426.25	6
Sub_basin_10	14674	1
Sub_basin_11	1198	10
Sub_basin_12	6476	5
Total area	74390.89	

Hence, the total irrigation potential of the study area is found to be 74390.89ha which accounts for 23.39 % is potentially suitable area that could be irrigated consistently with the available runoff from the river systems. However, based on master plan studies of RVLB, the planned irrigable land of Gidabo catchment was 9215ha. But during this study, to identify the irrigation suitability land they considered only soil and slope as well as they allocate the available water to other sectors (Halcrow Group Limited and GIRD, 2009). As it is indicated in the Table 26, in some sub watersheds the available water is less than with the corresponding crop water requirement.

Table 28: Summarized monthly flow available and gross irrigation water requirement of potential sites

Sub basin	Irrigable area (ha)	Flow &GIR of major Crops	Monthly flows available in each sub basin & gross irrigation requirement (GIR)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sub_1	4903.02	Available flow(m3/s)	3.58	2.69	4.06	6.62	10.26	8.46	6.33	6.14	7.50	10.30	7.11	4.33
		GIR (m3/s)	3.11	2.41	0.96	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
Sub_2	6653.89	Available flow(m3/s)	3.74	3.14	4.26	8.81	12.70	8.83	6.54	6.86	8.84	11.40	7.00	4.85
		GIR (m3/s)	3.72	3.10	1.13	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.33
Sub_3	14385.9	Available flow(m3/s)	9.74	8.29	8.99	12.88	17.09	14.37	13.54	14.55	16.48	18.50	14.33	11.72
		GIR (m3/s)	9.60	7.89	2.80	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.87
Sub_4	1160.65	Available flow(m3/s)	0.67	0.64	0.69	1.32	1.66	1.08	1.04	1.28	1.65	1.72	1.03	0.80
		GIR (m3/s)	0.66	0.59	0.21	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46
Sub_5	5290.7	Available flow(m3/s)	3.66	3.15	3.58	5.13	6.82	5.78	5.35	5.66	6.36	7.16	5.45	4.41
		GIR (m3/s)	3.50	2.81	0.97	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.11
Sub_6	471.34	Available flow(m3/s)	0.46	0.37	0.39	0.49	0.65	0.60	0.58	0.59	0.63	0.73	0.63	0.54
		GIR (m3/s)	0.44	0.34	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24
Sub_7	8332	Available flow(m3/s)	7.13	6.12	6.65	9.37	12.13	10.26	9.91	10.47	11.84	13.14	10.21	8.50
		GIR (m3/s)	7.02	5.24	1.75	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.35
Sub_8	4419.14	Available flow(m3/s)	4.85	4.38	5.11	10.05	12.29	7.66	7.56	8.98	11.57	12.00	6.93	5.32
		GIR (m3/s)	4.70	4.04	1.34	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.62
Sub_9	6426.25	Available flow(m3/s)	4.85	4.38	5.11	10.05	12.29	7.66	7.56	8.98	11.57	12.00	6.93	5.32
		GIR (m3/s)	4.70	4.04	1.34	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.62
Sub_10	14674	Available flow(m3/s)	10.97	9.57	10.88	15.67	20.22	16.75	15.91	16.55	18.67	20.82	15.94	13.04
		GIR (m3/s)	10.66	7.24	2.32	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.62
Sub_11	1198	Available flow(m3/s)	5.07	4.39	5.07	6.88	9.00	7.85	7.21	7.41	8.13	9.35	7.35	5.98
		GIR (m3/s)	1.11	0.75	0.27	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48
Sub_12	6476	Available flow(m3/s)	4.90	4.51	5.95	10.33	12.18	7.96	7.42	8.68	10.73	11.16	6.73	5.32
		GIR (m3/s)	4.87	4.07	1.47	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.60

Irrigation Potential of the Study Area: Irrigation potential of the river catchments in the study area was obtained by comparing irrigation requirements of the identified land suitable for surface irrigation and the available mean monthly flows in the river catchments based on the method suggested by FAO (1997). Tables 30 indicated potential area study area and table 29 revealed that the comparisons of monthly irrigation requirements of maize and tomato and available flow irrigation water requirements of both crops at their corresponding command area. The location of the diversion sites were shown in the appendix Table 26.

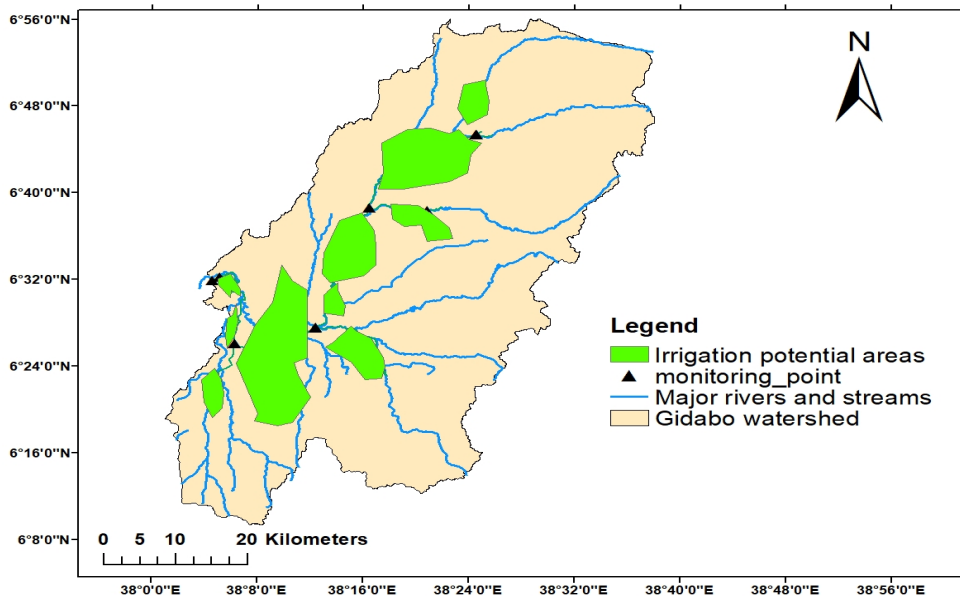


Figure 26: Suitable sites for surface irrigation development

As indicated in Table 30 gidabo at Meissa diversion site, high potential area 17065.61 ha of suitable area is obtained at the right and left of the diversion site. The minimum potential area is found at Woyima River near awada.

Table 29 : Comparing of irrigation demands and available flows of river catchments in the study

Potential area(ha)	Flow &GIR of major Crops(m ³ /s)	Monthly flows available in each sub basin & gross irrigation requirement (GIR)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4549.84	CWR	3.32	2.53	1.47	0.06	0.00	0.00	0.00	0.00	0.00	0.00	2.60	3.80
	Flow	3.58	2.69	4.06	6.62	10.26	8.46	6.33	6.14	7.50	10.30	7.11	4.33
5742.68	CWR	3.43	2.94	1.31	0.06	0.00	0.00	0.00	0.00	0.00	0.00	2.68	3.41
	Flow	3.74	3.14	4.26	8.81	12.70	8.83	6.54	6.86	8.84	11.40	7.00	4.85
8622.242	CWR	8.03	5.42	1.41	0.04	0.00	0.00	0.00	0.00	0.00	0.00	3.47	5.02
	Flow	9.74	8.29	8.99	12.88	17.09	14.37	13.54	14.55	16.48	18.50	14.33	11.72
823.02	CWR	0.66	0.45	0.16	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.49
	Flow	0.67	0.64	0.69	1.32	1.66	1.08	1.04	1.28	1.65	1.72	1.03	0.80
3059.037	CWR	2.31	1.63	0.56	0.08	0.00	0.00	0.00	0.00	0.00	0.00	1.22	1.51
	Flow	3.66	3.15	3.58	5.13	6.82	5.78	5.35	5.66	6.36	7.16	5.45	4.41
235.46	CWR	0.25	0.18	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.16
	Flow	0.46	0.37	0.39	0.49	0.65	0.60	0.58	0.59	0.63	0.73	0.63	0.54
6029.688	CWR	4.54	3.21	1.16	0.08	0.00	0.00	0.00	0.00	0.00	0.00	2.40	2.99
	Flow	7.13	6.12	6.65	9.37	12.13	10.26	9.91	10.47	11.84	13.14	10.21	8.50
2993.33	CWR	2.76	1.88	0.66	0.03	0.00	0.00	0.00	0.00	0.00	0.00	1.20	1.75
	Flow	4.32	3.62	3.84	5.03	6.53	5.79	5.71	6.00	6.59	7.42	6.06	5.15
625.66	CWR	0.58	0.39	0.14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.37
	Flow	5.07	4.39	5.07	6.88	9.00	7.85	7.21	7.41	8.13	9.35	7.35	5.98

Therefore, the irrigation potential of the river catchments in the study area are identified and ranked (Table 30).

Table 30: Summary of irrigation potential of the river catchments and their ranking for development possibilities

S/N	Water supply (Rivers)	Potential Area(ha)	Rank
1	Wamole	823.02	6
2	Gidabo	6566.22	2
3	Kolla	3059.037	4
4	Raro (Aleta Wondo)	5672	3
5	Woyima (Awada)	235.46	9
6	Bedessa (dilla)	2993.33	5
7	Gigessa (Kella)	625.66	7
8	Gidabo at Meissa	17065.61	1
9	Odomike	572.32	8

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary

This study was conducted to assess the available irrigable land and surface water potential for surface irrigation in the Gidabo River catchment.

Surface irrigation land suitability was investigated using parameters such as (slope, soil, land use/cover, proximity to river and road) through weighted overlay analysis in ArcGIS. Surface water availability in Gidabo watershed was simulated using SWAT model and calibrated using SWAT cup with the calibration and validation periods of (1992-2005 and 2006-2012) respectively on the monthly basis to examine the best fit of simulated and observed flows.

The results of slope suitability indicate that about 37.98 % of the land area was in the range of highly to marginally suitable for surface irrigation. Soil suitability analysis result also indicates that around 64.92% of the land is highly to moderately suitable and the remaining 35.08% of the area is categorized under marginally to non-suitable class for surface irrigation which was obtained from the weighted overlay result of (texture, depth and drainage). Whereas, in case of land use and land cover suitability 43.83% of land is in the range of highly to marginally suitable for irrigation. The total potential irrigable land accounts 23.39 % (74390.89ha) of the total watershed area which could be irrigated with the available water without any storage structures.

The comparison was made between gross irrigation water requirements of the irrigable land and available stream flows of each sub-watershed, obtained from the simulated outputs of SWAT model in monthly basis. Consequently, the available monthly flows in some sub basins were less than their monthly gross irrigation requirements in the identified area to conduct irrigation application throughout the year.

5.2. Conclusion

Ethiopia has immense potential in expanding irrigated agriculture. Irrigable land assessment is essential for the development of irrigated agriculture. The study was aimed at assessing surface irrigable land of Gidado watershed. Assessment of irrigation potential is considered an essential for improving agricultural production through effective utilization of natural resource.

Potential irrigable land was obtained by creating irrigation suitability model analysis which involved weighting of values of all data sets, land characteristics dataset and distance from the water supply and road. Generally, the result of suitability analysis through weighted overlay of the rasterized maps of the land suitability parameters revealed that about 4.32% (13731.85 ha), 31.47 % (100099.04 ha), 57.44 % (182699.67 ha) of land in the study area were in the ranges of highly to marginally suitable classes respectively and 6.77 % (21518.63 ha) of the area categorized under not suitable class.

Parameter sensitivity analysis was done in order to determine the key parameters that are needed for calibration. Ten calibration parameters that affect flow were sensitivity. Global sensitivity analysis method was used and the parameters that were found to be most sensitive were used in the calibration process. The t-stat is a measure of sensitivity where larger in absolute values are more sensitive. The p-value determines the significance of sensitivity where values closer to zero are considered to be more statistically more significant.

Surface water availability has been identified from the SWAT simulated outputs of stream flow in each sub-basin of the watershed. The mean minimum monthly surface water flow results of the sub watershed 1 to 12 indicated that $0.37\text{m}^3/\text{s}$ on February within sub basin six to a maximum of $20.82\text{m}^3/\text{s}$ on October within the sub basin ten. The area ranges from 820.61 to 54978.2 ha in the catchment. The maximum available water distribution was observed within sub basin ten though out the year with its maximum value observed on the month of October.

Gross irrigation requirements of each selected crops (Tomato and Maize) at identified potential irrigable lands were estimated using CROPWAT8.0 software. Each crop adopted in the area various in area coverage, 40% of Tomato and 60% of Maize of the total irrigable sites. Hence, the total irrigation potential of the study area is found to be 74390.89ha which accounts for 23.39 % is potentially suitable area that could be irrigated consistently with the available runoff from the river systems.

5.3. Recommendations

To estimate sound and reliable irrigable land for sustainable irrigation development in the watershed:

- Ground water potentials and the chemical properties of the soil and water should be considered. In addition, some other factors such as distance from the market/town, environmental, and socio-economic issues should also be taken in to account for further irrigable land assessment. So that researchers and experts in such field should considered under their study.
- In this study, estimation of irrigation water requirement was conducted by selecting only two (Tomato and Maize) crops. For details analysis study should consider several crops to calculate gross irrigation requirements. Agronomists must inculcate such crop dominancy in such tasks.
- In some sub basins the available flow is less than the irrigation requirement of the crops, so to satisfy the water demand of the crops: night storage, storage structures and deficit irrigation should be implemented. DA's or agricultural experts should consider such resilience mechanism in their agricultural tasks.
- In future research the researcher should be consider the water for domestic use, livestock use, industrial use and environmental flow.

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7. APPENDICES

APPENDIX -1 HYDROLOGICAL DATA

Table -1 monthly flow Gidabo River at Aposto (m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	2.41	3.80	6.05	10.10	10.58	6.26	6.01	6.01	6.82	6.94	3.75	3.18	71.91
1991	3.19	3.44	3.75	4.60	4.65	3.37	4.82	4.35	10.36	5.46	2.11	1.77	51.86
1992	1.16	1.55	1.20	6.63	6.51	5.04	7.14	22.81	19.48	27.46	10.74	4.47	114.20
1993	2.92	4.31	2.33	5.57	16.32	16.56	7.74	5.45	9.31	16.47	7.54	2.70	97.23
1994	1.81	1.45	1.72	3.13	9.79	6.87	16.02	17.69	12.56	6.37	5.31	2.44	85.16
1995	1.64	1.67	1.85	9.51	9.07	4.23	4.76	6.53	17.02	12.47	3.84	2.94	75.53
1996	2.86	1.87	5.98	11.29	14.83	14.70	15.92	18.21	18.78	19.23	4.13	2.60	130.40
1997	2.12	1.53	1.55	5.38	8.08	5.80	10.12	12.95	8.16	21.41	16.76	5.83	99.71
1998	2.06	1.05	1.19	3.34	10.10	4.48	7.58	23.14	10.93	29.75	6.11	2.73	102.46
1999	2.17	1.74	1.91	1.91	3.67	2.47	2.47	3.07	3.95	6.83	2.99	1.89	35.08
2000	1.41	1.30	1.27	1.96	4.91	4.91	2.51	7.83	7.20	18.48	6.27	2.45	60.52
2001	2.24	1.81	1.90	2.77	5.63	8.36	3.93	8.81	9.92	9.83	4.14	2.48	61.83
2002	2.01	1.56	2.04	2.93	3.94	5.29	2.71	3.66	4.89	3.53	2.19	2.24	36.98
2003	1.84	1.47	1.71	4.02	2.99	2.40	3.01	6.55	4.84	13.99	5.69	2.95	51.45
2004	2.14	1.93	2.38	4.84	7.41	3.24	2.79	4.02	6.21	7.94	2.62	2.17	47.70
2005	1.77	1.37	1.72	2.84	10.53	6.76	5.56	6.01	8.78	6.27	3.67	2.02	57.31
2006	1.65	1.67	2.75	4.56	9.25	5.27	10.96	13.93	8.87	10.99	6.37	4.54	80.79
2007	3.04	2.53	2.29	4.96	9.96	10.62	7.16	16.72	11.62	10.91	4.08	2.51	86.40
2008	2.01	1.73	1.53	2.01	3.43	4.06	4.34	5.47	6.20	6.25	14.17	2.93	54.12
2009	2.36	2.22	2.28	4.84	7.67	4.18	2.71	3.60	5.03	8.23	2.99	3.51	49.63
2010	3.41	2.79	5.74	10.93	13.41	6.20	8.29	9.55	13.84	7.86	3.51	2.41	87.93
2011	2.07	1.74	1.79	1.94	5.32	5.07	5.80	9.37	13.90	9.24	4.82	3.24	64.30
2012	2.18	1.84	1.74	2.33	3.00	2.88	5.44	7.83	8.39	5.75	3.44	2.46	47.28
2013	1.95	1.57	2.12	4.22	9.84	6.74	12.96	18.44	10.58	13.31	5.55	2.98	90.25
2014	2.30	2.38	2.61	4.18	12.86	7.42	14.25	21.54	16.71	14.82	5.68	2.82	107.58
Mean	2.19	2.01	2.46	4.83	8.15	6.13	7.00	10.54	10.17	11.99	5.54	2.89	73.90
Max	3.41	4.31	6.05	11.29	16.32	16.56	16.02	23.14	19.48	29.75	16.76	5.83	130.40
Min	1.16	1.05	1.19	1.91	2.99	2.40	2.47	3.07	3.95	3.53	2.11	1.77	35.08
SDTEV	0.55	0.80	1.42	2.82	3.77	3.44	4.19	6.57	4.43	6.88	3.55	0.90	25.58

Table -2 Mean monthly flow Bedessa River near Dilla

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	0.58	0.55	2.02	4.61	2.96	3.24	1.92	1.98	2.44	3.42	1.62	1.14	26.47
1991	0.65	0.51	0.58	0.75	0.69	1.46	2.09	1.25	4.02	2.23	1.40	0.66	16.31
1992	0.05	0.06	0.02	0.26	0.95	1.45	1.59	1.44	2.50	7.61	1.61	0.66	18.21
1993	0.38	0.48	0.24	0.14	3.85	3.62	0.96	0.96	2.61	3.15	2.40	1.38	20.16
1994	0.74	0.38	0.18	0.42	5.70	2.20	4.21	4.59	1.83	1.31	0.91	0.44	22.92
1995	0.22	0.14	0.12	1.48	3.59	1.10	1.38	1.38	3.83	3.61	1.30	0.54	18.71
1996	0.40	0.19	0.31	1.25	2.29	7.07	3.69	4.84	8.93	3.18	1.45	0.73	34.32
1997	0.41	0.19	0.17	0.98	2.02	0.88	2.02	1.27	0.79	2.81	5.73	2.58	19.85
1998	3.41	1.98	0.89	2.41	4.47	2.94	1.84	2.98	1.87	5.60	1.64	0.65	30.70
1999	0.33	0.16	0.45	0.97	1.89	1.08	1.54	1.78	1.62	5.80	3.28	1.00	19.89
2000	0.50	0.24	0.15	0.34	2.28	1.16	1.27	2.67	2.80	7.32	2.82	1.83	23.39
2001	1.14	0.60	0.40	0.82	2.68	3.20	1.52	4.35	10.17	6.14	2.88	0.80	34.68
2002	0.54	0.20	0.39	0.53	4.33	3.74	1.05	1.23	1.96	4.65	1.58	0.97	21.17
2003	0.76	0.35	0.23	0.81	1.68	3.04	1.29	10.25	12.19	8.01	2.64	1.06	42.31
2004	0.62	0.44	0.47	1.20	4.06	2.05	0.79	1.73	3.51	2.68	2.12	0.79	20.46
2005	0.40	0.21	0.21	0.32	4.09	2.21	1.27	1.43	4.78	6.32	2.70	0.51	24.45
2006	0.25	0.22	0.25	2.54	3.03	3.38	1.88	3.46	1.66	4.17	2.42	1.22	24.49
2007	0.79	0.44	0.27	0.51	3.64	7.31	3.09	3.76	7.67	6.24	2.29	0.93	36.93
2008	0.51	0.28	0.26	0.43	1.02	2.43	1.96	3.26	3.43	2.96	5.73	0.70	22.97
2009	0.35	0.26	0.40	1.37	2.98	1.25	0.41	1.73	2.05	2.48	0.49	0.27	14.04
2010	0.20	0.28	1.45	3.23	11.94	2.90	2.82	4.29	14.13	4.82	0.85	0.12	47.04
2011	0.04	0.09	0.04	0.04	1.39	0.88	1.30	2.68	4.23	2.59	2.79	0.90	16.97
2012	0.12	0.03	0.01	0.10	0.34	0.79	1.53	1.50	3.43	2.07	1.42	0.31	11.66
2013	0.14	0.05	0.28	1.43	3.50	1.31	3.26	3.41	17.56	8.78	1.44	0.28	41.45
2014	0.08	0.04	0.04	0.16	1.71	3.28	10.43	14.86	12.19	8.01	2.64	1.02	54.44
Mean	0.54	0.33	0.39	1.08	3.08	2.56	2.20	3.32	5.29	4.64	2.25	0.86	26.56
Max	3.41	1.98	2.02	4.61	11.94	7.31	10.43	14.86	17.56	8.78	5.73	2.58	54.44
min	0.04	0.03	0.01	0.04	0.34	0.79	0.41	0.96	0.79	1.31	0.49	0.12	11.66
SDTEV	0.65	0.38	0.45	1.09	2.28	1.70	1.94	3.10	4.58	2.19	1.27	0.52	10.93

Table -3 Mean Monthly Flow Kola River near Aleta wondo

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	0.92	1.32	1.53	2.50	3.42	3.45	2.21	2.87	2.76	2.03	1.24	0.85	25.10
1991	0.67	0.57	0.74	1.17	1.21	1.06	3.46	1.81	4.34	1.96	1.02	0.65	18.66
1992	0.47	0.58	0.44	1.30	1.42	2.21	2.54	9.09	5.14	11.40	3.01	1.29	38.89
1993	0.86	1.03	0.69	1.38	7.42	5.22	2.84	2.36	2.76	5.05	2.55	1.05	33.21
1994	0.67	0.51	0.58	0.86	1.82	1.78	8.75	7.05	3.83	3.40	2.19	0.99	32.43
1995	0.34	0.33	0.38	1.49	1.52	0.65	0.95	3.28	6.03	6.08	1.30	0.59	22.92
1996	0.38	0.17	0.51	1.21	2.79	10.91	3.60	7.05	7.26	4.65	1.07	0.45	40.07
1997	0.26	0.11	0.09	1.16	2.61	1.77	3.73	6.04	1.52	5.70	6.50	2.52	32.01
1998	2.03	1.26	0.88	1.41	2.65	3.76	4.53	11.76	4.87	9.31	2.51	0.98	45.93
1999	0.62	0.41	0.68	0.90	1.96	1.56	2.96	3.23	2.87	4.70	2.95	1.10	23.95
2000	0.51	0.30	0.29	0.63	1.51	1.26	1.81	7.60	3.50	8.71	2.99	1.08	30.18
2001	0.80	0.96	1.03	1.88	2.90	3.58	12.12	17.95	13.12	9.70	3.67	1.45	69.18
2002	0.70	0.42	0.58	0.87	2.38	2.14	1.32	2.05	2.04	2.00	1.56	0.97	17.02
2003	0.70	0.36	0.37	0.89	0.97	0.81	1.62	10.08	13.12	9.70	3.67	1.93	44.21
2004	0.80	0.93	1.03	1.37	1.98	2.25	1.30	1.94	2.45	3.90	1.37	0.81	20.14
2005	0.59	0.34	0.47	1.17	3.71	3.44	4.69	6.99	26.29	27.23	22.48	15.94	113.34
2006	0.71	0.62	1.02	2.10	4.50	3.62	6.54	5.91	4.38	3.92	2.84	2.51	38.68
2007	1.27	0.88	0.59	1.06	3.10	5.35	3.86	9.93	4.67	4.01	1.78	0.89	37.39
2008	0.56	0.33	0.24	0.39	0.96	1.96	1.37	3.20	3.49	2.77	5.58	1.07	21.93
2009	0.62	0.46	0.83	1.88	2.90	3.58	0.89	1.66	1.86	3.97	1.25	1.32	21.23
2010	1.19	0.71	2.43	4.59	7.60	3.51	4.63	5.11	5.68	5.14	1.65	0.77	43.02
2011	0.57	0.32	0.21	0.24	1.37	2.73	3.84	4.98	5.16	3.80	2.06	1.14	26.41
2012	0.55	0.27	0.15	0.46	0.72	1.16	2.86	4.25	4.03	3.13	1.49	0.87	19.92
2013	0.51	0.26	0.40	0.79	1.70	2.54	6.41	12.48	13.12	9.70	3.67	1.93	53.52
2014	1.31	8.97	8.89	9.14	12.01	1.97	11.93	17.95	13.12	9.70	3.67	1.85	100.52
Mean	0.74	0.90	1.00	1.63	3.01	2.89	4.03	6.67	6.30	6.47	3.36	1.80	38.79
Max	2.03	8.97	8.89	9.14	12.01	10.91	12.12	17.95	26.29	27.23	22.48	15.94	113.34
min	0.26	0.11	0.09	0.24	0.72	0.65	0.89	1.66	1.52	1.96	1.02	0.45	17.02
SDTEV	0.37	1.71	1.72	1.79	2.56	2.09	3.06	4.64	5.56	5.19	4.21	3.00	23.97

APPENDIX-2 METEOROLOGICAL DATA

Table - 4 Monthly rainfall Data at Aleta Wondo station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	15.60	236.50	77.50	180.36	195.10	77.50	120.70	116.80	164.50	70.20	76.20	23.10	1354.06
1991	58.90	67.00	146.80	211.90	176.40	179.30	115.30	106.60	172.00	82.20	10.00	30.00	1356.40
1992	0.00	97.30	54.90	239.00	217.90	167.10	112.50	162.80	190.70	218.80	81.40	41.00	1583.40
1993	99.90	146.00	59.40	192.30	402.10	178.90	75.40	52.60	153.00	227.00	45.20	8.50	1640.30
1994	0.00	15.30	91.60	271.90	175.50	153.60	237.90	150.00	291.70	124.00	39.00	10.10	1560.60
1995	0.00	65.10	79.10	316.30	179.30	73.40	151.50	119.50	218.70	106.80	34.40	64.70	1408.80
1996	64.30	7.60	184.40	219.00	324.20	243.60	130.50	142.60	218.10	97.10	20.50	19.00	1670.90
1997	40.94	0.00	60.00	248.70	227.30	136.60	217.50	225.60	260.00	292.80	215.10	40.94	1965.48
1998	68.50	103.60	103.60	127.60	111.50	187.30	173.20	152.30	163.60	327.50	46.30	16.70	1581.70
1999	7.30	7.70	131.60	168.00	204.80	88.40	119.50	105.80	108.70	256.50	18.50	20.80	1237.60
2000	5.10	0.00	23.20	154.60	173.00	72.30	130.70	246.10	191.80	248.60	142.60	37.30	1425.30
2001	21.30	40.20	168.00	225.70	353.40	128.50	126.80	229.80	360.70	233.00	34.90	50.50	1972.80
2002	32.80	31.90	152.40	155.90	197.40	206.80	76.90	90.40	136.00	200.30	33.50	126.10	1440.40
2003	41.50	21.80	206.40	271.50	111.20	111.70	226.00	219.70	111.50	105.80	34.90	33.70	1495.70
2004	111.20	57.50	90.80	242.00	193.50	117.50	70.30	78.10	172.40	50.50	53.80	49.00	1286.60
2005	28.80	5.60	120.60	389.20	333.00	122.30	208.10	96.40	360.30	100.10	50.60	3.10	1818.10
2006	43.70	51.20	131.20	281.30	254.70	178.80	210.20	151.90	171.40	243.90	99.60	19.00	1836.90

2007	65.20	11.70	43.40	236.50	167.70	283.70	208.30	394.60	472.00	66.60	85.20	0.00	2034.90
2008	8.80	1.80	44.00	116.90	228.20	128.10	88.70	108.60	272.60	338.40	111.30	15.40	1462.80
2009	117.30	39.40	96.90	118.90	110.20	120.10	76.20	96.20	196.80	231.70	40.00	126.90	1370.60
2010	101.50	75.10	211.90	272.90	279.00	114.20	106.30	209.70	297.80	96.20	96.20	37.20	1898.00
2011	3.00	28.50	139.30	93.40	254.80	167.00	91.20	168.80	337.80	77.50	132.57	7.00	1500.87
2012	1.30	40.30	64.00	6.10	250.10	73.20	113.30	103.30	196.90	235.60	98.70	25.60	1208.40
2013	61.80	0.00	160.60	90.21	203.90	119.52	279.00	182.00	185.00	223.00	73.90	0.00	1578.94
2014	10.20	50.11	122.20	112.80	424.80	132.60	227.70	217.80	244.70	95.67	113.20	13.80	1765.58
Mean	40.36	48.05	110.55	197.72	229.96	142.48	147.75	157.12	225.95	173.99	71.50	32.78	1578.21
Max	117.30	236.50	211.90	389.20	424.80	283.70	279.00	394.60	472.00	338.40	215.10	126.90	2034.90
Min	0.00	0.00	23.20	6.10	110.20	72.30	70.30	52.60	108.70	50.50	10.00	0.00	1208.40
STDEV	37.77	54.07	52.36	84.75	84.02	53.08	61.38	73.10	87.80	89.21	47.43	32.75	238.61

Table - 5 Monthly rainfall data at Dilla station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	13.20	198.80	159.60	161.40	158.90	53.70	42.10	108.90	132.80	94.10	59.30	25.30	1208.1
1991	72.30	51.90	123.60	195.00	157.50	129.01	136.75	132.94	143.60	101.80	9.00	45.30	1298.7
1992	14.10	37.80	44.90	207.50	179.90	156.90	100.90	97.40	186.10	250.00	54.20	46.40	1376.1
1993	74.65	88.16	60.59	153.60	340.80	158.10	34.50	78.70	114.80	163.20	50.50	17.60	1335.2
1994	1.30	10.20	132.70	384.30	147.60	105.50	257.40	164.00	142.60	92.10	38.40	0.40	1476.5

1995	0.50	55.40	73.90	262.90	190.30	67.00	151.80	105.40	200.00	174.00	42.40	18.40	1342.0
1996	87.60	33.20	165.80	280.10	252.90	232.80	123.80	151.60	258.98	86.10	27.90	12.40	1713.2
1997	17.50	5.30	25.50	256.80	272.30	161.30	111.50	93.10	149.00	220.30	203.50	85.50	1601.6
1998	58.40	45.60	108.40	232.90	210.60	67.90	124.70	146.20	107.50	155.20	82.30	7.20	1346.9
1999	20.70	15.10	124.41	148.00	266.68	75.50	46.60	44.20	163.52	192.24	35.10	13.80	1145.9
2000	0.00	0.00	20.40	190.10	312.90	19.70	98.70	113.30	144.60	162.80	69.80	13.10	1145.4
2001	23.24	34.41	105.60	226.70	194.80	144.40	72.40	145.30	157.40	197.40	52.40	28.80	1382.9
2002	35.60	18.70	208.00	86.60	137.90	104.80	69.60	109.00	88.20	57.40	69.90	115.70	1101.4
2003	56.70	4.00	76.10	146.90	100.30	102.90	55.50	118.70	67.30	128.00	95.40	22.20	974.00
2004	87.30	32.10	63.30	275.50	113.00	40.20	73.70	63.40	136.00	70.00	112.20	45.40	1112.1
2005	44.60	9.30	77.00	273.20	246.20	63.70	76.90	95.90	155.45	183.40	58.60	4.00	1288.3
2006	15.50	51.40	151.10	206.20	158.40	151.40	53.70	159.50	130.30	292.10	82.00	39.40	1491.0
2007	81.30	10.50	95.20	149.80	340.20	164.50	83.20	276.00	212.20	193.30	54.50	0.00	1660.7
2008	10.50	6.50	477.80	169.50	191.70	85.10	133.80	89.00	389.00	418.30	70.90	0.60	2042.7
2009	52.60	40.80	39.50	207.20	134.60	72.00	25.90	46.00	177.30	156.50	15.90	127.10	1095.4
2010	45.40	141.10	203.90	217.00	313.70	139.80	80.50	0.00	258.00	77.50	7.30	8.20	1492.4
2011	11.00	283.30	39.50	135.60	276.40	110.50	99.20	180.30	190.00	223.60	176.50	11.50	1737.4
2012	14.80	12.60	29.20	136.40	198.90	113.70	111.28	142.75	175.90	181.20	54.10	12.92	1183.7
2013	16.90	12.40	88.63	0.00	24.80	189.00	151.50	233.60	217.10	206.50	111.30	0.60	1252.3
2014	8.80	23.60	122.60	134.50	368.50	74.90	96.70	104.90	164.38	84.89	40.07	6.78	1230.6
Mean	34.6	48.89	112.7	193.5	211.6	111.4	96.51	120.0	170.5	166.5	66.94	28.34	1361.4

Max	87.60	283.30	477.80	384.30	368.50	232.80	257.40	276.00	389.00	418.30	203.50	127.10	2042.7
Min	0.00	0.00	20.40	0.00	24.80	19.70	25.90	0.00	67.30	57.40	7.30	0.00	974.00
STDEV	29.03	66.60	92.78	75.80	85.55	50.87	48.92	58.25	64.73	80.56	46.22	34.27	246.88

Table - 6 Monthly rainfall data at Kebado station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	17.65	149.03	150.70	235.00	221.40	144.20	55.20	73.80	96.50	68.11	38.80	23.72	1274.11
1991	60.90	74.10	106.30	99.20	137.04	97.40	108.20	25.20	191.00	108.30	16.60	9.50	1033.74
1992	46.00	60.63	71.00	175.00	258.00	119.80	66.00	97.60	167.40	314.70	12.50	59.30	1447.94
1993	38.00	152.00	140.50	217.70	284.60	175.90	56.10	52.20	126.20	193.80	19.20	16.90	1473.10
1994	0.00	20.90	119.20	374.70	297.20	158.00	170.40	159.90	177.40	72.40	62.90	9.80	1622.80
1995	0.00	80.30	99.10	419.70	244.80	52.40	77.00	104.50	176.20	158.20	23.40	76.10	1511.70
1996	77.70	78.80	245.10	298.10	250.80	169.40	105.20	148.00	180.50	118.00	40.50	50.50	1762.60
1997	61.90	0.00	34.30	308.20	272.90	127.60	152.40	102.70	162.80	236.90	157.10	68.90	1685.70
1998	73.40	94.70	98.50	171.40	137.00	120.80	124.20	99.80	185.80	192.70	90.00	16.10	1404.40
1999	18.80	25.90	194.00	98.00	312.40	99.30	75.60	99.80	141.40	211.90	28.20	26.10	1331.40
2000	4.40	0.00	20.80	139.10	175.70	42.20	105.80	121.10	190.10	211.10	82.00	30.90	1123.20
2001	18.70	39.00	105.10	188.00	167.50	193.00	73.70	172.70	215.20	292.60	70.60	40.10	1576.20
2002	35.80	6.60	188.20	70.34	182.60	139.50	30.80	91.60	174.80	144.10	18.60	183.30	1266.24
2003	31.60	3.80	54.80	226.80	163.80	144.80	56.10	134.70	120.20	122.00	59.30	32.80	1150.70
2004	111.10	63.10	58.90	171.40	153.00	28.20	58.10	106.60	147.10	73.30	89.80	85.40	1146.00

2005	17.70	7.20	120.10	287.10	209.50	145.90	76.60	59.20	177.50	156.30	17.90	0.00	1275.00
2006	21.00	55.60	127.50	195.50	207.50	115.20	121.80	160.10	150.20	358.70	77.10	13.60	1603.80
2007	62.80	75.20	90.30	158.50	271.10	106.50	68.20	280.70	293.10	184.10	36.70	0.00	1627.20
2008	2.60	10.40	42.10	168.00	285.10	83.30	90.80	62.00	282.50	197.60	66.70	7.90	1299.00
2009	84.80	28.00	102.00	176.10	192.70	49.00	26.40	54.40	211.80	168.10	6.00	96.90	1196.20
2010	47.30	130.70	162.90	289.60	282.00	165.60	147.50	181.70	95.40	119.10	26.70	5.60	1654.10
2011	12.20	15.40	27.90	116.50	272.00	71.20	39.80	252.80	262.10	135.30	199.40	9.70	1414.30
2012	4.60	0.00	48.10	166.00	112.13	128.10	184.60	92.90	275.10	121.00	41.90	31.90	1206.33
2013	28.70	7.30	107.30	209.70	119.70	101.20	54.00	139.70	150.40	139.48	54.57	0.10	1112.15
2014	8.68	27.50	159.60	168.80	306.77	88.67	157.40	182.44	123.00	204.80	38.60	6.66	1472.92
Mean	35.45	48.25	106.97	205.14	220.69	114.69	91.28	122.25	178.95	172.10	55.00	36.07	1386.83
Max	111.10	152.00	245.10	419.70	312.40	193.00	184.60	280.70	293.10	358.70	199.40	183.30	1762.60
Min	0.00	0.00	20.80	70.34	112.13	28.20	26.40	25.20	95.40	68.11	6.00	0.00	1033.74
STDEV	30.25	46.73	56.39	84.99	63.13	43.96	44.66	60.92	54.10	73.27	45.10	41.54	207.81

Table - 7 Monthly rainfall data at Yirgalem staion

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	13.30	214.90	148.80	228.10	111.30	104.50	96.30	115.80	118.90	75.20	30.40	12.90	1270.40
1991	6.20	32.00	74.50	153.00	176.70	126.10	85.10	185.10	274.20	77.60	0.00	37.20	1227.70
1992	26.10	36.90	64.30	126.80	164.20	95.80	130.00	147.40	170.20	260.00	61.40	22.20	1305.30
1993	27.20	76.70	32.50	148.70	298.20	138.00	29.30	48.60	127.80	290.4	23.30	2.50	952.80

1994	2.90	13.50	77.30	215.60	192.20	149.90	175.10	147.70	130.40	75.20	47.80	17.00	1244.60
1995	0.00	26.00	75.10	328.90	148.60	48.20	84.60	98.90	181.20	42.90	32.20	54.10	1120.70
1996	86.30	77.40	195.50	248.80	159.90	175.30	123.50	91.90	291.70	85.30	6.60	2.40	1544.60
1997	22.60	5.40	31.70	59.90	56.20	98.7	156.70	151.00	202.80	370.50	193.60	51.80	1302.20
1998	68.10	59.00	99.40	227.70	164.80	84.90	190.20	200.30	108.00	442.50	21.40	0.00	1666.30
1999	16.50	24.10	98.50	108.40	163.30	62.20	105.00	184.60	107.40	183.10	13.70	8.70	1075.50
2000	3.00	1.00	170.90	170.90	265.90	100.00	115.00	90.70	90.90	119.30	55.10	47.10	1229.80
2001	16.10	0.00	126.90	101.70	277.40	104.60	65.30	228.30	224.90	356.9	9.60	23.50	1178.30
2002	47.10	6.20	216.50	106.90	109.20	81.70	37.90	101.00	89.70	64.10	0.00	86.80	947.10
2003	52.50	12.90	88.50	177.00	25.80	52.60	61.70	76.90	101.30	109.90	61.70	60.00	880.80
2004	79.60	35.60	54.50	75.00	65.90	55.70	108.30	90.50	106.70	102.90	37.80	1.30	813.80
2005	34.40	1.10	81.30	134.00	243.50	80.10	129.70	67.40	130.10	105.90	64.60	0.00	1072.10
2006	2.90	36.80	162.90	212.20	153.90	91.40	128.70	197.40	116.00	282.30	42.30	84.50	1511.30
2007	66.90	13.00	111.90	172.60	164.70	164.00	116.30	210.70	219.30	175.50	67.30	0.00	1482.20
2008	36.00	32.70	15.60	161.10	195.90	113.30	163.50	109.80	103.60	181.30	104.70	6.60	1224.10
2009	55.80	46.20	86.50	192.30	98.70	171.80	28.00	66.10	129.90	145.80	25.10	44.30	1090.50
2010	24.60	94.80	106.00	209.20	253.80	138.30	86.00	178.60	89.20	0.30	18.40	28.20	1227.40
2011	0.80	19.40	0.00	160.00	277.10	17.30	159.50	38.00	17.30	112.50	51.60	0.00	853.50
2012	0.00	0.00	132.80	114.00	114.00	51.00	148.70	245.40	259.20	167.00	17.60	8.60	1258.30

2013	0.00	0.00	132.80	137.40	114.00	51.00	95.64	139.00	129.80	224.30	52.85	11.10	1087.90
2014	24.24	3.05	76.18	68.80	90.19	91.15	157.87	167.81	161.56	121.99	47.72	0.09	1010.65
Mean	28.70	36.07	99.36	165.43	166.47	98.16	109.17	133.80	146.69	154.70	43.29	25.45	1190.30
Max	86.30	214.90	216.50	328.90	298.20	175.30	190.20	245.40	291.70	442.50	193.60	86.80	1666.30
Min	0.00	0.00	0.00	59.90	25.80	17.30	28.00	38.00	17.30	0.30	0.00	0.00	813.80
STDEV	26.63	46.00	53.91	62.73	74.05	42.84	44.88	58.50	66.01	105.07	39.96	26.73	217.53

Table - 8 Monthly rainfall data at Morcho station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	46.20	281.30	316.10	141.60	166.10	78.10	128.90	211.50	186.00	111.20	78.70	11.40	1757.10
1991	24.80	181.80	324.20	168.50	111.60	158.00	204.70	222.48	70.40	34.50	39.30	29.70	1569.98
1992	162.70	98.10	103.70	111.90	207.30	120.10	120.20	159.30	176.30	190.10	99.50	18.90	1568.10
1993	146.30	61.80	39.20	191.50	208.60	69.60	67.00	89.50	128.40	230.50	24.20	41.00	1297.60
1994	8.00	15.80	153.40	250.70	200.40	180.40	168.00	208.30	248.30	62.90	38.50	6.30	1541.00
1995	0.00	65.50	89.90	243.10	148.10	82.10	53.80	64.00	416.90	250.10	0.00	77.00	1490.50
1996	78.60	39.10	161.90	279.60	233.90	224.20	212.90	187.30	309.60	120.90	13.20	0.70	1861.90
1997	18.50	0.00	75.30	174.10	146.30	76.90	152.50	120.30	86.10	291.40	222.50	14.50	1378.40
1998	77.50	58.40	173.70	150.50	142.00	62.00	112.70	66.10	141.50	181.80	26.10	2.70	1195.00
1999	21.80	10.90	96.10	102.70	81.20	112.90	92.10	84.70	175.70	149.30	3.50	16.30	947.20
2000	0.80	0.20	22.40	204.40	133.20	45.70	125.90	81.00	136.20	78.00	81.80	65.10	974.70

2001	27.80	20.00	112.30	128.90	182.30	112.40	55.20	87.40	221.00	224.70	14.60	25.70	1212.30
2002	29.00	42.30	122.70	72.90	97.30	56.30	93.20	112.70	91.50	75.40	0.00	59.70	853.00
2003	45.50	19.20	89.20	209.60	48.90	77.10	80.50	134.80	151.50	73.50	65.20	23.20	1018.20
2004	89.80	127.00	101.10	94.80	105.30	45.00	67.50	97.60	169.90	70.50	60.00	16.20	1044.70
2005	43.10	6.20	126.40	282.70	175.30	53.90	161.70	70.40	197.00	120.00	52.70	0.50	1289.90
2006	12.60	74.90	152.10	192.50	150.40	118.30	134.40	63.10	79.40	204.80	9.70	25.70	1217.90
2007	70.40	139.90	96.70	127.10	217.50	109.30	111.00	142.20	142.50	141.40	8.30	0.00	1306.30
2008	17.40	14.60	5.00	85.60	76.50	77.30	162.20	96.20	225.30	156.30	115.90	3.00	1035.30
2009	45.50	11.70	97.00	64.20	88.30	111.30	28.00	48.20	108.90	118.80	16.80	25.60	764.30
2010	25.60	73.10	130.50	47.20	93.30	59.30	48.50	123.20	118.90	17.00	30.90	18.00	785.50
2011	14.40	2.60	17.90	103.95	239.20	79.20	121.50	211.00	120.00	59.50	67.40	4.80	1041.45
2012	0.00	1.40	84.90	103.80	97.43	26.10	136.40	132.80	147.40	24.90	72.10	3.00	830.23
2013	8.37	37.97	66.00	101.50	160.10	38.20	140.00	56.68	125.80	72.49	34.21	3.10	844.42
2014	16.50	0.00	129.55	131.30	82.60	91.20	87.60	137.80	181.50	118.70	61.60	0.09	1038.44
Mean	41.25	55.35	115.49	150.59	143.73	90.60	114.66	120.34	166.24	127.15	49.47	19.69	1194.54
Max	162.70	281.30	324.20	282.70	239.20	224.20	212.90	222.48	416.90	291.40	222.50	77.00	1861.90
Min	0.00	0.00	5.00	47.20	48.90	26.10	28.00	48.20	70.40	17.00	0.00	0.00	764.30
STDEV	42.55	67.60	75.47	66.75	54.46	45.88	47.84	53.62	76.51	73.98	48.29	21.18	308.05

Table - 9 Monthly rainfall data Telam station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
1990	16.13	136.23	97.50	122.50	123.20	81.50	73.80	89.50	86.50	62.26	6.20	33.20	928.52
1991	42.40	83.80	101.00	128.10	125.80	45.70	76.64	91.10	91.10	49.80	8.30	38.50	882.24
1992	42.40	80.27	151.70	141.00	138.60	89.10	104.40	188.40	252.90	176.51	9.50	28.75	1403.53
1993	67.06	79.20	54.43	154.79	253.40	126.70	61.40	33.20	161.10	410.02	0.00	0.00	1401.30
1994	0.00	0.00	78.10	230.50	210.20	215.70	291.90	163.70	280.30	80.90	47.50	0.00	1598.80
1995	0.00	51.80	143.80	370.30	450.40	93.50	80.58	99.33	243.37	134.54	19.57	54.97	1742.14
1996	48.60	118.80	227.60	196.70	148.40	110.80	259.20	180.00	169.60	0.00	25.00	30.90	1515.60
1997	31.80	5.40	80.29	233.40	126.70	109.50	138.20	149.90	128.00	232.40	143.40	9.80	1388.79
1998	26.90	70.90	91.20	112.60	147.30	56.90	196.10	116.50	140.20	237.90	24.50	4.60	1225.60
1999	20.30	14.80	100.50	111.30	42.80	75.80	68.60	81.90	156.70	94.10	11.20	15.70	793.70
2000	3.50	0.00	19.00	171.40	170.40	39.20	138.20	133.30	116.40	168.40	61.50	40.40	1061.70
2001	10.40	38.80	142.20	146.80	247.90	167.90	95.50	186.80	256.50	162.00	22.80	29.60	1507.20
2002	48.30	22.80	170.30	152.10	123.60	119.70	94.90	131.30	161.70	54.70	9.40	94.00	1182.80
2003	67.50	28.20	126.80	281.80	78.40	155.10	117.10	153.60	234.90	77.40	48.30	23.50	1392.60
2004	90.40	40.80	53.90	151.70	134.00	106.50	130.50	124.10	196.60	96.90	24.00	20.20	1169.60
2005	33.00	4.90	155.10	243.90	246.10	148.60	140.50	63.80	203.60	116.00	19.60	2.60	1377.70
2006	10.00	84.10	243.80	221.30	199.00	189.70	211.70	206.10	212.00	246.40	100.60	55.30	1980.00
2007	50.10	46.60	114.80	142.20	177.50	196.50	100.90	200.40	233.60	103.70	24.60	0.00	1390.90

2008	18.20	13.40	176.14	168.40	218.80	74.10	147.60	74.20	82.50	180.00	77.20	9.50	1240.04
2009	61.40	44.70	125.40	161.80	57.60	141.50	44.90	37.00	128.00	132.60	22.90	108.10	1065.90
2010	76.20	121.40	217.30	323.50	148.50	76.40	127.70	134.30	174.20	53.50	54.90	29.90	1537.80
2011	19.90	20.40	59.70	145.90	291.90	96.80	163.00	193.90	238.20	130.50	59.20	6.20	1425.60
2012	8.00	73.10	177.60	102.49	79.03	99.97	186.70	168.60	56.80	60.10	11.60	3.10	1027.10
2013	13.80	3.18	79.62	71.91	94.27	97.71	219.90	214.40	190.40	176.90	47.20	0.09	1209.38
2014	8.80	159.40	119.40	233.50	298.96	146.20	190.90	221.00	234.60	134.50	65.80	14.80	1827.86
Mean	32.60	53.72	124.29	180.80	173.31	114.44	138.43	137.45	177.19	134.88	37.79	26.15	1331.06
Max	90.40	159.40	243.80	370.30	450.40	215.70	291.90	221.00	280.30	410.02	143.40	108.10	1980.00
Min	0.00	0.00	19.00	71.91	42.80	39.20	44.90	33.20	56.80	0.00	0.00	0.00	793.70
STDEV	25.66	45.68	56.96	71.42	90.52	46.36	63.60	55.43	62.25	85.56	33.63	28.11	289.98

Table - 10 Mean monthly Tmax (°c) and Tmin (°c)

Month	Tmax				Tmin			
	Dilla	Yirgalem	Awondo	Bilate	Dilla	Yirgalem	Awondo	Bilate
January	28.46	28.20	28.50	31.8	10.24	10.09	7.20	15.3
February	28.53	28.93	28.50	32	10.05	10.36	8.83	14.8
March	29.34	28.81	26.20	32.4	12.35	11.60	8.65	15.1
April	27.96	27.39	26.80	29	13.75	12.06	10.10	16.1
May	26.61	25.84	27.20	29.6	13.60	12.10	8.80	16.2
June	25.90	25.01	25.50	28.1	13.59	12.27	9.10	16.1
July	25.08	23.48	24.80	26.2	14.06	12.50	9.50	16
August	25.61	24.02	25.70	26.3	14.12	12.73	9.10	16
September	25.82	24.43	24.80	28.5	13.50	12.08	9.30	15.3
October	26.58	25.31	25.80	29.2	13.24	11.52	8.30	14.1
November	27.72	26.31	25.70	30.3	11.75	10.57	7.12	15
December	28.20	26.89	26.70	30.5	10.03	9.47	8.23	14.5
Mean	27.15	26.22	26.35	29.49	12.52	11.45	9.93	15.38

APPENDIX-3 ETO AND CLIMATIC DATA OF METEOROLOGICAL STATIONS

Table - 11 ETO and climatic data of Dilla meteorological station

ETo and climatic data of Dilla meteorological station							
Monthly Eto Penman Monteith							
Country: Ethiopia				Station: Dilla			
Altitude: 1579 m		Latitude: 6.41 °N		Longitude: 38.30 °E			
Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	12	29.5	61.9	130	8.4	20.5	4.07
February	11.8	30.7	58	130	8	21	4.38
March	12.6	30.8	63.7	147	7.4	20.9	4.38
April	13.5	28.6	74.4	130	7.5	21	4.06
May	12.6	27.2	78.2	130	7.2	19.9	3.69
June	12.3	26.7	76.6	147	6.6	18.5	3.31
July	13.5	25.7	78.7	112	4.7	15.9	2.97
August	12.8	25.7	77.4	112	4.9	16.7	3.13
September	12.6	26.2	80	86	6.1	18.7	3.41
October	12.6	26.1	77.9	69	7.1	19.7	3.62
November	11.3	27.2	73.8	95	8.5	20.8	3.75
December	10.8	28.3	69.3	104	8.2	19.8	3.8
Average	12.4	27.7	72.49	116	7	19.4	3.71

Table - 12 ETo and climatic data of Aleta Wondo meteorological station

ETo and climatic data of Aleta Wondo meteorological station							
Monthly Eto Penman Monteith							
Country: Ethiopia				Station: Aleta Wondo			
Altitude: 1947 m		Latitude: 6.80 °N		Longitude: 38.41 °E			
Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	4	28.5	86	104	7.7	20.5	3.81
February	6.8	28.5	80	104	7.1	21	4.05
March	8.6	26.2	78	130	6.6	20.9	3.94
April	10.1	26.8	95	104	5.9	21	3.84
May	8.8	27.2	92	104	6.2	19.9	3.64
June	9.1	25.5	92	138	4.9	18	3.17
July	9.5	24.8	93	104	3.3	15.8	2.85
August	9.1	25.7	94	104	4.6	16.5	3.08
September	9.3	24.8	94	69	4.7	18.7	3.33
October	8.3	25.8	85	69	5.5	19.4	3.53
November	6.9	25.7	86	86	7.5	20.9	3.63
December	4.6	26.7	73	95	7.9	19.9	3.63
Average	7.9	26.4	87.3	101	6.0	19.4	3.54

Table - 13 ETO and climatic data for Yirgalem meteorological station

ETo and climatic data of Yirgalem meteorological station							
Monthly Eto Penman Monteith							
Country: Ethiopia				Station: Yirgalem			
Altitude:1786 m		Latitude: 6.82 °N		Longitude: 38.39 °E			
Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	8.8	28.5	78	104	8.5	20.6	3.93
February	9.5	29	73	104	8	20.9	4.13
March	10.6	29	78	130	7.4	20.8	4.23
April	11.1	27.2	89	104	7.5	21	3.97
May	11.1	26.7	88	104	7.2	19.9	3.72
June	11.1	25.2	87	138	6.6	18.6	3.32
July	12.1	23.7	85	104	4.6	15.8	2.92
August	12.8	24.1	83	104	4.8	16.5	3.1
September	12.1	24.6	90	69	6.1	18.7	3.38
October	11.6	25.7	80	69	7.8	20.8	3.75
November	10.1	26.3	82	86	8.6	20.9	3.71
December	10.1	27.5	73	95	8.3	19.8	3.75
Average	10.9	26.5	82.17	101	7.1	19.5	3.66

Table - 14 ETO and climatic data for Bilate meteorological station

ETo and climatic data of Bilate meteorological station							
Monthly Eto Penman Monteith							
Country: Ethiopia				Station: Bilate			
Altitude:1361 m		Latitude: 6.82 °N		Longitude: 38.08 °E			
Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	15.3	31.8	50.1	104	8.4	20.1	4.25
February	14.8	32	52.1	104	7.6	20.9	4.52
March	15.1	32.4	59.9	130	7.8	21	4.69
April	16.1	29	70	104	6.3	19.8	4.15
May	16.2	29.6	72.6	104	7.4	19.8	3.94
June	16.1	28.1	71.6	138	6	18.6	3.67
July	16	26.2	73.9	104	4.8	15.8	3.09
August	16	26.3	70.7	104	5	17.4	3.35
September	15.3	28.5	71.2	69	6.1	17.8	3.49
October	14.1	29.2	67.5	69	9.5	19.2	3.74
November	15	30.3	57.3	86	7.6	20.7	4.13
December	14.5	30.5	51.4	95	6.8	20.5	4.16
Average	15.4	29.5	64.03	101	7	19.3	3.93

Table - 15 Rainfall data of dilla (table_a)

Month	Rain Mm	Eff rain Mm
January	35	33
February	48	44.3
March	99	83.3
April	174	125.6
May	150	114
June	105	87.4
July	129	102.4
August	102	85.4
September	167	122.4
October	158	118.1
November	65	58.2
December	21	20.3
Total	1253	994.3

Rainfall data of Aleta wondo(b)

Month	Rain Mm	Eff rain mm
January	54	49.3
February	59	53.4
March	114	93.2
April	192	133
May	227	144.6
June	119	96.3
July	130	103
August	153	115.5
September	239	147.6
October	175	126
November	65	58.2
December	39	36.6
Total	1566	1156.8

Rainfall data of Yirgalem (table_c)

Month	Rain Mm	Eff rain Mm
January	43	40
February	57	51.8
March	104	86.7
April	153	115.5
May	143	110.3
June	94	79.9
July	114	93.2
August	136	106.4
September	153	115.5
October	126	100.6
November	57	51.8
December	36	33.9
Total	1216	985.7

Rainfall data of Bilate (table_d)

Month	Rain mm	Eff rain Mm
January	20	19.4
February	22	21.2
March	74	65.2
April	91	77.8
May	98	82.6
June	89	76.3
July	104	86.7
August	91	77.8
September	73	64.5
October	41	38.3
November	17	16.5
December	14	13.7
Total	734	640

APPENDIX-4 CROP WATER REQUIREMENT USING CROPWAT

Table - 16 Crop water requirements report for maize at dilla station

CROP WATER REQUIREMENTS REPORT							
Eto Station @ Dilla				Crop Maize			
Rain Station @ dilla				Planting date 15/11			
Irrigation Efficiency=60%				Harvesting date 19/03			
Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.3	1.13	6.8	11	0
Nov	3	Init	0.3	1.13	11.3	14.5	0
Dec	1	Deve	0.36	1.35	13.5	9.4	4
Dec	2	Deve	0.6	2.3	23	4.4	18.6
Dec	3	Deve	0.88	3.43	37.7	6.6	31.1
Jan	1	Mid	1.15	4.58	45.8	9.6	36.2
Jan	2	Mid	1.23	4.98	49.8	11.1	38.8
Jan	3	Mid	1.23	5.11	56.2	12.3	43.9
Feb	1	Mid	1.23	5.24	52.4	12.7	39.7
Feb	2	Late	1.21	5.29	52.9	13.5	39.4
Feb	3	Late	1.01	4.41	35.3	18.2	17
Mar	1	Late	0.74	3.26	32.6	23.4	9.2
Mar	2	Late	0.47	2.04	18.4	24.9	0
Total					435.6	171.7	278

Table – 17 Crop water requirements report for Tomato at dilla station

CROP WATER REQUIREMENTS REPORT							
Eto Station @ Dilla				Crop Tomato			
Rain Station @ dilla				Planting date 15/11			
Irrigation Efficiency=60%				Harvesting date 08/04			
Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.6	2.25	13.5	11	4.3
Nov	3	Init	0.6	2.26	22.6	14.5	8.1
Dec	1	Init	0.6	2.27	22.7	9.4	13.3
Dec	2	Deve	0.63	2.4	24	4.4	19.5
Dec	3	Deve	0.77	3	33	6.6	26.4
Jan	1	Deve	0.92	3.66	36.6	9.6	27
Jan	2	Deve	1.06	4.33	43.3	11.1	32.2
Jan	3	Mid	1.17	4.87	53.5	12.3	41.2
Feb	1	Mid	1.17	5	50	12.7	37.4
Feb	2	Mid	1.17	5.13	51.3	13.5	37.8
Feb	3	Mid	1.17	5.13	41	18.2	22.8
Mar	1	Late	1.17	5.12	51.2	23.4	27.8
Mar	2	Late	1.09	4.79	47.9	27.7	20.2
Mar	3	Late	0.97	4.14	45.6	32.4	13.2
Apr	1	Late	0.86	3.57	28.6	31.1	0.10
Total					564.9	237.9	331.3

Table – 18 Crop water requirements report for maize at Aleta Wondo station

CROP WATER REQUIREMENTS REPORT							
Eto Station @ Aleta Wondo				Crop Maize			
Rain Station @ Aleta Wondo				Planting date 15/11			
Irrigation Efficiency=60%				Harvesting date 19/03			
Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.3	1.08	6.5	10.4	0
Nov	3	Init	0.3	1.08	10.8	15.6	0
Dec	1	Deve	0.36	1.29	12.9	13.5	0
Dec	2	Deve	0.61	2.21	22.1	10.6	11.5
Dec	3	Deve	0.9	3.29	36.2	12.5	23.6
Jan	1	Mid	1.17	4.37	43.7	15.3	28.5
Jan	2	Mid	1.25	4.73	47.3	16.8	30.5
Jan	3	Mid	1.25	4.83	53.2	17.1	36
Feb	1	Mid	1.25	4.93	49.3	16.3	33.1
Feb	2	Late	1.23	4.96	49.6	16.2	33.5
Feb	3	Late	1.03	4.09	32.7	21.1	11.6
Mar	1	Late	0.76	2.98	29.8	26.6	3.2
Mar	2	Late	0.47	1.84	16.5	28	0
Total					410.6	219.9	211.4

Table – 19 Crop water requirements report for Tomato at Aleta Wondo station

CROP WATER REQUIREMENTS REPORT							
ETo Station @ Aleta Wondo				Crop Tomato			
Rain Station @ Aleta Wondo				Planting date 15/11			
Irrigation Efficiency=60%				Harvesting date 08/04			
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.6	2.18	13.1	10.4	4.5
Nov	3	Init	0.6	2.18	21.8	15.6	6.2
Dec	1	Init	0.6	2.18	21.8	13.5	8.2
Dec	2	Deve	0.63	2.29	22.9	10.6	12.3
Dec	3	Deve	0.77	2.85	31.4	12.5	18.8
Jan	1	Deve	0.93	3.47	34.7	15.3	19.4
Jan	2	Deve	1.07	4.08	40.8	16.8	24
Jan	3	Mid	1.17	4.57	50.3	17.1	33.1
Feb	1	Mid	1.18	4.68	46.8	16.3	30.5
Feb	2	Mid	1.18	4.77	47.7	16.2	31.6
Feb	3	Mid	1.18	4.73	37.8	21.1	16.7
Mar	1	Late	1.18	4.68	46.8	26.6	20.1
Mar	2	Late	1.1	4.33	43.3	31.1	12.2
Mar	3	Late	0.97	3.79	41.7	35.5	6.2
Apr	1	Late	0.86	3.32	26.5	32.6	0
Total					527.3	291.2	243.9

Table - 20 Crop water requirements report for maize at Yirgalem station

CROP WATER REQUIREMENTS REPORT							
ETo Station @ Yirgalem				Crop Maize			
Rain Station @ Yirgalem				Planting date 15/11			
Irrigation Efficiency=60%				Harvesting date 19/03			
Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.3	1.11	6.7	9.5	0
Nov	3	Init	0.3	1.12	11.2	14.3	0
Dec	1	Deve	0.36	1.33	13.3	12.6	0.7
Dec	2	Deve	0.6	2.27	22.7	10.2	12.5
Dec	3	Deve	0.88	3.36	37	11.3	25.7
Jan	1	Mid	1.15	4.46	44.6	12.5	32.1
Jan	2	Mid	1.23	4.83	48.3	13.1	35.2
Jan	3	Mid	1.23	4.91	54	14.5	39.5
Feb	1	Mid	1.23	4.99	49.9	15.3	34.6
Feb	2	Late	1.21	5	50	16.2	33.8
Feb	3	Late	1.01	4.2	33.6	20.4	13.2
Mar	1	Late	0.74	3.13	31.3	25.2	6.1
Mar	2	Late	0.47	1.98	17.8	26.2	0
Total					420.3	201.3	233.4

Table - 21 Crop water requirements report for Tomato at Yirgalem station

CROP WATER REQUIREMENTS REPORT							
ETo Station @ Yirgalem				Crop Tomato			
Rain Station @ Yirgalem				Planting date 15/11			
Irrigation Efficiency=60%				Harvesting date 08/04			
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.6	2.22	13.3	9.5	5.4
Nov	3	Init	0.6	2.23	22.3	14.3	8
Dec	1	Init	0.6	2.24	22.4	12.6	9.9
Dec	2	Deve	0.63	2.36	23.6	10.2	13.4
Dec	3	Deve	0.77	2.94	32.3	11.3	21
Jan	1	Deve	0.92	3.56	35.6	12.5	23.1
Jan	2	Deve	1.06	4.18	41.8	13.1	28.7
Jan	3	Mid	1.16	4.66	51.2	14.5	36.8
Feb	1	Mid	1.17	4.75	47.5	15.3	32.3
Feb	2	Mid	1.17	4.83	48.3	16.2	32.1
Feb	3	Mid	1.17	4.87	39	20.4	18.5
Mar	1	Late	1.17	4.9	49	25.2	23.8
Mar	2	Late	1.09	4.62	46.2	29.1	17.1
Mar	3	Late	0.97	4.01	44.1	32.3	11.9
Apr	1	Late	0.86	3.47	27.8	29.1	0
Total					544.6	265.5	282

Table – 22 Crop water requirements report for maize at Bilate station

CROP WATER REQUIREMENTS REPORT							
ETo Station @ Bilate				Crop Maize			
Rain Station @ Bilate				Planting date 15/11			
Irrigation Efficiency=60%				Harvesting date 19/03			
Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.3	1.24	7.4	2.8	5.1
Nov	3	Init	0.3	1.24	12.4	4.6	7.8
Dec	1	Deve	0.35	1.47	14.7	4.6	10.1
Dec	2	Deve	0.6	2.48	24.8	4.2	20.6
Dec	3	Deve	0.87	3.64	40	5	35
Jan	1	Mid	1.13	4.77	47.7	5.9	41.8
Jan	2	Mid	1.2	5.11	51.1	6.6	44.5
Jan	3	Mid	1.2	5.22	57.4	6.8	50.7
Feb	1	Mid	1.2	5.33	53.3	5.6	47.7
Feb	2	Late	1.19	5.36	53.6	5.1	48.5
Feb	3	Late	0.99	4.53	36.2	10.7	25.5
Mar	1	Late	0.73	3.4	34	17.8	16.1
Mar	2	Late	0.46	2.17	19.6	20.9	0
Total					452.3	100.6	353.5

Table - 23 Crop water requirements report for tomato at Bilate station

CROP WATER REQUIREMENTS REPORT							
ETo Station @ Bilate				Crop Tomato			
Rain Station @ Bilate				Planting date 15/11			
Irrigation Efficiency=60%				Harvesting date 08/04			
Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Nov	2	Init	0.6	2.48	14.9	2.8	12.6
Nov	3	Init	0.6	2.49	24.9	4.6	20.2
Dec	1	Init	0.6	2.49	24.9	4.6	20.3
Dec	2	Deve	0.63	2.62	26.2	4.2	22
Dec	3	Deve	0.77	3.21	35.3	5	30.4
Jan	1	Deve	0.91	3.85	38.5	5.9	32.6
Jan	2	Deve	1.05	4.47	44.7	6.6	38.1
Jan	3	Mid	1.15	5	55	6.8	48.2
Feb	1	Mid	1.15	5.12	51.2	5.6	45.6
Feb	2	Mid	1.15	5.22	52.2	5.1	47.1
Feb	3	Mid	1.15	5.28	42.3	10.7	31.6
Mar	1	Late	1.15	5.34	53.4	17.8	35.6
Mar	2	Late	1.08	5.05	50.5	23.2	27.3
Mar	3	Late	0.96	4.31	47.4	24.1	23.3
Apr	1	Late	0.84	3.65	29.2	19.8	4.5
Total					590.6	146.8	439.3

Table - 24 Random consistency index

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

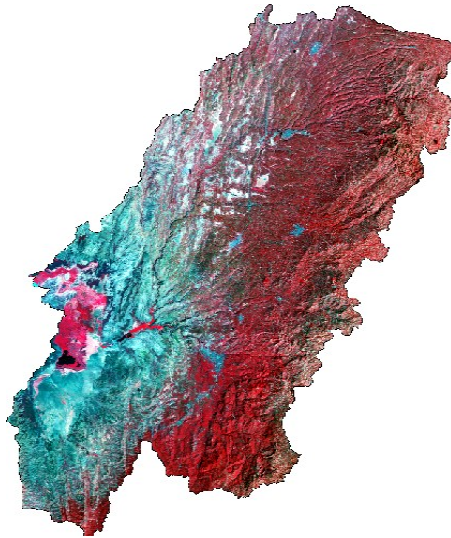
Table-25 Summary of missing rainfall and date of length used in the analysis

Meteorological information of missing data			
S.No	Station	Date of length	Missing data
1	AletaWondo	1990-2014	1997(Dec), 2011(Nov), 2013(Apr & Jun) and 2014(Feb & Oct).
2	Dilla	1990-2014	1991(May, Jun & Jul), 1993(Jan, Feb & Mar), 1999(Mar), 20001(Jan & Feb), 2012(Jul & Dec), 2013(Mar) and 2014(Sep, Oct, Nov & Dec).
3	Yirgalem	1990-2014	2002(Dec), 2012(Mar, May & Jun), 2013(Jul, Nov & Dec) and 2014 (full year).
4	Kebado	1990-2014	1990(Jan, Feb, Oct, Nov & Dec), 2013(May, Oct, Nov & Dec) and 2014(Jun & Dec).
Hydrological data			
082016(Apost)	Gidabo	1990-2014	2003(Oct, Nov & Dec), 2004(Jan-May), 2009(Mar-May) and 2014(Jun-Dec).
082018(Aletawondo)	Kolla	1990-2014	2001(Feb to Nov), 2003(Sep-Dec), 2004(Jan-Mar), 2009(Mar-Jun), 2013(Sep-Dec) and 2014(Jun-Dec).
082034(Dilla)	Bedessa	1990-2014	2003(Aug-Dec), 2004(Jan-Mar), 2009(Mar - Jun) and 2014(May- Dec).

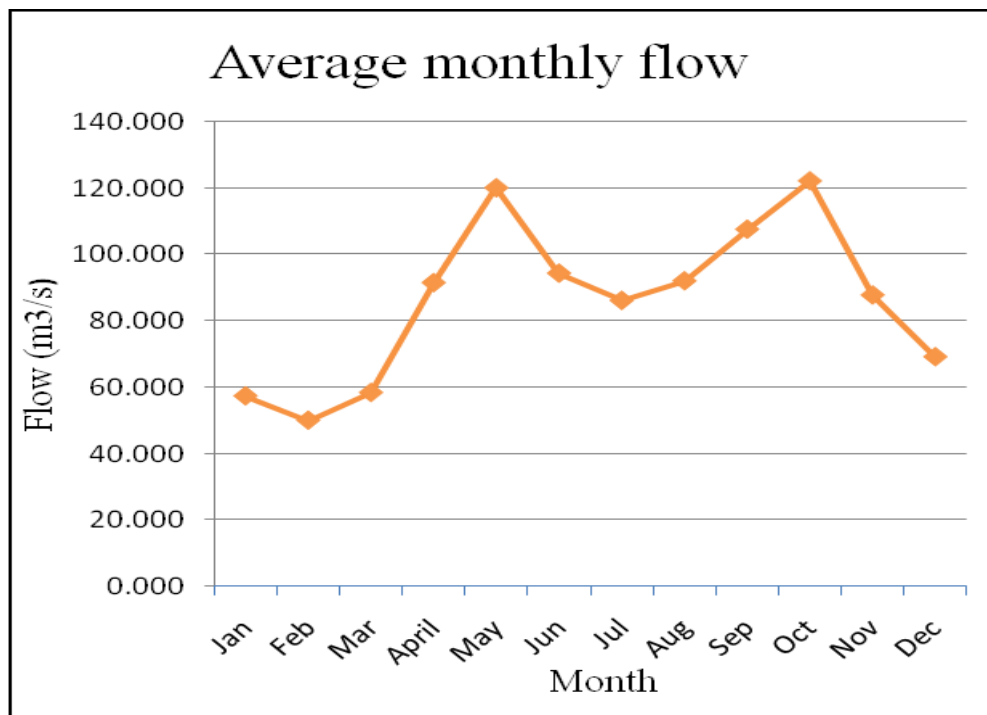
Table 26. Suitable land for surface irrigation in the study area

S/N	Water supply (Rivers)	Diversion site location		Potential Area(ha)
		X(Latitude)	y(Longitude)	
1	Wamole	436062.134	756350.036	823.02
2	Gidabo	434618.545	746908.053	6566.22
3	Kolla	419757.154	734389.153	3059.037
4	Raro (Aleta Wondo)	427825.033	734463.563	5672
5	Woyima (Awada)	410675.148	712307.533	235.46
6	Bedessa (dilla)	411544.693	713966.682	2993.33
7	Gigessa (Kella)	451324.603	711857.838	625.66
8	Gidabo at Meissa	398212.792	722443.14	17065.61
9	Odomike	397094.174	698597.788	572.32

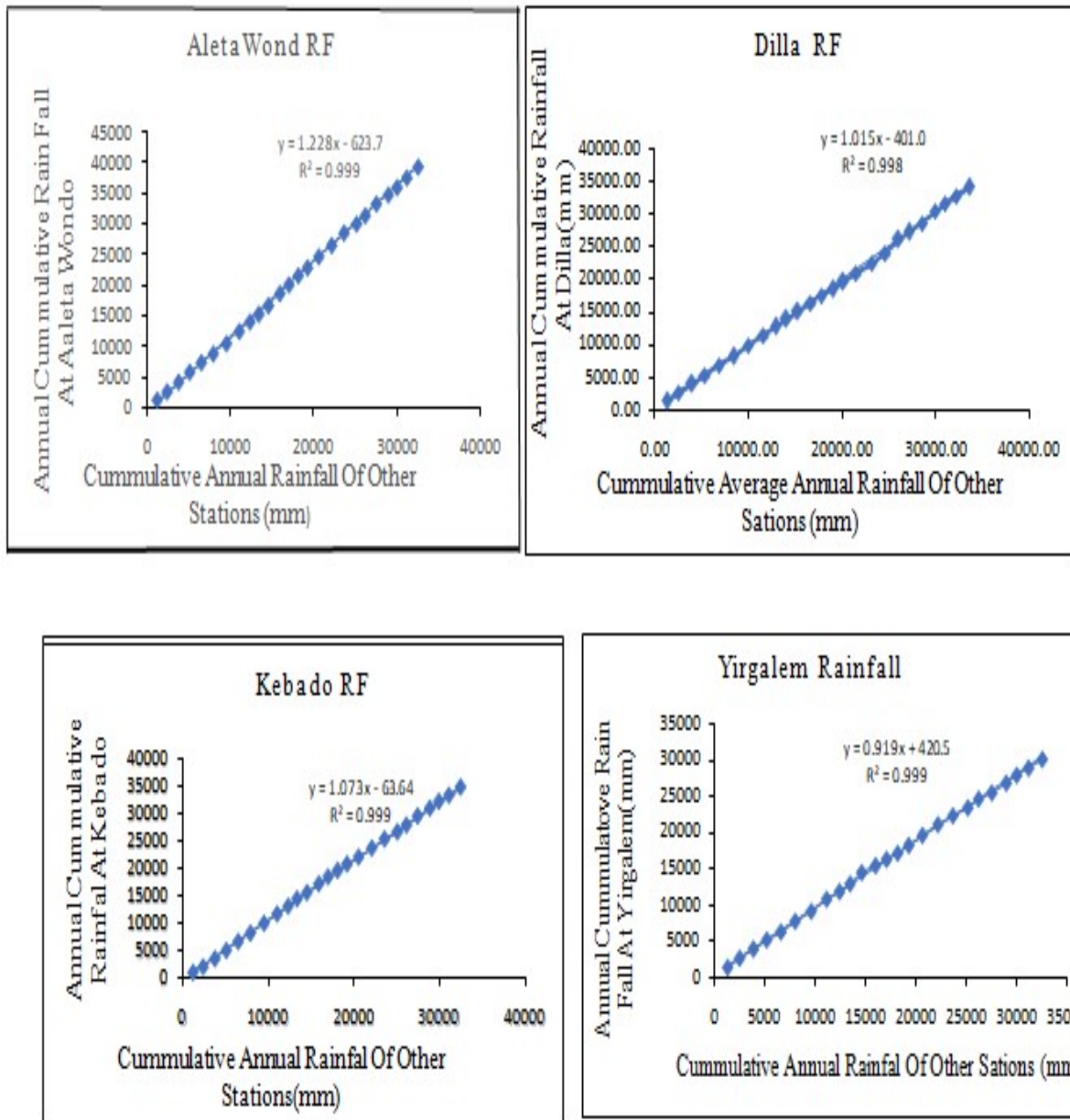
APPENDIX-5 FIGURES; LANDSAT, MONTHLY TEMPORAR FLOW,
DOUBLE MASS CURVES, AND CROP PATTERNS



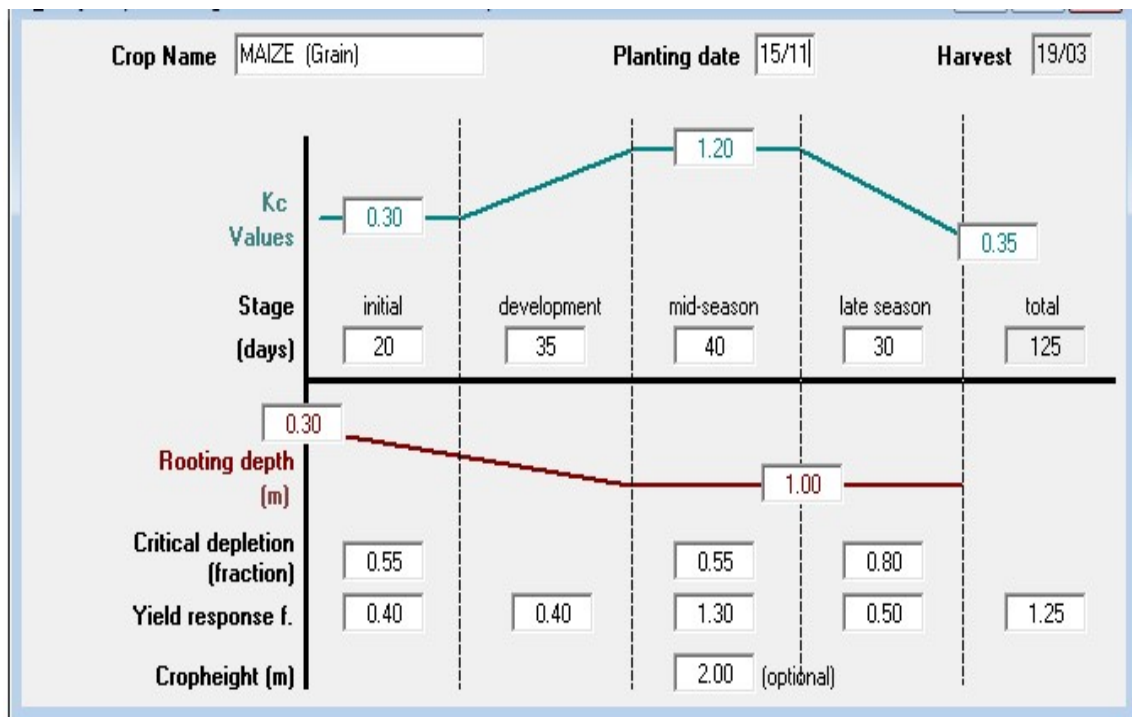
Appendix figure - 1 Raw Landsat image of the study area



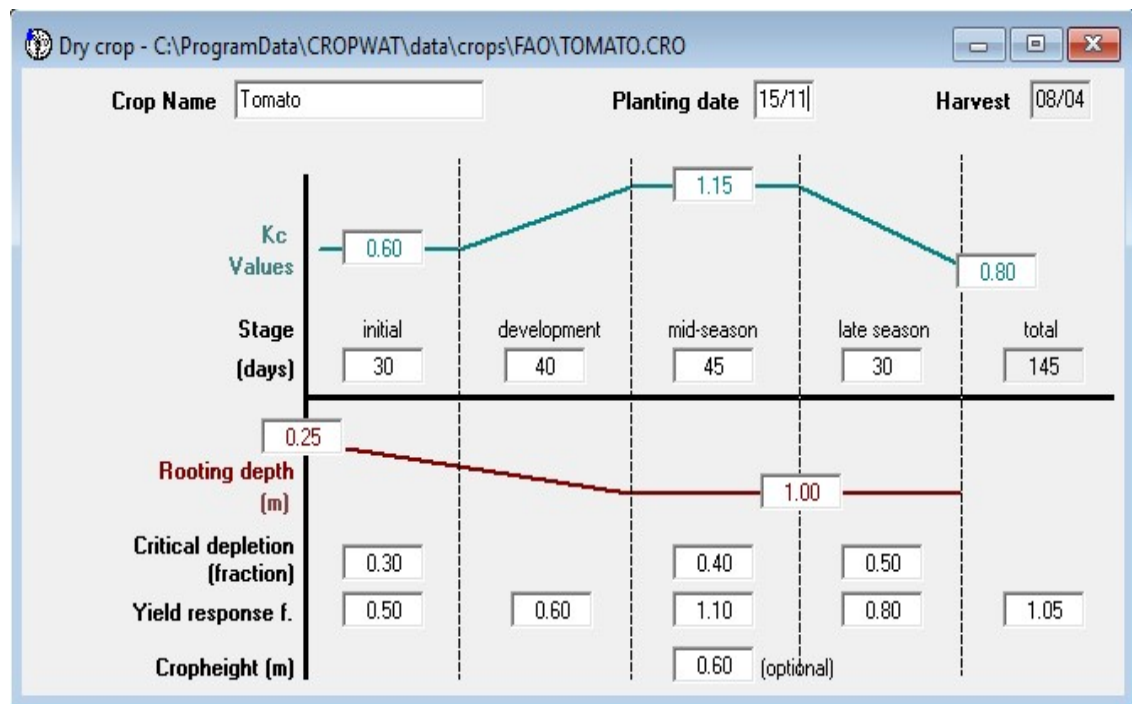
Appendix figure – 2 Average monthly temporal flow of the catchment



Appendix figure - 3 Double mass curves for the consistency of Aleta Wondo, Dilla, Kebado and Yirgalem meteorological stations rainfall data.



Appendix figure - 4 Crop pattern of maize



Appendix figure - 5 Crop pattern of Tomato