GIS-BASED APPROACH FOR ASSESSIMENT OF SURFACE IRRIGATION POTENTIAL IN AWASH ARBA WATERSHED, AFAR, ETHIOPIA.

Tsegaye Girma Asres

A Thesis Submitted to the Department of Water Resources Engineering, School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies
Adama Science and Technology University

Adama, Ethiopia

June, 2022

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Major Advisor: Zelalem Biru (PhD)

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DECLARATION

I hereby declare that this Master Thesis entitled "GIS-BASED APPROACH FOR ASSESSIMENT OF SURFACE IRRIGATION POTENTIAL IN AWASH ARBA WATERSHED, AFAR, ETHIOPIA" is my original work. That is, it has not been submitted for the award of any academic, degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Tsegaye Girma Asres	________________	________________
Name of the student	Signature	Date

RECOMMENDATION OF THE ADVISOR

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "GIS-BASED APPROACH FOR ASSESSIMENT OF SURFACE IRRIGATION POTENTIAL IN AWASH ARBA WATERSHED, AFAR, ETHIOPIA" prepared under my guidance by Tsegaye Girma Asres submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resource Engineering (specialization in Irrigation Engineering). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

________________	____________	____________
Name of Advisor	Signature	Date

APPROVAL PAGE

I, the advisor of the thesis entitled "GIS-BASED APPROACH FOR ASSESSIMENT OF SURFACE IRRIGATION POTENTIAL IN AWASH ARBA WATERSHED, AFAR, ETHIOPIA" and developed by Tsegaye Girma Asres, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

________________________	____________________	___________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Tsegaye Girma Asres have read and evaluated the thesis entitled "GIS-BASED APPROACH FOR ASSESSIMENT OF SURFACE IRRIGATION POTENTIAL IN AWASH ARBA WATERSHED, AFAR, ETHIOPIA" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Mater of Science in Water Resources Engineering (Specialization in Irrigation Engineering).

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the office of postgraduate studies (OPGS) through the Department Graduate Committee (SGC).

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LIST OF ABBREVIATIONS

CA	Comprehensive Assessment of water management for agriculture
CNES	Centre National d'Études Spatiales
DEM	Digital Elevation Model
DFID	Department for International Development
EMA	Ethiopian Mapping Agency
ENVI	Environment for Visualizing Images
ESRI	Environmental Systems Research Institute
ETc	Crop Evapo-transpiration
ETo	Reference Crop Evapo-transpiration
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
GLCN	Global Land Cover Network
GPS	Global Positioning System
IFAD	International Fund for Agricultural Development
ILRI	International Livestock Research Institute
IWR	Irrigation Water Requirement
LULC	Land use Land cover
MoA	Ministry of Agriculture
MoWR	Ministry of Water Resources
NASA	National Aeronautics and Space Administration
NGA	National Geospatial intelligence Agency
NMSA	National Meteorological Services Agency
SPOT	Système Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
UNESCO	United Nations Scientific and Cultural Organization

ABSTRACT

Irrigation development is one of the key strategies to increase agricultural production to generate income. One of the main factor rain fed dependent agriculture is rainfall variability and unreliability occurrences. Due to this effect, crops are failed and consequence, food insecurity often turns into famine. The main problem on this study area, potential of irrigable area, available water and irrigation water demand for dominant crops were not yet identified. In order to come with solutions for this problem, evaluation of land and surface water resource potential for surface irrigation was big issue. To meet the main objective, land suitability, available water and irrigation water demand was assessed in this study.

Materials used to assessing surface irrigation potential were GIS, CROPWAT8.0, kutools, ERDAS IMAGINE2014 and PCP. Land suitability was assessed by using GIS model. The most determinant factors of surface irrigation were land use/cover, slope and soil suitability was assessed for this study. Soil suitability was examined in terms of soil depth; texture and drainage for surface irrigation using GIS model. All soil parameters were reclassified based on their suitability for surface irrigation. Land suitability potential was evaluated by overlying soil, slope and land use/cover. Based on this analysis suitability area of surface irrigation is 57,595.23ha (S_1), 21057.87ha (S_2), 39710.62ha (S_3) and 45905.28 ha (S4) from the total study area for surface irrigation. On average, to irrigate this irrigable area 1514.7mm/growing period of water is needed for wheat, maize, onion and tomato.

Throughout the season irrigation water demand was greater than available stream flow. The total irrigable area due to the available stream flow for wheat was about 274.3 ha. From total identified irrigable area for maize, onion and potato the irrigation water demand was greater than the available flow the same as wheat. Therefore, to irrigate the whole potential land the decision maker should take the mitigation measure by increasing upland infiltration, exploring water from ground and construct soil water conservation. Furthermore, other irrigation suitability factors such as soil chemical properties, socio-economic aspects, environmental hazards and ground water investigation should be studied additionally in detail for further irrigation development as well as enhancing sustainability over Awash Arba watershed.

Keywords: *suitability factor, land suitability, irrigation potential, irrigation demand.*

CHAPTER ONE: INTRODUCTION

1.1. Background

Ethiopia is endowed with a substantial amount of water resources. The surface water resource potential is impressive, but only little developed. This renewable surface and usable ground freshwater estimated to 123 billion m^3 and 2.6 billion m^3 respectively (MOWR, 2001a). Furthermore, Ethiopia has huge cultivable lands (30 to 70 Mha), but only about a third of that is currently cultivated (nearly 15 Mha) and current irrigation schemes covering about 640,000 ha across the country (Seleshi B. A. (2010).

Even though, Ethiopia has huge land and water resources but the country 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 (Belete, 2006). 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 consequence, food insecurity often turns into famine with the slightest adverse climatic incident, particularly, affecting the livelihoods of the rural poor. 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).

These methods, however, can be broadly classified into three categories: surface (basin, border, and furrows), sprinkler, and drip /micro irrigation/ methods. Surface irrigation is the application of water by gravity flow to the surface of the field, either the entire field is flooded (basin irrigation) or the water is fed into small channel (furrow) or strip of land (borders). It is the oldest and still the most widely used method of water application to agricultural lands. Surface irrigation offers a number benefits for the less skilled and poor farmers. Under such circumstances, more than 90% of the world uses surface irrigation, even if local irrigators have least knowledge of how to operate and maintain the system (Saymen, 2005).

Furthermore, these systems can be developed at the farm level with minimal capital investment. The major capital investment on surface system is mainly associated with land grading, but if the topography is not too undulating, these costs are not high. Hence, surface irrigation development requires favorable topography and information on land and water resources for proper planning (FAO, 1995).

Therefore, planning process for surface irrigation has to integrate information about the suitability of the land and water resources availability for irrigable areas in time and place (FAO, 1997). Determining the suitability of land for surface irrigation requires thorough evaluation of soil properties and topography (slope) of the land within field (Fasin *etal*, 2008).

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). The amount of runoff in river catchments with limited stream flow data can be determined from runoff coefficient of gauged river basin (Goldsmith, 2000; DFID, 2004; Sikka, 2005).

However, these factors should be assessed in an integrated manner, geo-referenced and mapped for surface irrigation development possibilities. With an adequate database, Geographic Information Systems (GIS) can serve as a powerful analytic and decision-making tool for irrigation development (Aguilar-Manjarrez and Ross, 1995). 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. In this kind of situation, the factors that are involved for irrigation potential assessment such soil, land cover/use; land slope and distance between water supply and suitable command area should be weighted and evaluated by the use of GIS according to their suitability for irrigation.

Therefore, to overcome these uncertainties, this study was carried out by using GIS as a tool for assessing irrigation potential in Awash Arba watershed using input data from soil and digital elevation model (DEM) and geo-referencing 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 in the watershed.

1.2 Statement of the problem

Awash Arba watershed is one of the sub watersheds of Awash basin and flows towards the Middle main Awash River. Planning and decision making for new irrigation development projects requires the systematic assessment of irrigable land together with available water resources. The data required are usually not available in developing countries, and therefore a method will develop for quantifying surface water resources and potentially irrigable land using Geographic Information System (GIS) model and Multi-Criterion Decision Evaluation (MCDE).

In Awash Arba watershed, there is land and water resources availability. Due to the lack of a properly planned idea and lack of potential area assess for using Awash Arba watershed for agriculture purpose, the people living near to the study area cannot use the area for surface irrigation practice. So, the study will give attention to aware the people living near to the study area about the available water and suitable land for surface irrigation on the watershed, which helps finally the people to initiate using the land for surface irrigation practices.

1.3 Objectives of the study

1.3.1 General Objective

The general objective of this study was to assess the surface irrigation potential of Awash Arba watershed and developing maps of the resources using Geographic Information System (GIS).

1.3.2 Specific objectives

To achieve the above main objective this research was focused on the following specific points:

- To assess the potential land suitability for surface irrigation
- To estimate the available water resources for surface irrigation in the study area
- To provide geo referenced maps for land and water resources and
- To estimate irrigation water demand to satisfy the dominant crops

1.4 Research Questions

- How slope, soil, land cover/use and distance between water supply and the potential command area can define potential land suitability?
- How stream flow discharges (obtained from the Ministry of Water Resources) and rainfall data (obtained from NMSA and ILRI GIS database) estimates available water for surface irrigation in the study area?
- How Arc Map software using a geodetic reference system such as WGS-84 (National Imagery and Mapping Agency 2000) provide geo-referenced maps for water and land resources?

1.5 Significance of the study

An irrigation project design which do not consider or taken available water resources data leads to insufficient water resources in the irrigated season. This study has been used to identify and quantify the water resource potential and land suitability in the study area to give good awareness for policy makers, verities of experts and planners for developing short term and long term plan for planning of new irrigation development projects as a source of water.

Generally, the information obtain from the research will assist the decision makers to evaluate existing irrigation schemes, plan future developments of the area, initiated to know and estimate the available water for surface irrigation and suitable sites for water harvesting on the area, which helps finally for assessing the potential land suitability for surface irrigation and improving the agricultural production sustainability.

1.6. Scope of the study

Even if, many problems are exist in the study area, but the research was mainly focused on GIS-based approach for assessment of surface irrigation potential and development of maps for land and water resources and geo-referencing of different parameters with respect to slope, soil, availability of water and land use/land cover of the study area. On the other hand, this study was not incorporated the irrigation water quality, the impact of climate change on surface irrigation sustainability, soil samples and irrigation suitability factors other than slope, soil and LULC. The reason was due to lack of data, lack accessibilities of materials and financial constraints.

1.7. The Thesis Organization

The study is organized in to five chapters. Chapter one is introduction which includes background, statement of the problem, objectives, research questions, significance of the study, and scope of the study. Chapter two contains the detailed cited literature part related to the study. Chapter three focused on material and methods which includes description of the study areas, data collection methods and data analysis techniques. Chapter four contains the result and discussion of the study finding while chapter five includes conclusion and recommendation of the findings.

CHAPTER TWO: LITERATURE REVIEW

2.1 Definition of Irrigation Potential

The definition of irrigation potential is not straight forward and implies a series of assumptions about irrigation techniques, investment capacity, national and regional policies, social, health and environmental aspects, and international relationships, notably regarding the sharing of waters. However, to assess the information on land and water resources at the river basin level, knowledge of physical irrigation potential is necessary. 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. Therefore, physical irrigation potential represents a combination of information on gross irrigation water requirements, area of soils suitable for irrigation and available water resources by basin (FAO, 1997).

2.2 Irrigation Potential in Ethiopia

Ethiopia has 12 river basins which accounts annual runoff volume 122billion m3 of water and 2.6-6.5 billion m^3 of groundwater potential with in an average of 1575 m^3 of physical available water per person per year was estimated (Awulachew et al, 2007) 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 of the country. The earlier reports, for example the (World Bank, 1973) as cited by Awulachew et al, (2005) shows the irrigation potential at a lowest of 1.0 and 1.5 million hectares, and a highest of 4.3 million hectares. According to the Ministry of Agriculture, (1986) as cited by (Kebede Ganole, 2010) the total irrigable land in the country was measured to be 2.3 million hectares. The International Fund for Agricultural Development (IFAD, 1987), on the other hand gives a figure 2.8 million ha. The total irrigable land of Ethiopia is 3.7 million ha of potential had been identified by (MoWR, 2002). Ethiopia has vast cultivable land (30 to70Mha), but currently estimates shows that 15Mha is under cultivation. From this cultivation land 4 to 5% is irrigated with existing equipped irrigation schemes covering about 640,000 ha across the country (Awulachew, S.B et al, 2010). However, the study estimates that total irrigable land potential in Ethiopia is 5.3 Mha assuming use of existing technologies, including 1.6 Mha through RWH and ground water. This means that there are potential opportunities to vastly increase the amount of irrigated land, as detailed below. Most of these figures are derived by adding up the irrigation potential of the country's twelve river basins (Awulachew, et al, 2007). F

Table 2.3. Surface Water and Irrigable Land Potential in Ethiopia. Source:(Awulachew et.al., 2007).

No	River Basin	Catchment Area(km^2)	Small Scale	Medium Scale	Large Scale	Runoff (BM^3)	Irrigable area(ha)
1	Abbay	199,812	45,856	130,395	639,330	54.8	815,581
2	Tekeze	82,350	N/A	N/A	83,368	8.2	82,350
3	Baro-Akobo	75,912	N/A	N/A	1,019,523	23.6	1,019,523
4	Omo-Ghibe	79,000	N/A	10,028	57,900	16.6	67,928
5	Rift-Vally	52,739	N/A	4,000	45,700	5.6	139,300
6	Awash	112,696	30,556	24,500	79,065	4.9	134,121
7	Genale-Dawa	171,042	1,805	28,415	1,044,500	5.8	1,074,720
8	Wabi-Shebele	202,697	10,755	55,950	171,200	3.16	237,905
9	Denakil	74,002	2,309	45,656	110,811	0.86	158,776
10	Mereb	77,121	-	-		0.65	6500
	Total	1,127,371				124.17	3,654,354

Ethiopia, indeed, has significant irrigation potential assessed both from available land and water resources potential, irrespective of the lack of accurate estimates of potentially irrigable land and developed area under irrigation.

2.3 Irrigation Land Suitability Evaluation Factors

Land suitability evaluation according to FAO standards has been applied in many parts of the world, particularly in the developing countries (FAO, 2007b). In Ethiopia, a number of investigations were conducted to evaluate land suitability for crops and irrigation (Agidew, 2015; Alemu et al., 2013; Ayalew, 2014; Girma, Moges, & Quraishi, 2015; Hailu, Kibret, & Gebrekidan, 2015; Liambila & Kibret, 2016; Melak, 2007; Mengesha, 2014; Motuma, Suryabhagavan, & Balakrishnan, 2016; Nahusenay & Kibebew, 2015; Selassie, Ayalew, Elias, & Getahun, 2014; Teka & Haftu, 2012; Worqlul et al., 2017; Yitbarek, Kibret, Gebrekidan, & Beyene, 2013). These studies are inadequate to made decision on proper utilization of resources in Andit Tid watershed, because locally adapted evidence from the combination of topographic, soil, climatic and management factors is needed for proper management decision where the productivity of the land in the study area is limited; this situation also aggravated through short fallow period as a result of uncontrolled grazing (Engda, 2009).

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).

As extensively discussed in FAO land evaluation guidelines (FAO, 1976, 1983, 1985), the suitability of these factors for surface irrigation method and for the given land utilization types can be expressed corresponding to the following suitability classes.

Order S – suitability Classification

S1 (highly suitable): land having no significant limitation to sustained application of a given use.

S2 (moderately suitable): land having limitation which in aggregate is moderately severe for a sustained application of a given use.

S3 (marginally suitable): land having limitation which in aggregate are severe for a sustained application of a given use and will reduce productivity or benefits.

Order N suitability classification

N1 (temporarily not suitable): land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.

N2 (Permanently not suitable): land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land of a given land use. The factors considered for surface irrigation land suitability evaluation are narrated separately in subsequent sub-sections.

2.3.1. 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)

Table 2.4**.** Slope ranges from irrigated land: (FAO, an interactive multi criteria analysis for land resource appraisal, 1996

Slope	Percent (%)	Factor of rating
Horizontal	0-2	0-2
Very flat	2-5	2-5
Flat	5-8	5-8
Steep	>8	>8

2.3.2. 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).

2.3.3. Land cover or land use

Land cover and land use are often used interchangeably. Definitions of land cover or land use in this way provide a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation. Therefore, matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, present possible lands for new agricultural production (Jaruntorn, *et al*., *2004).*

2.3.4. Water availability

It is important to make sure that there will be no lack of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle (FAO, 2001). Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which 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. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length) and thereby develop the irrigation system economical (Silesh, 2000).

2.4. Crop 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. Sileshi Bkele, (2007).

2.4.1. Evapotranspiration (ET)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the top soil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop developed and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. The evapotranspiration (ET) rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month, or even an entire growing period of years. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as a crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, the crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration.

2.4.2 Reference crop evapotranspiration (ETo)

The evapotranspiration rate from a reference surface, not short of water, is called the ETo Reference Crop Evapotranspiration). The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices. As water is abundantly available at the reference evapotranspiration surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman- Monteith method is recommended as the sole method to determine ETo. Moreover, procedures have been developed for estimating missing climatic parameters.

$$ETo = \frac{o.408 \triangle (Rn - G) + \gamma \frac{900}{T+273} u^2 (es - ea)}{\triangle + \gamma (1 + 0.34 u^2)} ----------------- (2.1)$$

Where

ET_O reference crop evapotranspiration [mm/day]

R n net radiation at the crop surface [MJ/day M^3]

G soil heat flux density [MJ/day M^2]

T Mean daily air temperature at 2 m height [^{O} C]

U2 wind speed at 2 m height [m/s]

es saturation vapor pressure [k Pa]

ea actual vapor pressure [k Pa]

es – ea vapor pressure deficit [k Pa]

$\triangle$ Slope vapor pressure curve [k Pa/ ^{O} C]

γ Psychometric constant [k Pa/ ^{O} C]

2.4.3. Crop evapotranspiration under standard condition

The ETc (Crop Evapotranspiration under standard condition) is the evapotranspiration from disease free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the 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.

$$ETc = Kc * ETo ------------------------------ (2.2)$$

Irrigation efficiencies: Efficiency is the ration of the water output to the water input, and is usually expressed in percentage. Input minus output is nothing but losses, and hence, if losses are more, the output is less and therefore, efficiency is less.

Net irrigation requirement: It is an amount of irrigation water required in order to meet the Evapotranspiration need of the crop as well as other needs such as leaching. Therefore,

$$NIR = ETc - Pe + Loss ---------------------------(2.3)$$

Effective precipitation: Out of given precipitation, the only effective part is available for plant use, which is stored as available water in the soil within the root zones of crop grown. The water, which flows away as surface runoff, or percolate below the root zone is lost. Effective rainfall depends on meteorological and non-meteorological parameters. Meteorological parameters are characteristics of rainfall (amount, frequency, intensity and distribution over the area and in time), air temperature, radiation, relative humidity and wind velocity. Other, non-meteorological parameters are: land characteristics (topography, slope, type of use), soil type (depth, texture, structure, bulk density, salt and organic matter content), management factors (type of tillage, degree of leveling, use of soil conditioners, type of layout, bund, terracing, ridging), crops (nature of crops, depth of root system, degree of ground cover, stage of growth, crop rotations) and characteristics of groundwater and irrigation channels(Valher, 2013).

2.4.4. Gross irrigation

To calculate gross irrigation requirement of crops at specified potential irrigable sites, irrigation efficiencies of 54% is used for surface irrigation (FAO, 1989,).

$$GIWR = \frac{NIWR * AREA}{E} ------------------------------(2.4)$$

2.5 Overview of GIS Application

A Geographic Information System (GIS) is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data (Goodchild, 2000). Geographically referenced data are data that describe both the locations and characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface. The ability of a GIS to handle and process geographically referenced data distinguishes GIS from other information systems which are the other information system. It also establishes GIS as a technology important to a wide variety of applications. Clearly, the increased availability of large, geographically referenced data sets and improved capabilities for visualization, rapid retrieval, and manipulation inside and outside of GIS will demand new methods of exploratory spatial data analysis that are specifically tailored to this data-rich environment (Wilkinson, 1996; Gahegan, 1999).

2.5.1. Application of Remote Sensing

Remote Sensing refers to the technique of obtaining information about an object or feature through the analysis of data acquired by a device that is not in contact with the object or feature under investigation (Lille sand and Kiefer, 1994). This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. Remote sensing is a technology that has close tie to GIS. Remote sensing can provide timely data at scales appropriate to a variety of applications. Land cover/use mapping is one of the most important and typical applications of remote sensing (Lillesand, 200). Land cover corresponds to the physical condition of the ground surface.

2.5.2. Review of Commonly Used GIS and Remote Sensing Data.

Geographic Information System (GIS) can integrate Remote Sensing and different data sets to create a broad overview of potential irrigable area. While the remotely sensed image of an area gives a true representation of an area based on land cover / use, grid interpolated climate data can serve many purposes and used as climatic data base where meteorological data from gauging networks are not adequate. The topographic and hydrologic attributes of land and landscape such as slope, aspect and watershed modeling can be derived directly from the DEM. They are point elevation data stored in digital computer files. The detailed review of these data is provided in the following sections.

2.5.3. Spatially interpolated climate data on grids

These data are referred to as the 'WorldClim' database. The World Clim dataset created by (Hijmans *et al*., 2003; Jones and Gladkov, 2003; Parra *et al*., 2004) are used in many applications, particularly in environmental, agricultural and biological sciences (Hijmans *et al*., 2005). With this dataset, several analyses by means of GIS can be performed. These data were compiled based on monthly averages of climate as measured at weather stations from a large number of global, regional, national, and local sources, mostly for the 1950–2000 periods with spatial resolution of 30 arc-seconds or 1 km resolution. World Clim provides high resolution monthly maximum (t_{max}), minimum (t_{min}), and mean temperatures (t_{mean}), and monthly precipitation (prec).

2.5.4. 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 (SRTM) 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 Models (DEM) 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 10-m resolutions. The point elevation data are very useful as an input to the GIS. This data is used to yield important derivative products such as slope, aspect, flow accumulation, flow direction and curvature in process of watershed delineation.

2.6 Assessment of Water Resources

Assessment of water resources can only be done at basin level (FAO, 1997). According to the CA (2007), "river basins are the geographic area contained within the watershed limits of a system of streams and rivers converging toward the same terminus, generally the sea or sometimes an inland water body. Tributary sub-basins or basins more limited in size (typically from tens of square kilometers to 1,000 square kilometers) are often called watersheds (in American English), while catchment is frequently used in British English as a synonym for river basins, watershed being more narrowly defined as the line separating two river basins.

An important consideration in water resource assessment is to estimate how much flow is available at the outlet of river catchment. The volume of water reliably available on an annual or seasonal basis can be determined from the available data in case of gauged rivers and for completely ungauged rivers the runoff coefficient method can be employed (Goldsmith, 2000). According to DFID (2004), when this is the case, then data from the gauging site should be used to estimate mean annual runoff (MAR) at unguaged site, provided that the requirements to be met catchment characteristics should be similar, the distance between the centroids of the catchments should be less than 50 km and at least ten years of mean monthly flows should be available otherwise, the simplest method of estimating mean annual runoff in un-gauged site was established in applying a runoff coefficient to the mean annual rainfall.

To determine the mean annual runoff (mm) at the gauged site

$$MARg = K * MAP \text{ --------------------------- } (2.5)$$

Where:

MARg = Mean annual runoff at gauged site (mm)

MAP = Mean annual Precipitation at gauged site (mm)

$$K = \frac{MARg}{MAP} \text{ ------------------------------ } (2.6)$$

Where:

K = Runoff coefficient at gauged site

To Determine the MAR at ungauged site

$$MARu = K * MAPg -----------------------------(2.7)$$

Where:

MARu = Mean annual runoff at un-gauged site (mm)

The mean annual or monthly runoff depth obtained from equitation at un-gauged site can be converted to mean monthly runoff considering, average areal monthly rainfall and catchment area of both gauged and ungauged sites (Jamshid, 2003). Estimation of areal rainfall over a given catchment is therefore, useful for estimating the total runoff generated from the entire catchment. There are several methods of determining the spatial distribution of rainfall, and all of them yield slightly different variations of rainfall patterns across an area. The Thiessen method is a widely recognized scheme proven to be reasonably accurate for estimating areal precipitation distributions. The primary assumption in the Thiessen method is that areas closest to a precipitation station are most likely to experience similar rainfall conditions to those measured at the station location (Chow *et al.*, 1988). Thiessen polygons can be constructed using the GIS to determine the spatial distribution of storms for computation of spatially variable excess rainfall. Grids of rainfall can also be computed and mapped for selected storm events (Melesse, 2002).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the Study Area

Awash Arba River is one of tributary in Awash basin that flows into Awash river. It is located in the Middle Awash Valley (MAV) of the southern Afar regional state. This watershed is located between 8°46' and 9°51' N Latitude and 39°40' and 40°40' E Longitude and have areas of 1666 Km^2 .The topography of this area is generally flat with a maximum altitude of up to 826.00 m above sea level. The climate of the area is hot and semi-arid.

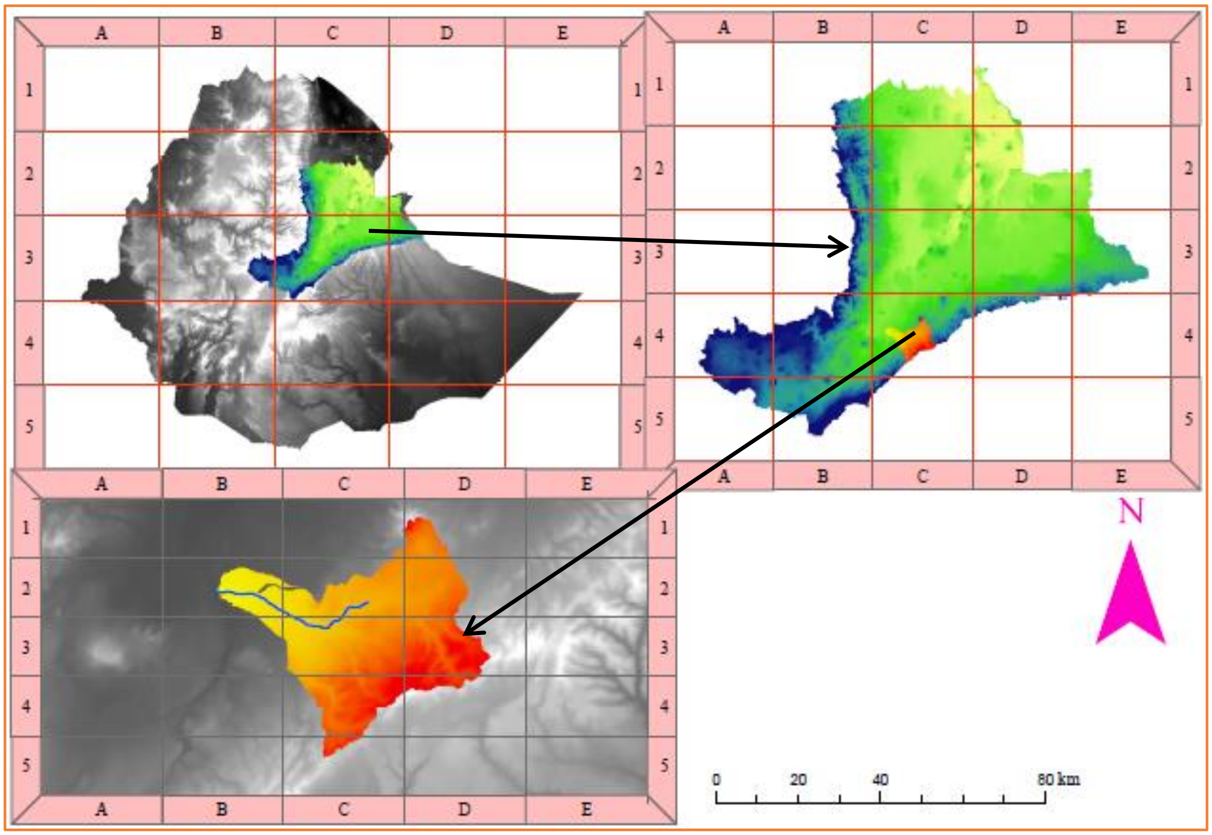

Figure 3.1. Location Map of Awash Arba Watershed

3.2. Topography

Topography is the most determinant factor influencing surface irrigation practice. Land classification factor were evaluated by topographical qualities slop gradient. The elevation of the study area is extends from 783 to 2,648 meters above mean see level. The maximum elevation of Awash Arba watershed is located in the South East and the North part of watershed and also minimum elevation of this watershed is located in the western part of this watershed. Elevation map of watershed is shown below in the Figure 3.2

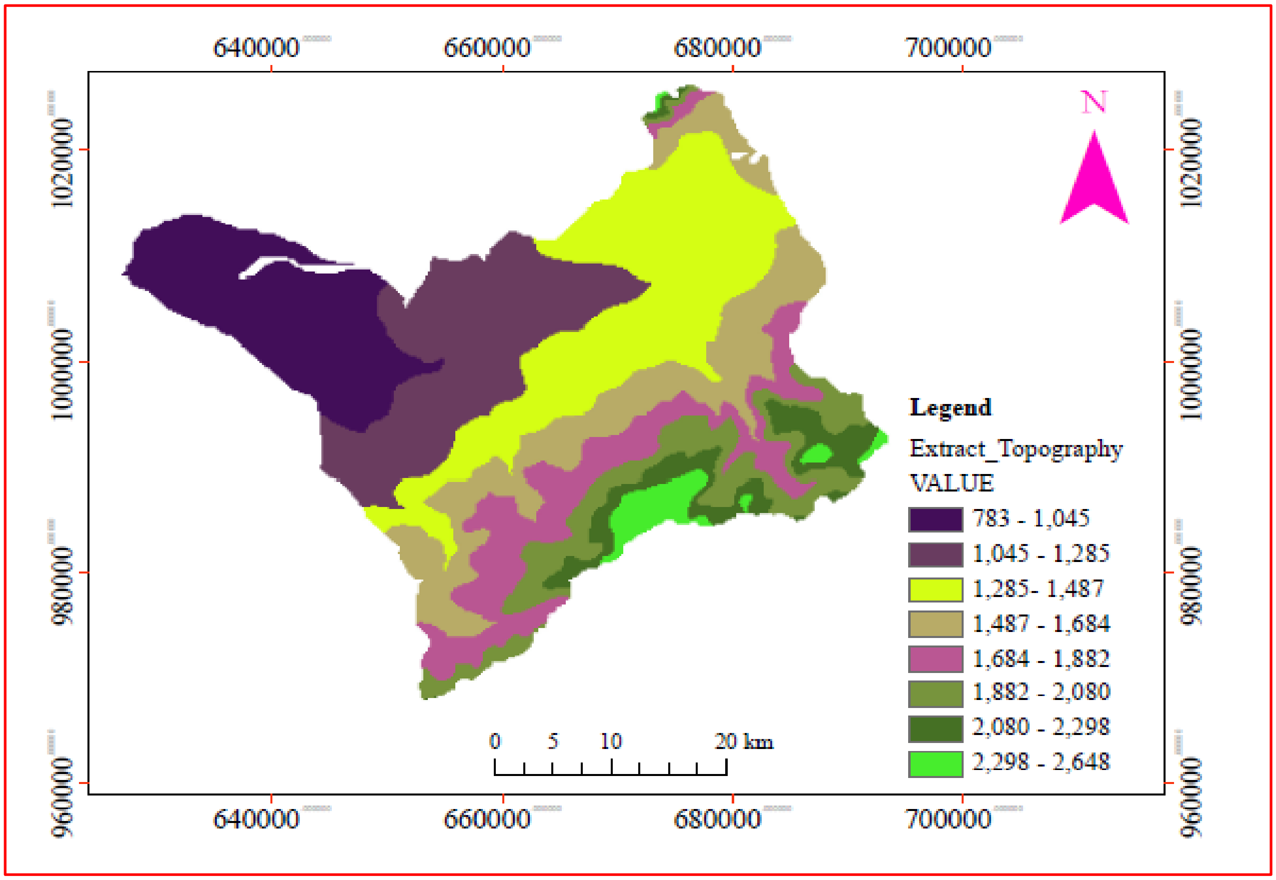

Figure 3.2. Elevation Map of Awash Arba Watershed

3.3. Climate

Climatic zone indicates as altitude increase with decreasing temperature and increase precipitation. Temperature and rainfall are the most important elements in characterizing the climatic condition of a given region. Average annual precipitation varies from 377 to 902 mm and average monthly minimum and maximum temperature is 18.1 °C to 33.3 °C respectively. The altitude of this watershed is varying from 783 to 2,648m.

3.3.1 Temperature

The mean temperature of Awash Arba watershed is in the range 18.1 to 33.3 °C. Monthly mean maximum temperature is varying from 36.7°C in June and 36 °C in May and monthly mean minimum temperature varies from 13.6 °C to 14.5 °C in December and January respectively. Average monthly maximum and minimum temperature for each station from 1997-2021 was used.

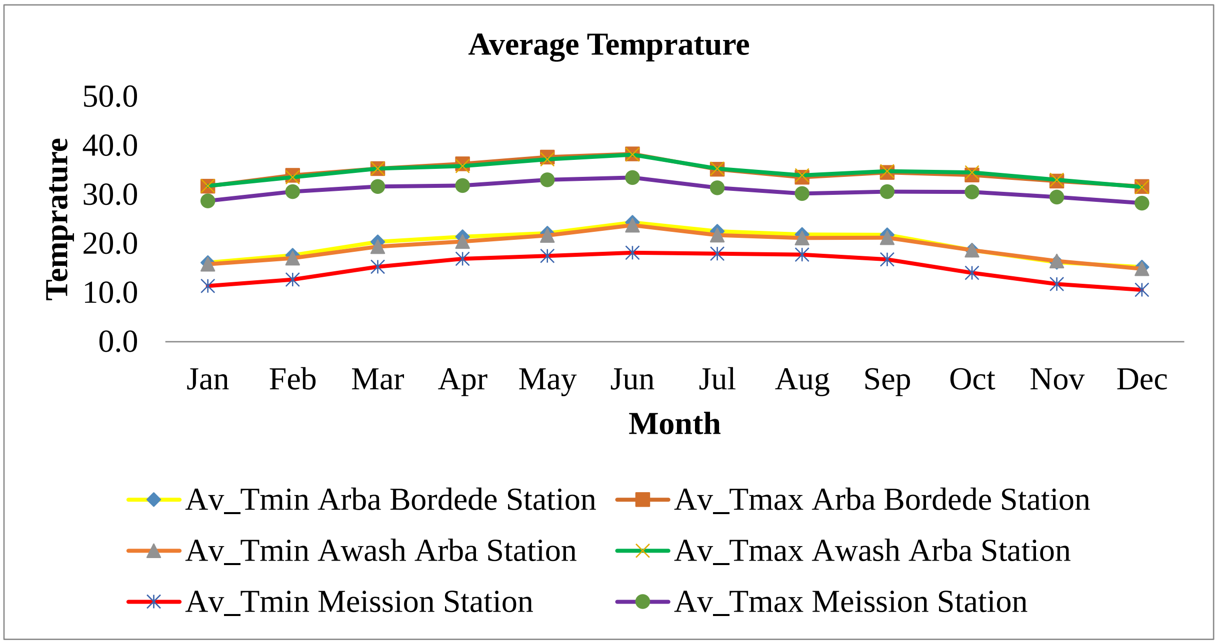

Figure 3.3. Average monthly Temperature of each station

3.3.2. Rainfall

The highest rainfall is occurred in South East part of this watershed. The maximum and minimum annual precipitation of Awash Arba watershed was varying from 901.67 to 377 mm respectively. Average maximum and minimum monthly precipitation is varying from 123.3 mm and 9.9 mm respectively Fig 3.5. As shown in the figure 3.4 maximum and minimum precipitations was record in Meission and Awash Arba station in July and December respectively. Generally, the higher elevation receives higher rainfall.

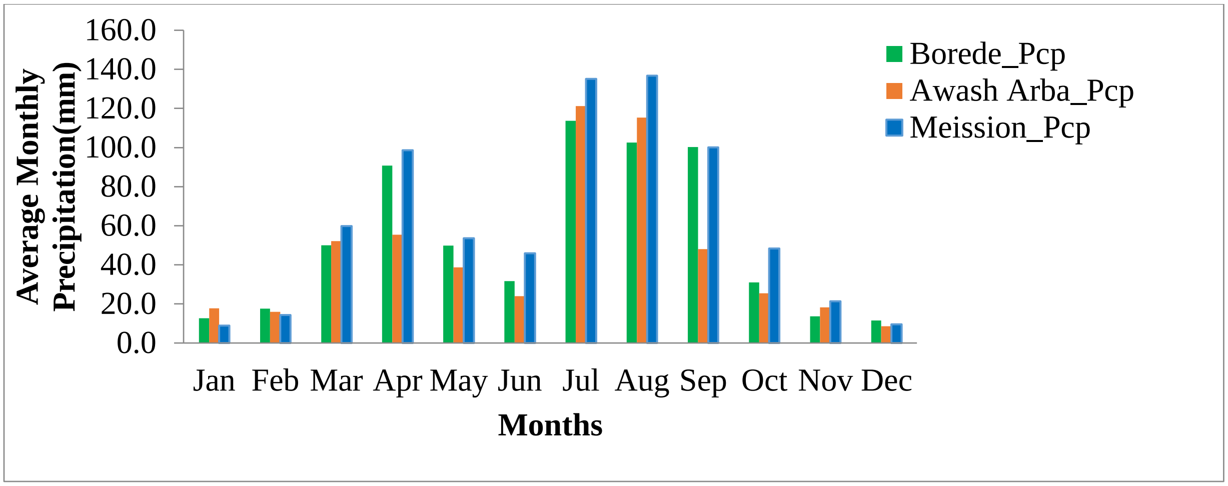

Figure 3.4. Average monthly precipitation of each station

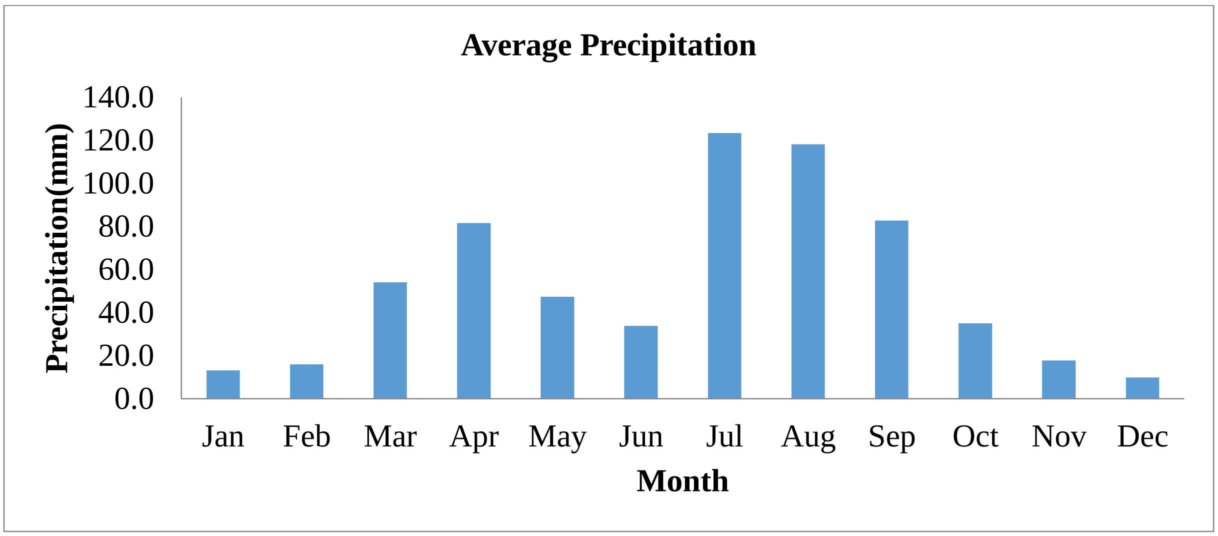

Figure 3.5. Average monthly precipitation of study watershed

3.4. Hydrological characteristics analysis generated for Awash Arba watershed

Digital Elevation Model

Digital Elevation Model is abbreviated as conventionally DEM which is required as an input to calculate the watershed parameters (flow accumulation, flow direction and sub watershed delineation) using Arc SWAT interceded in ArcGIS10.2 watershed delineator tools.

Digital Elevation Model describes the elevation of any point in a given area at a specific spatial resolution as a digital file and which was obtained from earth explorer NASA shuttle radar topographic mission (SRTM) with a resolution of 30 by 30m. DEM is composed of three basic components coordinates in the direction of x (longitude), y (latitude), and elevation. This DEM of the study area was created after two pixel cells downloaded from internet in earth explorer and make mosaic those two pixel cells.

After the pixels mosaic, the unit of the coordinates was converted in to UTM zones. The unit was degree before it converts in to UTM zone 37. This conversion was done for the purpose of area calculation in km^2 as well as slope suitability analysis.

3.5 Watershed delineation

In order to successfully delineate the watershed and sub watershed of the study area, 30 m resolution DEM was used using Arc SWAT model watershed delineation function. Once the DEM was prepared to delineate the watershed, SWAT project setup was created primarily. The watershed delineation process consists of five major procedures. Frist, DEM setup was done, stream definition, outlet and inlet definition, watershed outlet selection and definition and calculation of sub basin parameters. After the DEM setup was completed and the location of the outlet was specified on the DEM. The model automatically calculates the direction and accumulation of the watershed. Subsequently, stream networks, sub watersheds and topographic parameters were calculated using the respective tool. After watershed delineation has been done, the area of sub watersheds was estimated by adding field area and calculates it geometrically. The overall watershed area was estimated by taking the sum of the whole sub watersheds

3.6 Methods of data collection

Both primary and secondary data has been collected to achieve the specify objectives. So, to quantify the amount of available water and land resource potential for irrigation the following data has been collected from the responsible organization like MoIE, NMSA, MoA, woreda agriculture office, farmer’s interview and GPS coordinate from the watershed.

3.6.1. Meteorological data

Meteorological data of Awash Arba watershed such as precipitation temperature wind speed, sunshine were collected from National Meteorological Service Agency (NMSA). These data have been used to quantify crop water requirement of some selected crops using cropwat8.0 software. This software uses the Climate data (Mean daily hours of sunshine, (hours/day), mean monthly wind speed (m/s), monthly precipitation (mm), mean monthly maximum and minimum temperatures, per month (^{o}C), mean monthly precipitation (mm), and agronomic data as an input data for estimation of irrigation water demand. In addition, the rainfall data were used to calculate average areal rainfall using Thiessen polygon extension in ArcGIS. The areal rainfall was used in the estimation of stream flow at un-gauged sites from gauged sites.

Table 3.1. Description and acquisition of climatic data

No	Station name	Location(UTM)		Required data	Elevation (m)
		X	Y		
1	Bordede	652460.77	996246.79	1997-2021	1111
2	Awash Arba	627336.77	1010657.68	1997-2021	826
3	Meiso Mission	692.914.35	1020754.78	1997-2021	1329
4	Werer research center	626314.06	1024907.07	1997-2021	740

Agronomic data, the data was collected from Agriculture development office and from farmers by preparing interview in Amibara woreda and surrounding. Agronomic data include types of crop, cropping pattern (planting date, growth length, (early stage, medium stage development stage and late stage) in days.

Stream flow data: Discharges of gauging stations on Arba Trap River was obtained from Hydrology Department of the Basin Development Authority. The stream flow data were used to assess both water resources potential of the gauged and un-gauged sites for irrigation purpose.

Soil data: FAO/UNESCO- Soil Map of East Africa (1997), available in Arc/Info format with scale of 1:1000000, and soil laboratory results was obtained from GIS and Remote Sensing Department, Ministry of Water Resources**.** These data was used for soil suitability analysis for irrigation.

3.6.2 Materials Used

The materials and data used to assess the irrigation potential of this study area are:

GPS and Digital Camera: GPS and digital camera was used to collect geographic-coordinate values in (UTM, Lat-Long) and field photographs, respectively. The geographic-coordinate values were used as ground control points to locate field photographs on SPOT5 image for supervised classification. The field photographs were used as signature of land cover class which helped as region of interest in supervised image classification.

Topographic maps: Topographic maps of the study area, with a scale of 1:50,000 obtain from the Ethiopian Mapping Agency, were used as a background for the GPS to locate the samples of ground truth data and to use the data during the satellite image classification

DEM (Digital Elevation Model): This data was obtained from shutter radar topographic mission (STRM) with resolution of 30 by 30 m pixel cells. This digital elevation model was an input data for ArcGIS to delineate watershed, to derive slope map of the study area, drainage condition/flow direction and for suitability analysis for surface irrigation.

Software: The software use to prepare and analyze data was ArcGIS10.4, ArcMap, ENVI4.3, CROPWAT4.3, and Global Mapper7.

3.7 Methodology

3.7.1. 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**.**

3.7.2. Consistency of 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 discharge/rainfall data at site of interest against the accumulated average at the surrounding stations is generally used to check consistency of stream flow /rainfall data. To check the degree of consistency, Nemec (1973) provided the value of coefficient of correlation as follows:

$r = 1$: direct linear correlation, $0.6 \leq r < 1$: good direct correlation, $-0.6 < r < 0$: insufficient – reciprocal correlation, $-1 < r < 0.6$: good reciprocal correlation and $r = -1$: reciprocal linear correlation

For the grid interpolated rainfall data, analysis was not done and they were used in further analysis directly. The stream flow and rainfall data are relatively consistent if the periodic data are proportional to an appropriate simultaneous period, and of these data, which are inconsistent, can be adjusted by proportioning, using correlation coefficient, between the stations (selesh, 2000, Moutaz, 2001 and Yarahmad, 2003).

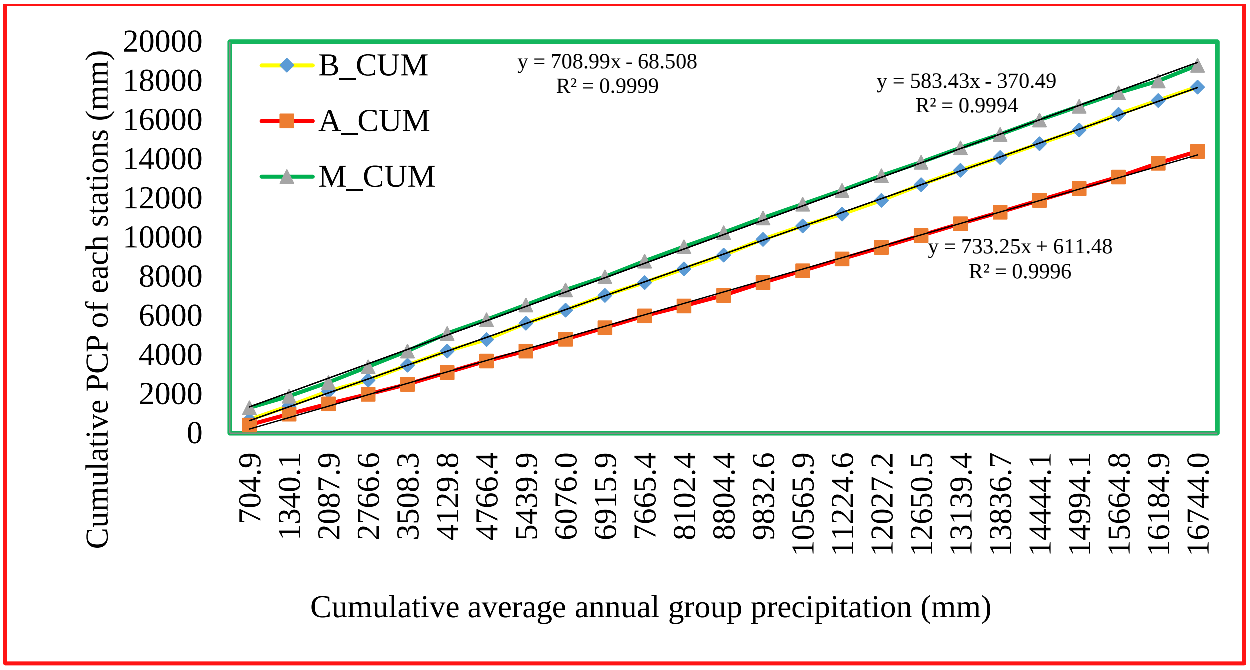

Figure 3.6. Double mass curve of Awash Arba watershed precipitation

3.7.3 Filling missing rainfall data

Missing records of the rainfall stations was estimated by using normal ratio method which is recommend to estimate missing data in regions where annual rainfall among stations differ by more than 10% (Dingman, 2002). This approach enables an estimation of missing rainfall data by weighting the observation at N gauges by their respective annual average rainfall values as expressed by equation 3.1.

$$Px = \frac{Nx}{M}\left[\frac{P1}{N1} + \frac{P2}{N2} + \frac{Pm}{Nm}\right] - (3.1)$$

Where: N1,N2,N3,Nm Normal annual precipitation represent average annual rainfall at station 1,2,3 and respectively P1,P2,P3,and represent annual precipitation data, Px represent missing annual precipitation data at station X and M is the surrounding station

3.7.4. Determination of areal rainfall

There are three a number of stations on Awash Arba watershed and the rainfall data were collected from each station and converted to area rainfall. Rainfall over the watershed was determined by using thienssen-polygon. In this method line are drawn to connect reliable rainfall station and line are bisected perpendicularly to form a polygon around each station. To determine the mean rainfall amount of each station is multiplied by the area of its polygon and sum of the product is divided by the total area. If P1, P2, Pn is rainfall magnitude recorded by station 1, 2, n respectively and A1, A2…An are respective area of thienssen polygon then the average rainfall over the watershed P is given by

$$P = \frac{P1A1 + P2A2 + \cdots + PnAn}{A1 + A2 + \cdots An} ----------------------(3.2)$$

Where, n is number of station

Generally, average yearly and monthly areal precipitation of Awash Arba watershed is 632.83 mm and 52.74 mm respectively.

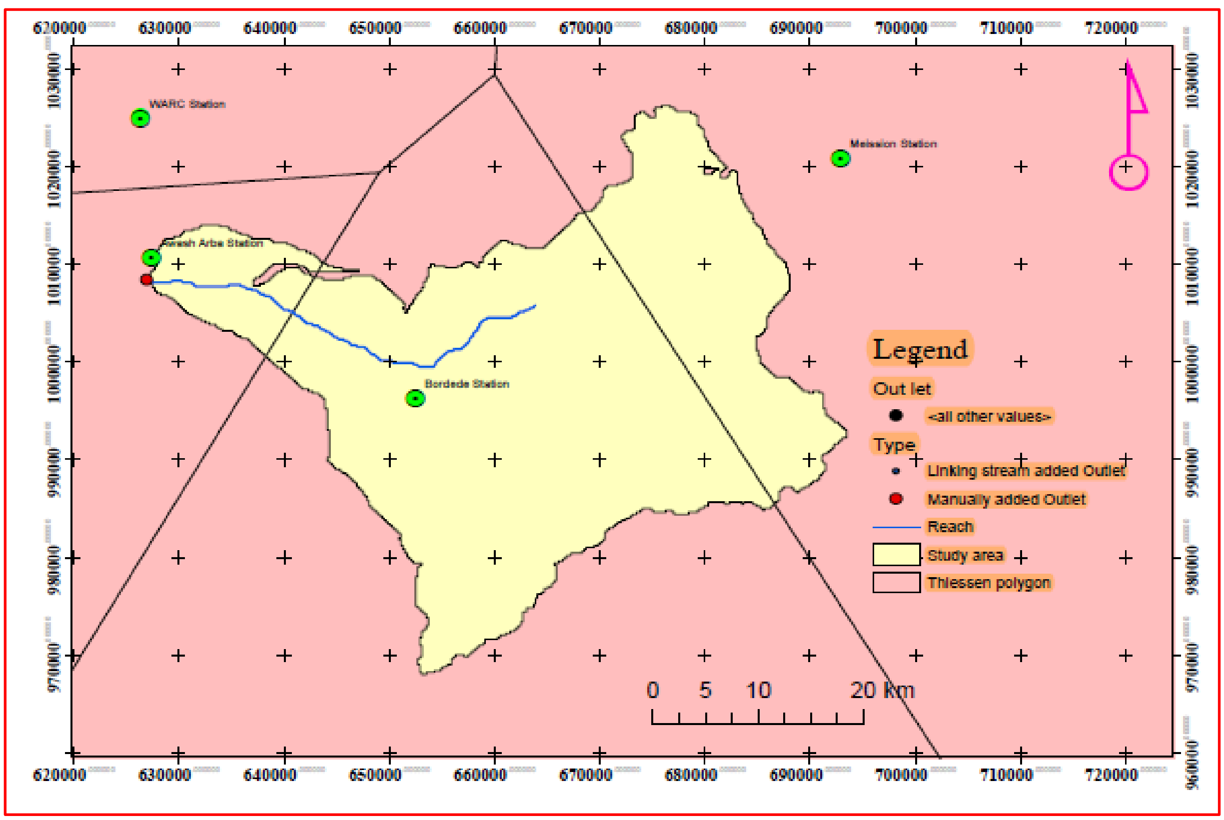

Figure 3.7. Awash Arba Watershed meteorological station Thiessen polygon

3.8. Identification of potential land for irrigation

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

3.8.1 Slope suitability assessment

Land slope is the most important topographical factor influencing land suitability for irrigation. To derive slope suitability map of the study area, digital elevation model of the area was clip from SRTM of NASA satellite with 30 meters resolution by masking layer of Area boundary using Global mapper7 software. Then a slope map of the Area and watersheds was derived using the "Spatial Analysis Slope" tool in ArcGIS. The Slope derived from the DEM was classified based on the classification system of FAO (1996) using the "Reclassification" tool, which is an attribute generalization technique in ArcGIS. The four suitability ranges (S1, S2, S3 & N) was classified for surface irrigation as shown in Table

Table 3.2. Slope suitability classification for surface irrigation

Legend	Slope (%)	Factor rating
1	0-2	S1
2	2-5	S2
3	5-8	S3
4	>8	S4

Source: FAO (1996).

The classified raster data layers were then converted to feature (vector) data layers for the overlaying analysis. Using data management tools in Arc Tool box, generalization of the feature (vector) data layers was performed to make a clearer slope suitability map.

3.8.2 Soil suitability assessment

Soil is the most determinant factor for land suitability evaluation of irrigation in agriculture. Mainly it affects water holding capacity. To identify soil suitability for surface irrigation FAO/UNESCO geomorphology and soil map of Ethiopia (MWIE) were used.

The basic physical soil properties on the study area which is soil suitability for surface irrigation development were used for analysis. Soil physical property includes salinity, organic content (OC), CEC, soil drainage, soil depth, soil texture. From these characteristics the most determinant factors were soil depth, soil drainage and soil texture on the current study was analyzed. The following soil suitability factor rating was used based on FAO Guideline land evolution (FAO, 1991) and FAO land and water bulletin (FAO, 1997).

Table 3.3. Soil suitability factor rating

Factor of rating

Factor	S1	S2	S3	N
Depth	>120	100-120	50-100	<50
Texture class	C,SiC,CL	Si-SCL	SL,LS,FS	Course sand
Drainage	W	MW &i	P	V
Salinity(EC in ds/m	<4	4-8	8-12	>12
PH	<4	4.5-5	4-4.5	>4
CEC (cmol(+)/kg)	>25	15-25	15-5	<5
Sodicity	<10	10-15	15-20	>20

Source: FAO guideline for land evaluation, (1976, 1979 and 1991)

CEC = Cation Exchange Capacity, ESP = Exchangeable Sodium Percentage, EC = Electrical Conductivity Generally, soil vector layers were converted to raster layer using conversion tool- to raster-feature to raster. The rasterized Soil map of the study area were reclassified based on soil depth, texture, and soil drainage. By using Weighted overlay tool from spatial analysis tool-overlay- Weighted Overlay of three determinants reclassified raster soil map were performed to determine soil suitability for surface irrigation. Then the new value was reassigned for each soil factor. The new value were given based on common evaluation scale factor rating from 1to 4 for weighted overlay analysis. 1 represent highly suitable. 2 represent moderately suitable, 3 represent marginal suitable etc.

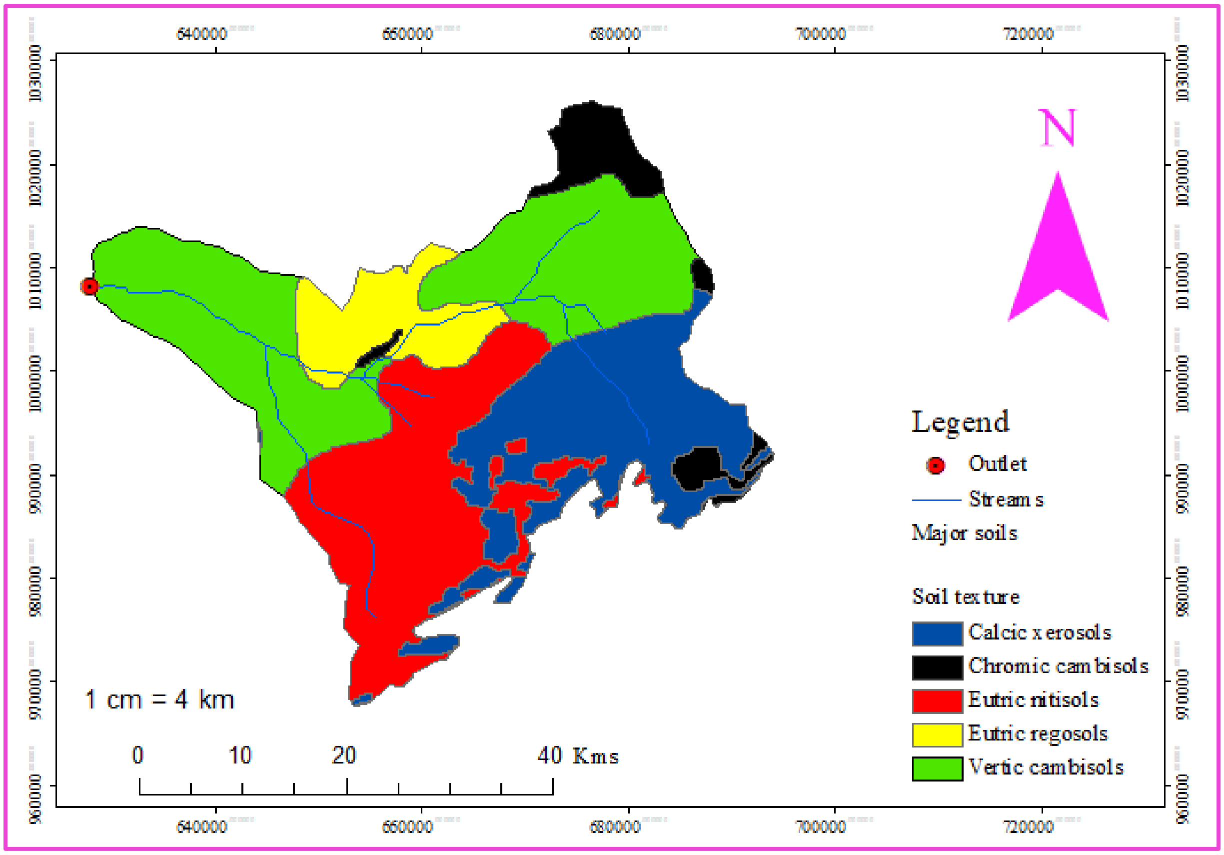

Figure 3.8. Soil types map of Awash Arba watershed

3.8.3. Land cover/use assessment

Land cover/use of the study area is also one of the factors, which was used to investigate the land suitability for irrigation. The LULC map of the study area was derived from the satellite image. This image was used to develop only the LULC map of the study area. Then the watershed was ranked based on the importance of surface irrigation potential by using ERDAS IMGINE2014 software program.

Land cover/use usually requires multi-temporal images to identify it successfully. Land sat8 image was used for the study area which was taken from January 2019 to December 2020.The format of the image was .Img which could be imported in to ERDAS through fit to frame. Then, the true color composite images were created by layer stacking spectral bands which were mostly close to the range of vision of the human eye and it was cloud free for LULC analysis. Band-5, Band-4 and Band-3 where used for the analysis. The classification was supervised instead of unsupervised and has scale of 1:100,000.

Image pre-processing

Successful identification of land cover usually requires multi-temporal images. Unfortunately, the SPOT image for the study area was available only from January 2019 to December 2020. The format of this image was .Img, which could be imported into ERDAS directly. The SPOT images were geo-referenced by ancillary data such as topographic maps and geographic coordinates of the study area. Then true color composite images were created by combining the spectral bands that most closely resemble the range of vision of the human eye which in the SPOT images are normally used for land cover analysis.

Image classification

There are two approaches to extract spectral information: the supervised and unsupervised classification (Richards, 1986). Unsupervised classification is the method in which image pixels are assigned to spectral classes without the user having previous knowledge about the study area whereas, supervised classification is a method that involves selection of areas in the image, which statistically characterize the categories of interest. Prior to the field work, unsupervised classification from the SPOT image was conducted to understand the general land cover classes of the study area. Based on results from unsupervised classification and information from topographic map of the study area, sample training sites were selected to collect geographic coordinates and field photographs during the field work. The geographic coordinate values of field photographs were then added to the SPOT image by Ground Control Points Selection dialog box in ERDAS. This process, therefore, establishes the framework of the GCPs positions of the pixels for output image. The problem then is to decide how best to examine the different land cover signatures at pixels in the image and comparing field photographs of the same GCPs locations with the unclassified image. This information was then used in the selection region of interest for the supervised classification. By using supervised classification with maximum Likelihood method, seven land cover classes were classified for the study area except towns, which were not separable and they were classified by masking using their polygon layers.

Compilation of final land cover/use map

Classified images require post-processing to generalize classes for export to image-maps and vector GIS. ERDAS post classification tool, majority analysis was applied to generalize image classification. Then classification to vector tool was used to convert classification results to ERDAS polygon vector layers (.evf files) and then exported to shape files, Arc GIS 10.4 - compatible file set. The classification images have had a vector layer for each selected class. Due to higher spatial resolution of SPOT image, a countless of very small polygons were created in classified image.

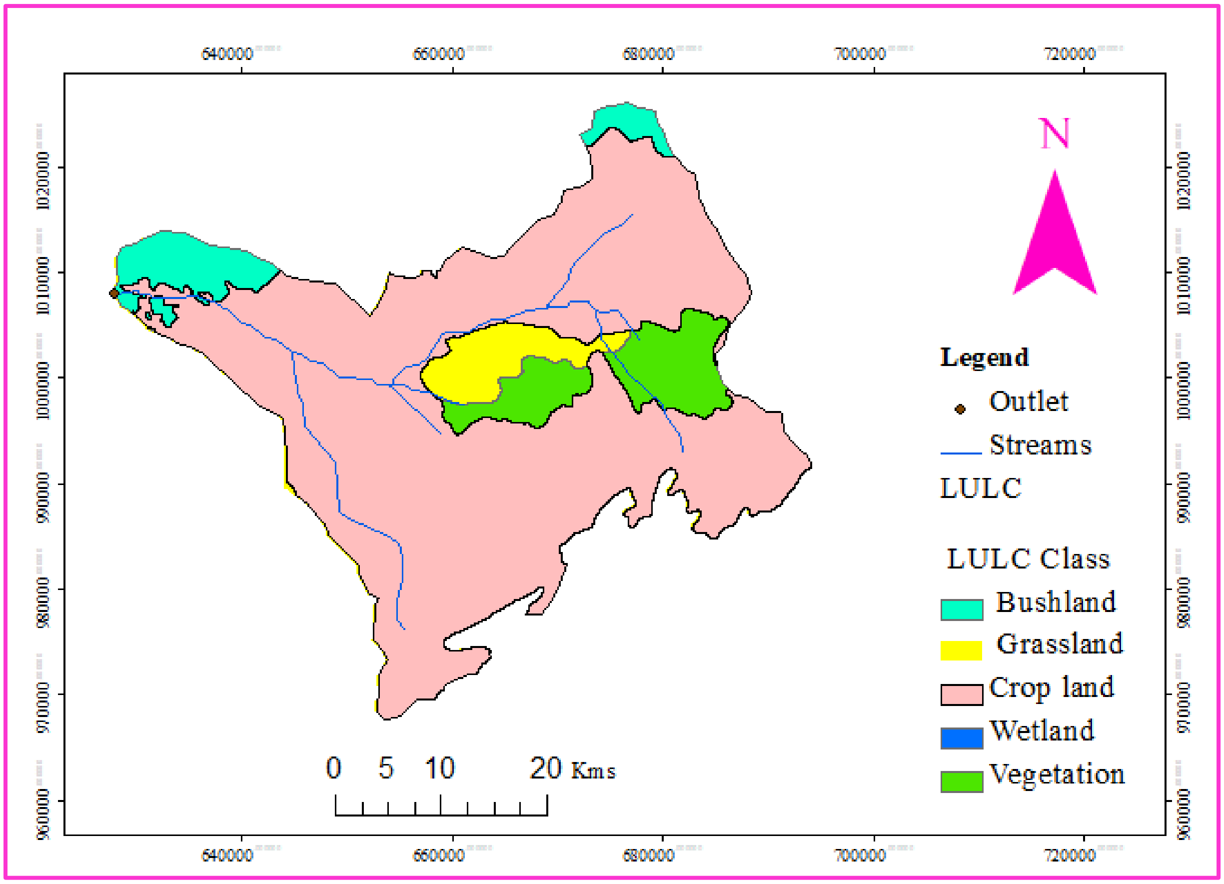

Figure 3.9. LULC map of Awash Arba watershed

3.9. Estimating Surface Water Resources Availability

The available surface water of the catchments was estimated using stream flow discharges (obtained from the Ministry of Water and Energy) and rainfall data (obtained from NMSA and ILRI GIS database). The stream flow data of gauged rivers in the sub basin were used to estimate surface water resources at the site.

3.10. Providing geo-referenced map of water and land resources

A Geographic Information System (GIS) is computer software use for capturing, storing, querying, analyzing, and displaying geographically referenced data (Goodchild, 2000). A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. The map represents geographic information as a collection of layers and other elements in a map view. So, using GIS software geo-referenced map of water and land resources was provided.

3.11. Irrigation Water Demand

To determine irrigation water demand some selected crops over the watershed like wheat, maize, onion and tomato were identified in the study area. Crop distribution on the study area was weighted based on their productivity, farmers' preference and profit. Agricultural practice on the study area has double cropping such as rainfed agriculture and traditional irrigation agriculture in some parts of the study area.

Gross irrigation water demand: Irrigation water demand for each selected crop was determined by using Awash Arba Meteorological Station. Since, Awash Arba station has full metrological data which is an input for CROPWAT8 software.

CROPWAT software takes assumption, 100% efficiency and 24 hours irrigation duration for the calculation of ETc/CWR. But it is impossible in real-world. According to FAO Irrigation Water Management guideline, FAO, 1989 in the study area application efficiency (Ea) 60% was assumed for surface irrigation development. Conveyance efficiency (Ec) of 90% was assumed since there will be uninterrupted supply of irrigation water with no significant change in flow according to FAO irrigation and drainage paper no 24, (FAO, 1992).

Therefore, the overall irrigation efficiency of the scheme was calculated using the recommended formula by FAO irrigation and drainage paper no.24 and it was 54%. Additionally, the CROPWAT software assumed 24 hours of irrigation time per day which was practically difficult so, irrigation hours of 8 hours/day were assumed. By reducing the efficiencies and irrigation hours over all irrigation efficiency of the scheme were reduced from 100% to 54%. As a consequence, application rate of the scheme was increased.

Irrigation water demand was be estimated by using CROPWAT8.0 software. This software use input data such as climate and agronomic data. The water requirement of a crop depends on the climate variability. Within the same condition different crops require different amount of water and the quantities of water used by particular crop vary with its stage of growth. Initially during seeding, developing and early growth a crop uses water at a relative slow rate. The rate will increase with growth of crop reaching the maximum in most crops as it approaches flowering and then decline towards maturity.

$$ETc = Kc * ETo \text{ --------------------------------- } 3.3$$

ETO is the rate of evaporation from an extensive surface of 8-15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and with no shortage of water. It is a climatic parameter and can be computed from weather data (i.e. temperature, humidity, wind speed, sunshine hour). ETo expresses the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors. For the purpose of calculating ETo Awash Arba meteorological station had been used. There are different formulas to calculate ETo, but Penman-Monteith method is considered to be the most accurate method for estimating ETo, though it requires relatively more data than others. The method is considered to offer the best results with minimum possible error in relation to a living grass reference.

After determining the reference potential evapotranspiration by penman method, the next step is calculating crop water requirement/design supply for the scheme. The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well fertilized crops, grown in large fields under optimum soil water conditions and achieving full production under the given climatic conditions. The values of ETc and CWR (Crop Water Requirements) are identical, whereby ETc refers to the amount of water lost through Evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss. ETc can be calculated from climatic data by directly integrating the effect of crop characteristics into ETo. Experimentally determined ratios of ETC/ETo, called crop coefficients (Kc) are used to relate ETc to ETO. ETc was calculated using FAO Crop Wat version 8. Kc values presents relationship between reference ETO and crop evapotranspiration. The values of kc are varying with the crop, its stage of growth, growing season and the prevailing weather condition.

$$\text{NIR} = \text{ETc} - \text{Pe} ---------------------------------3.4$$

Effective rain fall (Pef) 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 does not include precipitation loss due to deep percolation below the root zone. It is calculated using the following formula on FAO Cropwat version 8. Effective rain fall (Pef) = (Total rain fall*0.6) -10 when total rain fall is < 70 mm/month Effective rain fall (Pef) = (Total rain fall*0.8) - 24 when total rain fall is > 70 mm/month Then, gross irrigation water requirement was computed using the following formula;

$$GIWR = \frac{1}{E}(NIR * Acrop) ----------------------------3.5$$

Where;

GIWR – is Gross irrigation water requirement (M^3/month)

NIR – is Net irrigation water requirement (M^3/month)

Acrop – is the potential irrigable area to be cultivated with selected crop (ha)

E – Is Irrigation efficiency (%)

The irrigation efficiency 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 part of the intake water is lost during transport through the canals and in the fields by the evaporation, infiltration and others. The remaining part is stored in the root zone and used by the crop. The irrigation efficiency is computed by the following formula.

$$E = \frac{Ec * Ea}{100} ----------------------------------3.6$$

Where;

E - Is Irrigation efficiency (%)

Ec - is Conveyance efficiency (%)

Ea – is Field application efficiency (%)

The conveyance efficiency is the ratio of the quantity of water supplied to the fields out of the quantity of intake water from the water source. It represents the efficiency of water transport in the canals. The field application efficiency is the ratio of the quantity of water used for the growth of the crop out of the quantity of water supplied to the fields. It represents the efficiency of water application in the field. The field application efficiency mainly depends on the irrigation method and the level of farmer practice. Then, for the current study, conveyance efficiency (Ec) is assumed to be 90% since there will be continuous supply of irrigation water with no substantial change in flow (FAO, 1992). Field application efficiency was assumed to be 60% since the method of irrigation proposed to be used is surface irrigation with furrow method (FAO, 1989). Therefore,

$$E = \frac{90\% * 60\%}{100} = 54\% ----------------------------3.7$$

CAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Slope suitability

Slope is one of the parameter in determining surface irrigation development potential. The raster DEM of the study area was clipped and then slope was generated on spatial analysis tool – surface –slope. Slope suitability was categorized highly suitable, moderately suitable, marginal suitable and not suitable. Based on this classification the following result was found in the table 4.1. From table 4.1, shows 54.85% of the study area was under highly suitable and covers the area from the total of the study area of land was 90,104 ha. The land which covers 49,748 ha (30.28%) is moderately suitable, the area covered by 6,088 ha (3.71%) is not suitable and 18,329 ha (11.16%) is marginal suitability. Slop distribution of the land was analyzed in Arc GIS by importing raster DEM into suitability model of Arc GIS. Then this raster grid slope was reclassified and converted to feature.

Table 4.1. Result of slope suitability of Awash Arba Watershed

No	Slope range	Slope suitability	Area(ha)	Area (%)
	<2	Highly suitable	90104	54.85
	2-5	Moderately suitable	49748	30.28
	5-8	Marginally suitable	18329	11.16
	>8	Not suitable	6088	3.71
Total			164,269	100

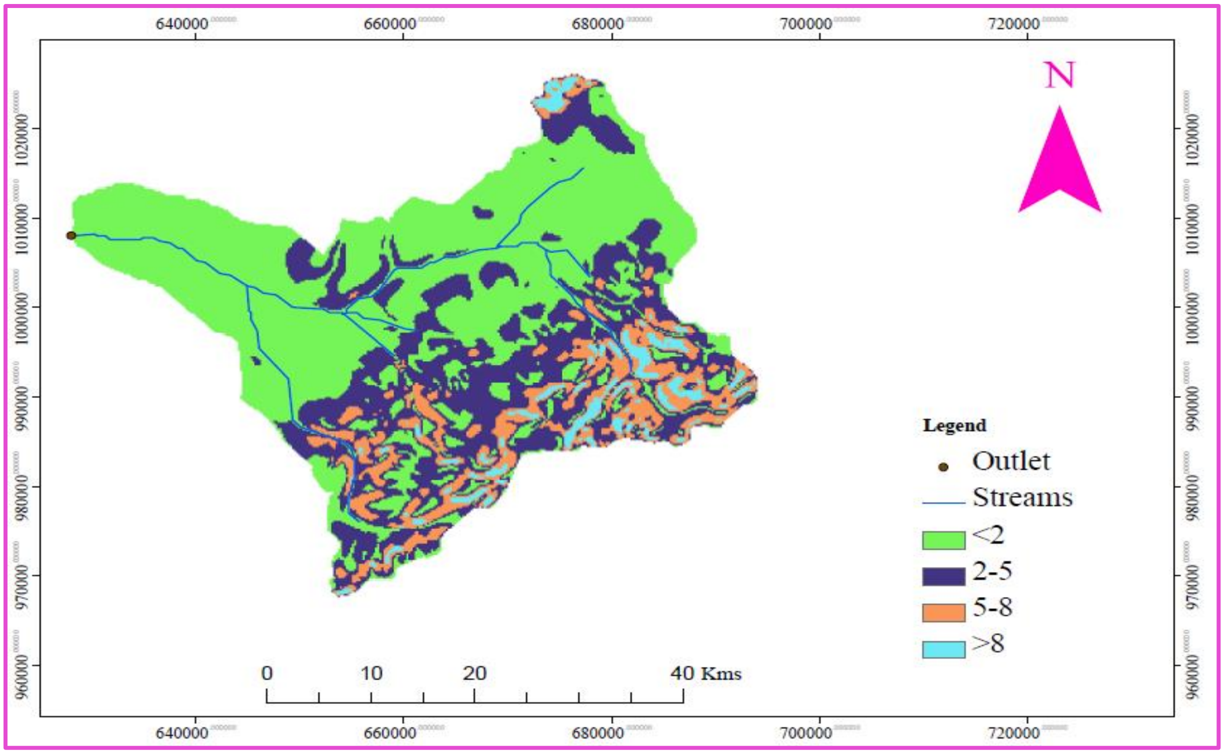

Figure 4.1. Distribution map of slope suitability range

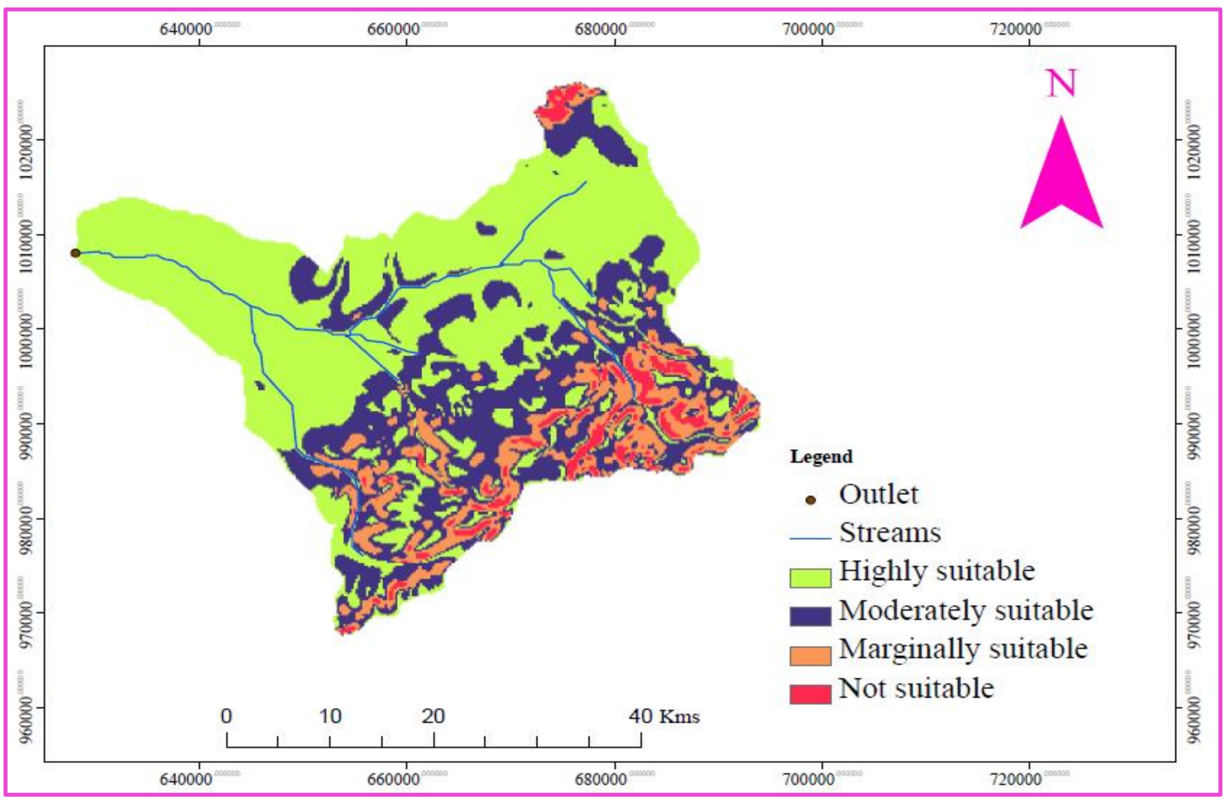

Figure 4.2. Slope suitability class map of the study area

Slope is one of the parameter in determining surface irrigation development potential. The raster DEM of the study area was clipped and then slope was generated on spatial analysis tool – surface –slope. Slope suitability was categorized highly suitable, moderately suitable, marginal suitable and not suitable. Based on this classification the following result was found in the table4.1. From table 4.1, shows above 54.85% of the study area was under highly suitable and covers the area from the total of the study area of land was 90,104 ha. The land which covers 49,748 ha (30.28%) is moderately suitable, the area covered by 6,088 ha (3.71%) is not suitable and 18,329 ha (11.16%) is marginal suitability. Slop distribution of the land was analyzed in Arc GIS by importing raster DEM into suitability model of Arc GIS. Then this raster grid slope was reclassified and converted to feature.

4.2. Land use/Land cover suitability

A certain illustrative points supposed to represent the various land cover classes were taken using GPS at the field visit for the accessible places. These points were used to sample representative signatures for the various land cover types identified during the field visit. Following this, supervised land use/land cover classification has been carried out using ERDAS Imagine 2014 version software from Landsat8 satellite image of the year 2019.

Accordingly, five land use/land cover types were identified. These are; bush land, grass land, vegetation land, crop land and wet land. As per the results presented in the table 4.2 Crop land accounts for the large part of the area (47.915%) and the other land use/land covers types accounts the rest part of the area as follow; vegetation land (6.727%), bush land (36.82%), grass land (8.188%) and wet land (0.346%).

Accordingly, such class's crop land and grass lands were classified as highly suitable for irrigation development. These land use land cover types were account about 56.1% of the area. The bush land use/land cover types identified in the area were considered as moderately suitable for irrigation which accounts for 36.82 % of the area. Other land use land cover types in the area are wet land and vegetation land were categorized under non-suitable for irrigation development accounts only about 7.07%.

Table 4.2. The watershed LULC area coverage result

No	LULC Class	Area (ha)	Area (%)
1	Bush land	60,485	36.82
2	Grass land	13,451	8.188
3	Crop land	78,711	47.915
4	Wetland	570	0.346
5	Vegetation	11,052	6.727
Total		164,269	100

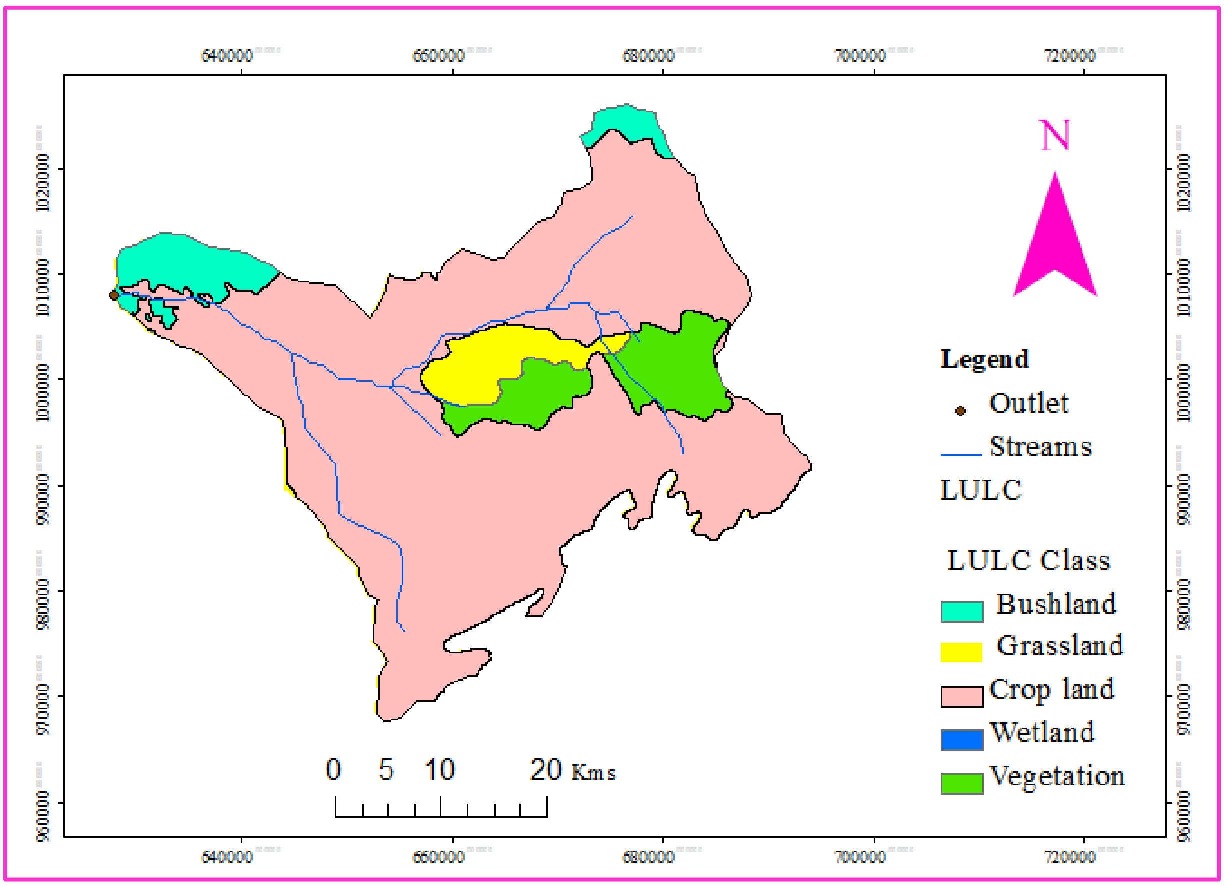

Figure 4.3. Distribution of Land use land cover map of the study area

Accordingly, the rasterized LU/LC map of the area was reclassified in to three suitability classes (highly suitable, moderately suitable and not suitable classes) and used in the suitability to identify potentially irrigable sites being with the other parameters.

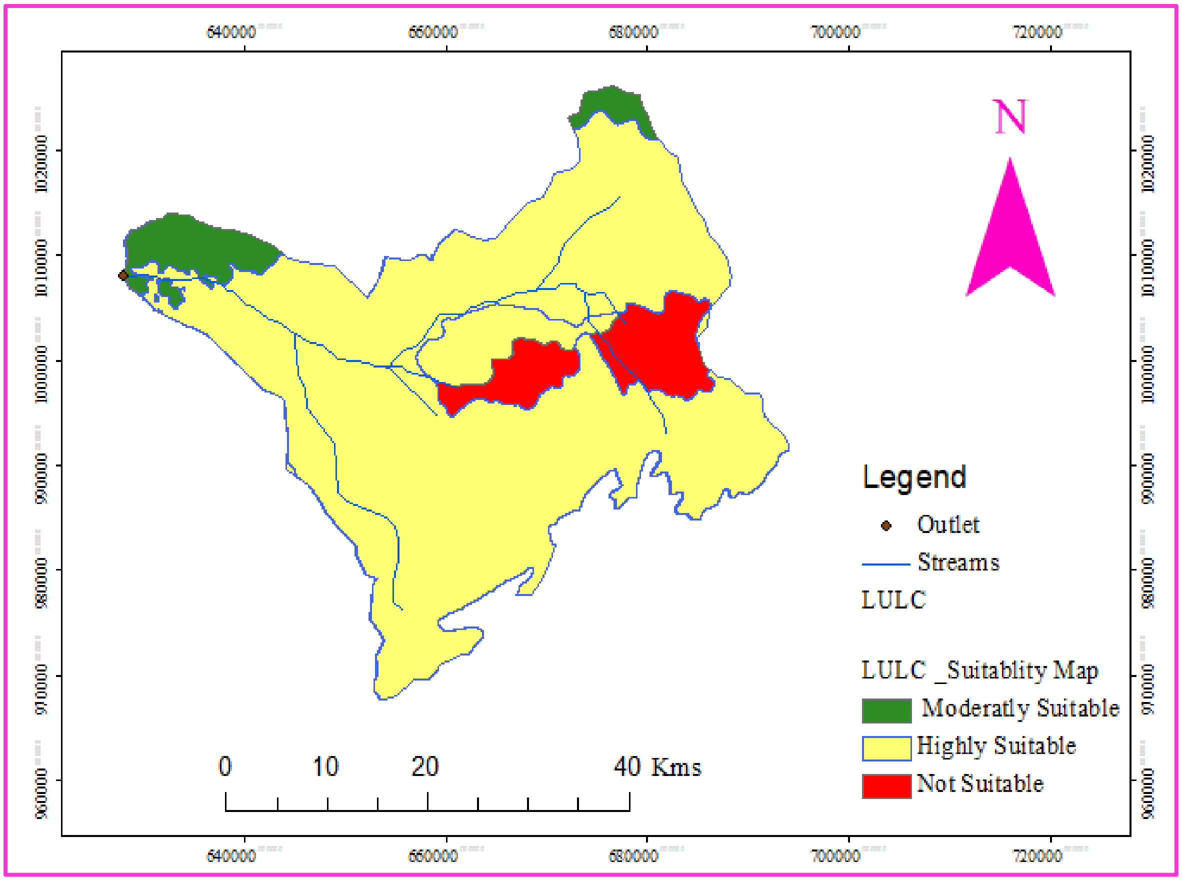

Figure 4.4. Distribution of LULC map suitability of the study area

4.3. Soil suitability for surface irrigation

In case of soil suitability there are different factors that affect water holding capacity infiltration and drainage of the soil. To develop surface irrigation with in the study area the most determinant factor are soil depth, soil drainage, and soil texture were assessed.

4.3.1. Soil Texture Suitability

Table 4.3.Textural suitability of the study area

No	Texture	Suitability class	Area (ha)	Area (%)
1	C	Highly suitable	57,826	35.2
2	SL	Not suitable	14,522	8.8
3	SCL	Marginally suitable	9,991	6.1
4	S	Not suitable	38,269	23.3
5	CL	Moderately suitable	43,661	26.6
Total			164,269	100

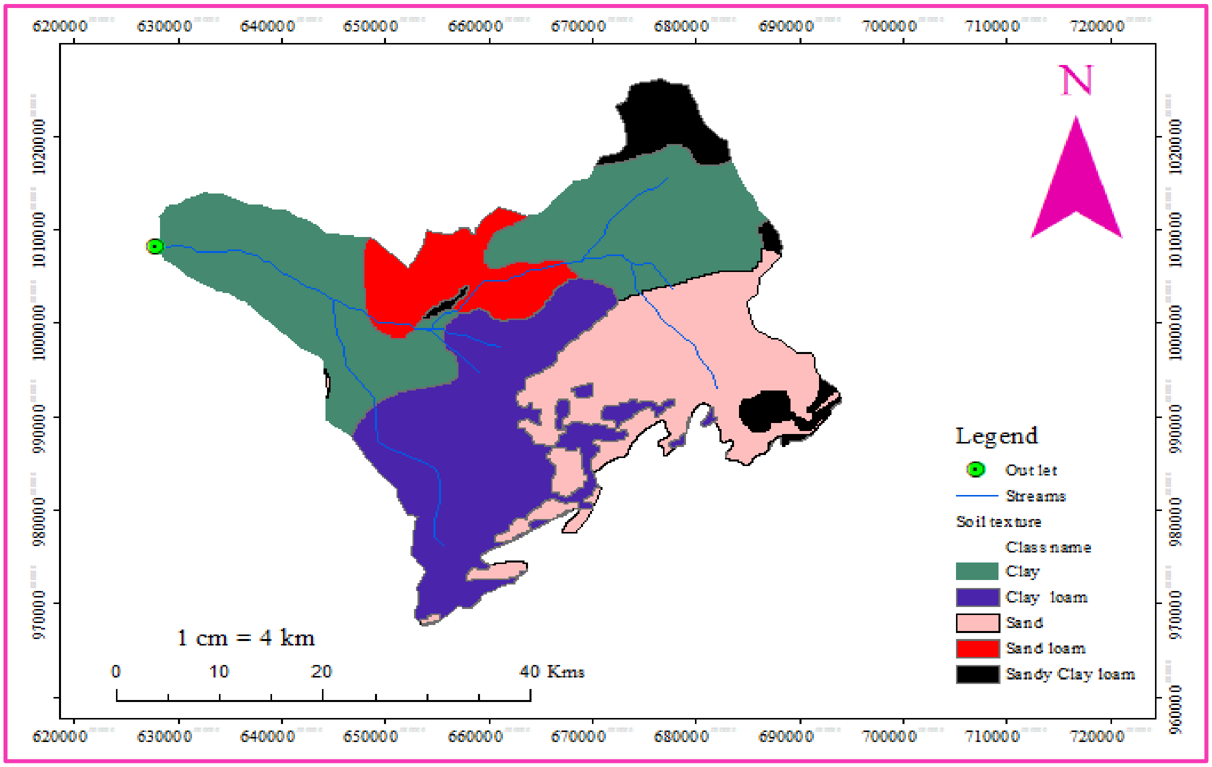

Figure 4.5. Soil textural class map of the study area

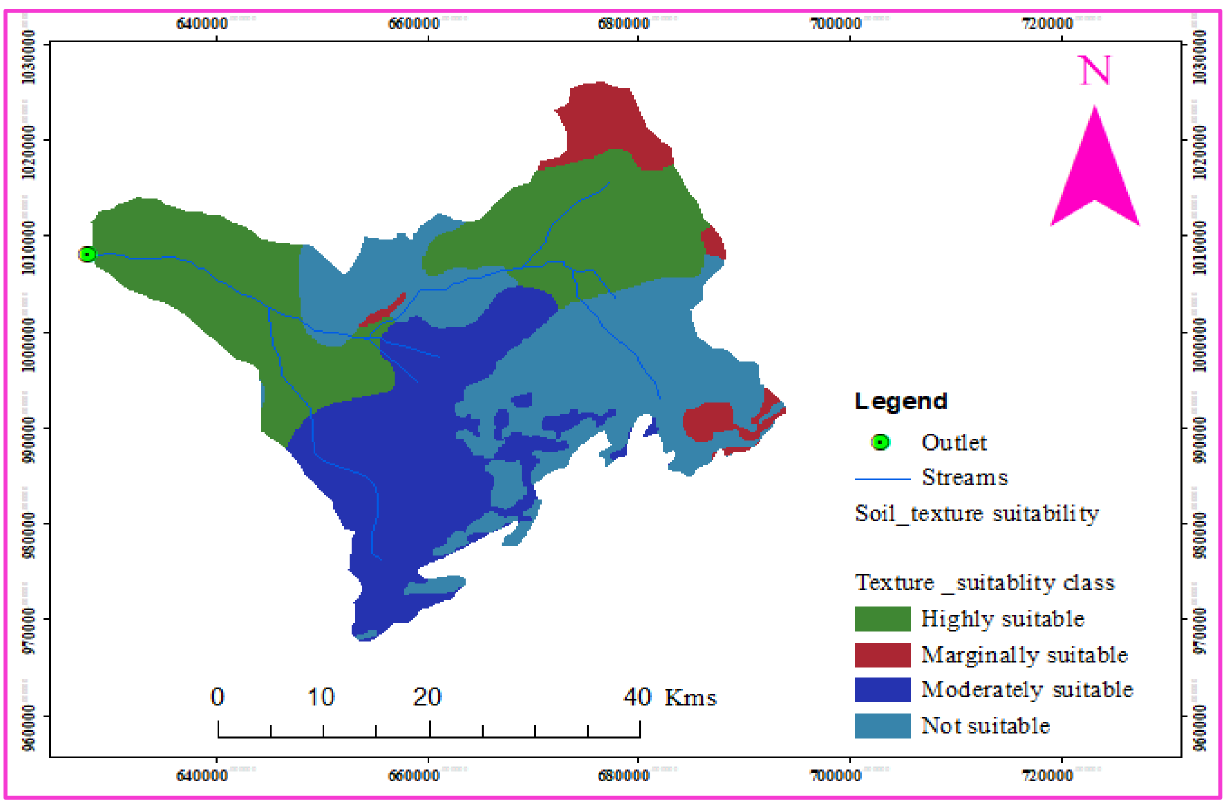

Figure 4.6. Soil textural suitability map of the study area

Soil texture is relative proportion of sand silt and clay in the soil and it is one of the physical characteristics of soil that affects infiltration rate and water holding capacity of soil. Fine texture soil is high water holding capacity and low infiltration rate and course texture soil is low water holding capacity with high infiltration rate. The current textural class was investigated on the study area vary from clay, clay loam, sand and sand clay loam. The textural class was analysis on FAO, 1988 Awash basin master plan. Soil textural class has a great important role in nutrient management by storing nutrient. Suitability of textural class of the study area is shown above in the Table 4.3. The evaluation of textural class of suitability for surface irrigation development on the study area 6.1% is marginal suitable, 32.1% is under not suitable, 26.6% moderately suitable and 35.2% is highly suitable for surface irrigation development. Under this analysis most of the study is highly suitable for irrigation due to textural class. Textural suitability map and class of the study was generated and given Figure 4.6 & 4.7 respectively

4.3.2. Soil depth suitability

The soil depth variation from place to place determines the suitability of surface irrigation development. This suitability factor was found from the geomorphology study and legend map of FAO (1988). Once the parameter interpreted from the source, it was analyzed in GIS environment. Then, soil depth was classified into four classes which are ranging from deep to very deep and shallow to very shallow.

Table 4.4**.** Result of soil depth suitability of the study area

No	Texture	Suitability class	Area (ha)	Area (%)
1	Very deep	Highly suitable	57,826	35.2
2	Shallow	Not suitable	24,513	14.9
4	Very shallow	Not suitable	38,269	23.3
5	Deep	Highly suitable	43,661	26.6
Total			164,269	100

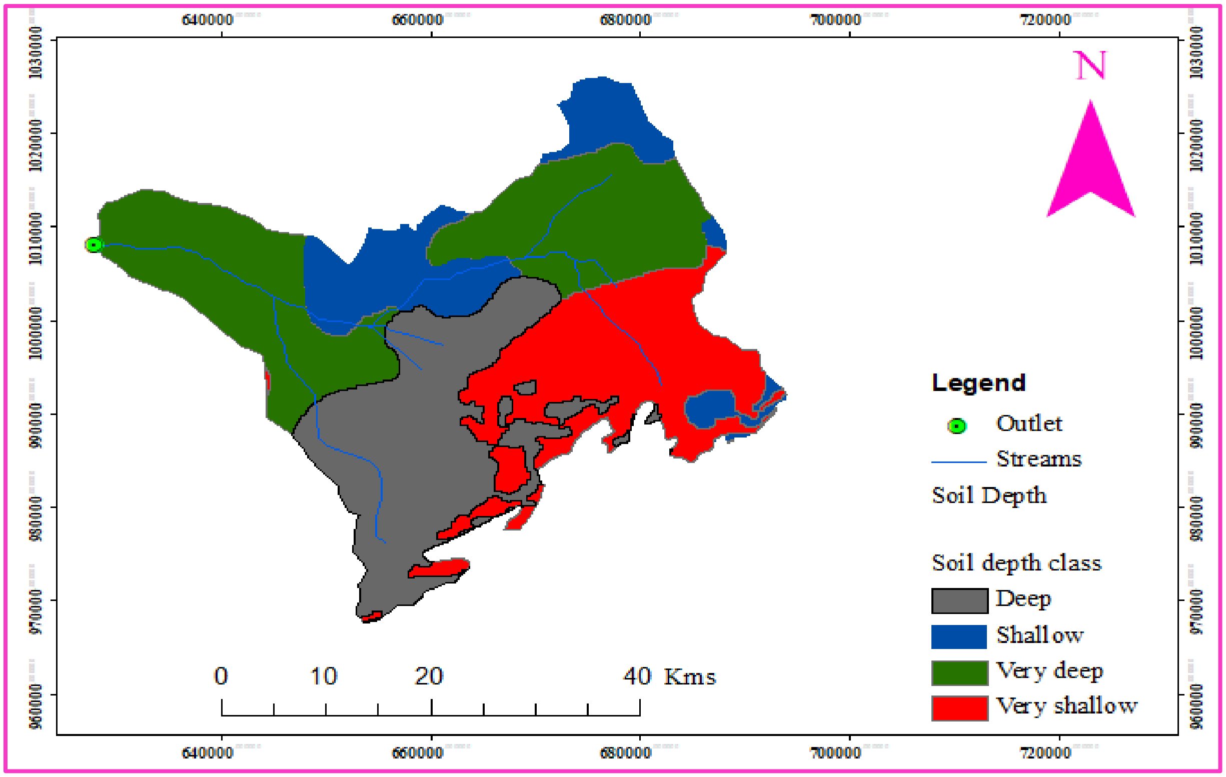

Figure 4.7. Soil depth class map of the study area

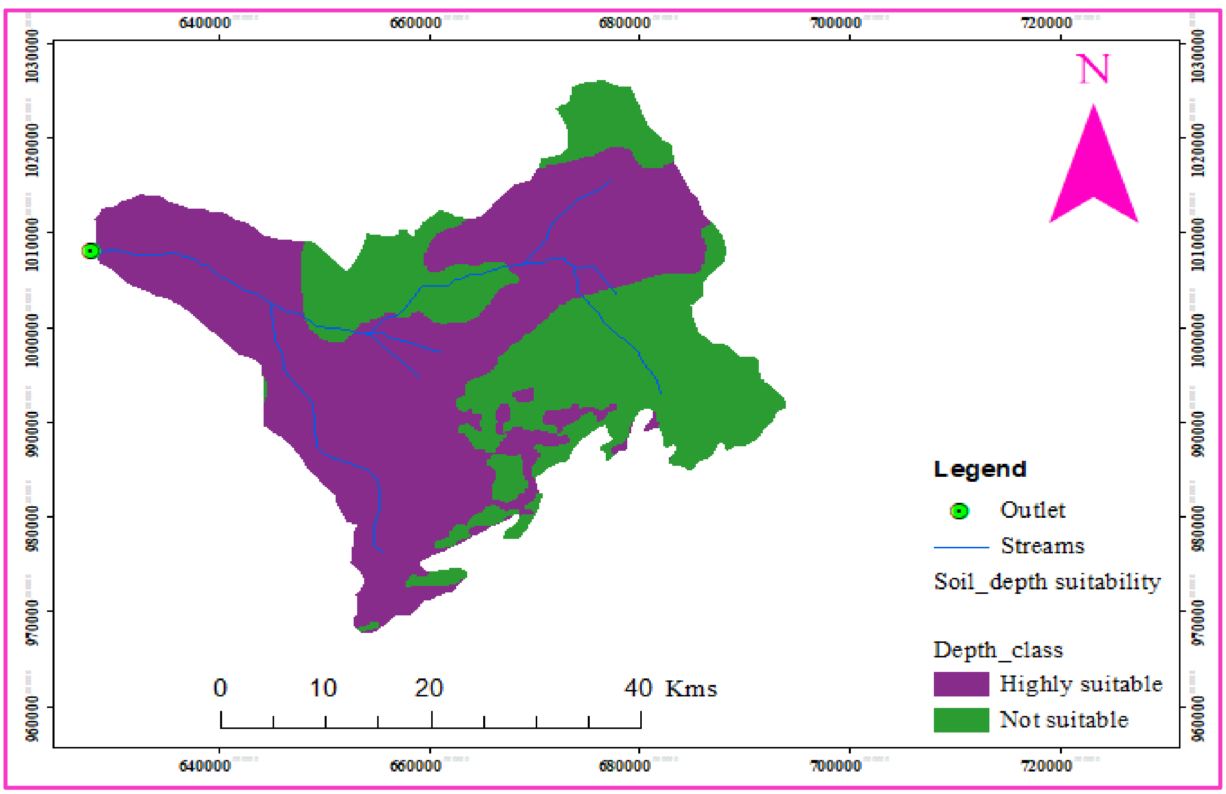

Figure 4.8. Soil depth suitability map of the study area

The rasterize soil depth of the study area was classified into highly suitable and not suitable. According to soil depth most of the study area was dominantly highly suitable from deep to very deep for surface irrigation development and not suitable from shallow to very shallow for irrigation development. Based on soil depth suitability 38.2 % is not suitable and 61.8 % is highly suitable for surface irrigation development. The rasterized map of soil depth and soil depth class was analyzed suitability model of Arc GIS 10.4 version shown above Figure 4.8 & 4.9.

4.3.3. Soil drainage suitability

Table 4.5. Result of drainage suitability on the study area

No	Drainage	Suitability class	Area (ha)	Area (%)
1	Poor	S3	57,826	35.2
2	High	S3	24,513	14.9
4	Well	S1	38,269	23.3
5	Imperfect	S2	43,661	26.6
Total			164,269	100

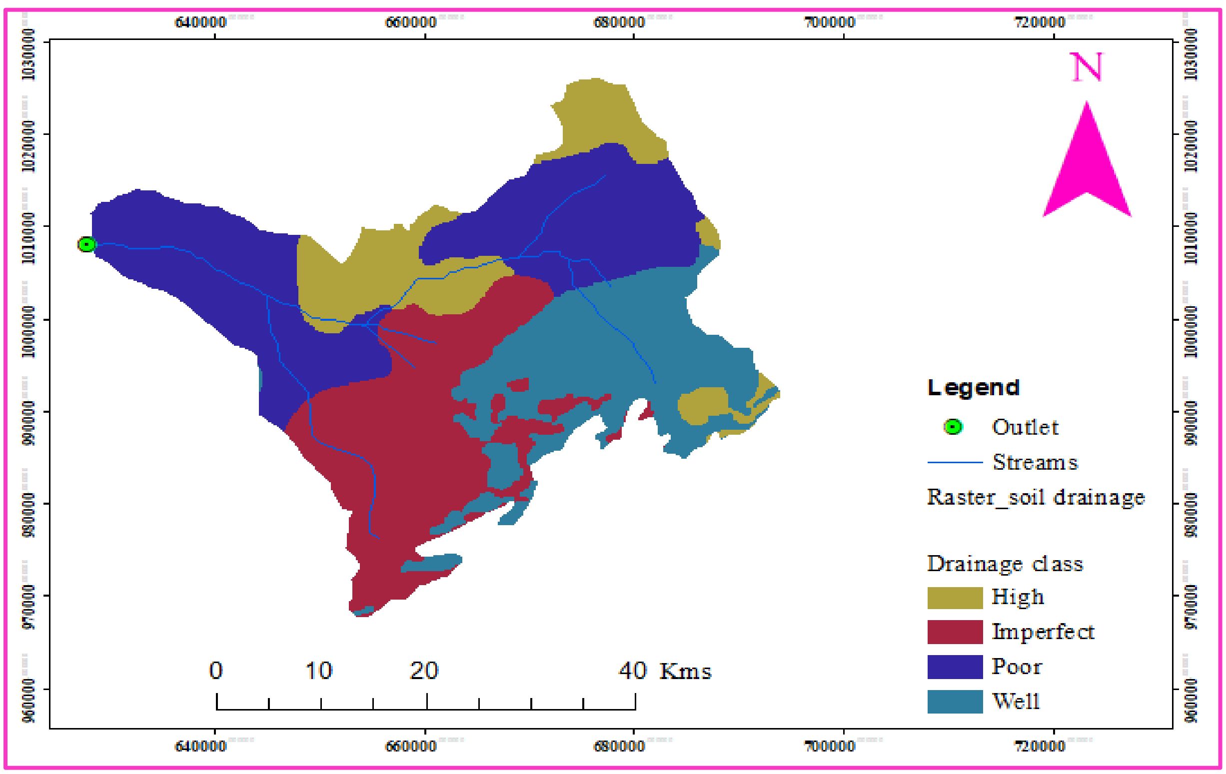

Figure 4.9. Soil drainage class map of the study area

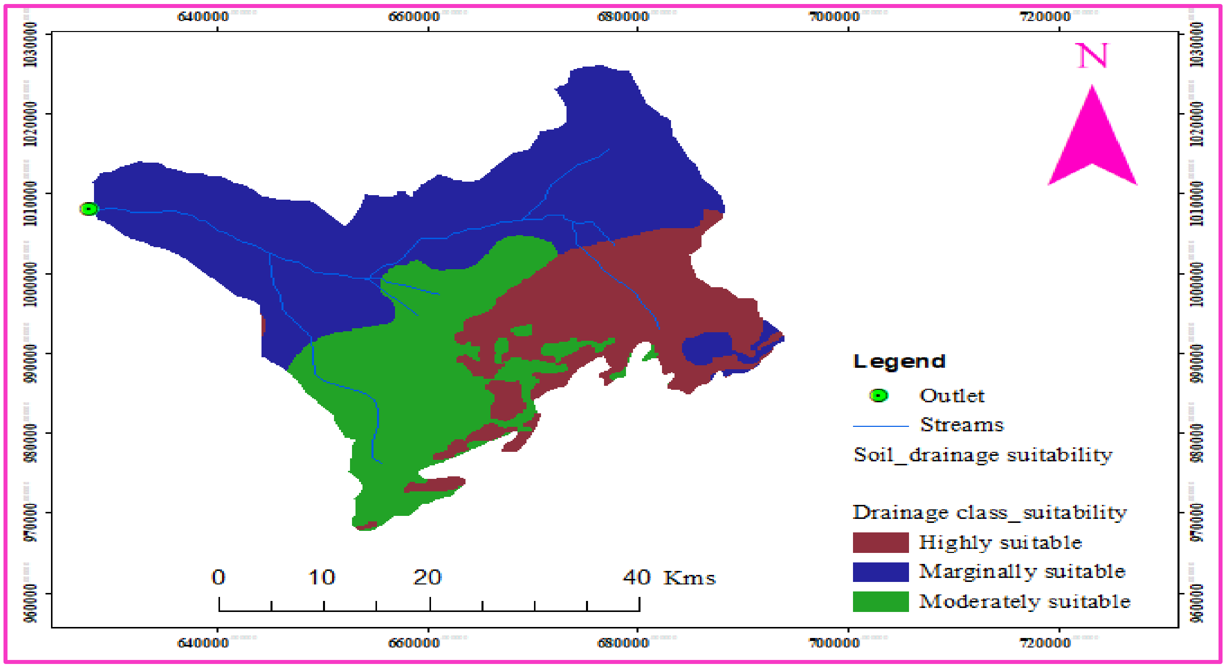

Figure 4.10. Soil drainage suitability map of the study area

Drainage is one of the determinant factors to evaluate land suitability for surface irrigation development. Suitability of the land for surface irrigation based on the drainage was classified into three parts, such as well drained, highly drained, poorly drained and imperfectly drained. This classification was assessed from (FAO, 1997) Awash basin master plan. According to this classification, the result of drainage suitability was given in the table 4.5. Most of the study area is category under marginally suitable for surface irrigation which covers the area of 50.1%. The second coverage was 26.6% is categorized under moderately suitable for surface irrigation and 23.3% is highly suitable for surface irrigation in agricultural development. The drainage suitability map of the study area was analysis on Arc GIS10.4 suitability model as shown in the Figure 4.11.

4.3.4. Weighing of Irrigation Suitability Factors

Based on the physical characteristics of the irrigation suitability parameters like slope, soil texture, soil drainage, soil depth, and land use land cover the qualitative land evaluation for surface irrigation suitability implies that 57,595.23 ha (S_1), 21,057.87 ha (S_2), 39,710.62 ha (S_3) and 45,905.28 ha (S4) as it shown from Table 4.6. The total suitable area for surface irrigation is 118,363.72 ha.

Table 4.6. Result of Land suitability of the study area

No	Land suitability	Area(ha)	Area (%)
1	S_1	57,595.23	35.06
2	S_2	21,057.87	12.82
3	S_3	39,710.62	24.17
4	S_4	45,905.28	27.95
Total		164,269	100

The last output of irrigation suitability model analysis which was involved by weighting of factors such as soil (soil texture, soil depth and soil drainage), slope and land use/ land cover by restricted other land use for irrigation development without agricultural land and by considering the jointing point of tributary River in to the main River as potential reservoir or diversion sites (water supply point) indicated that most areas of the River catchment was moderately suitable for surface irrigation development.

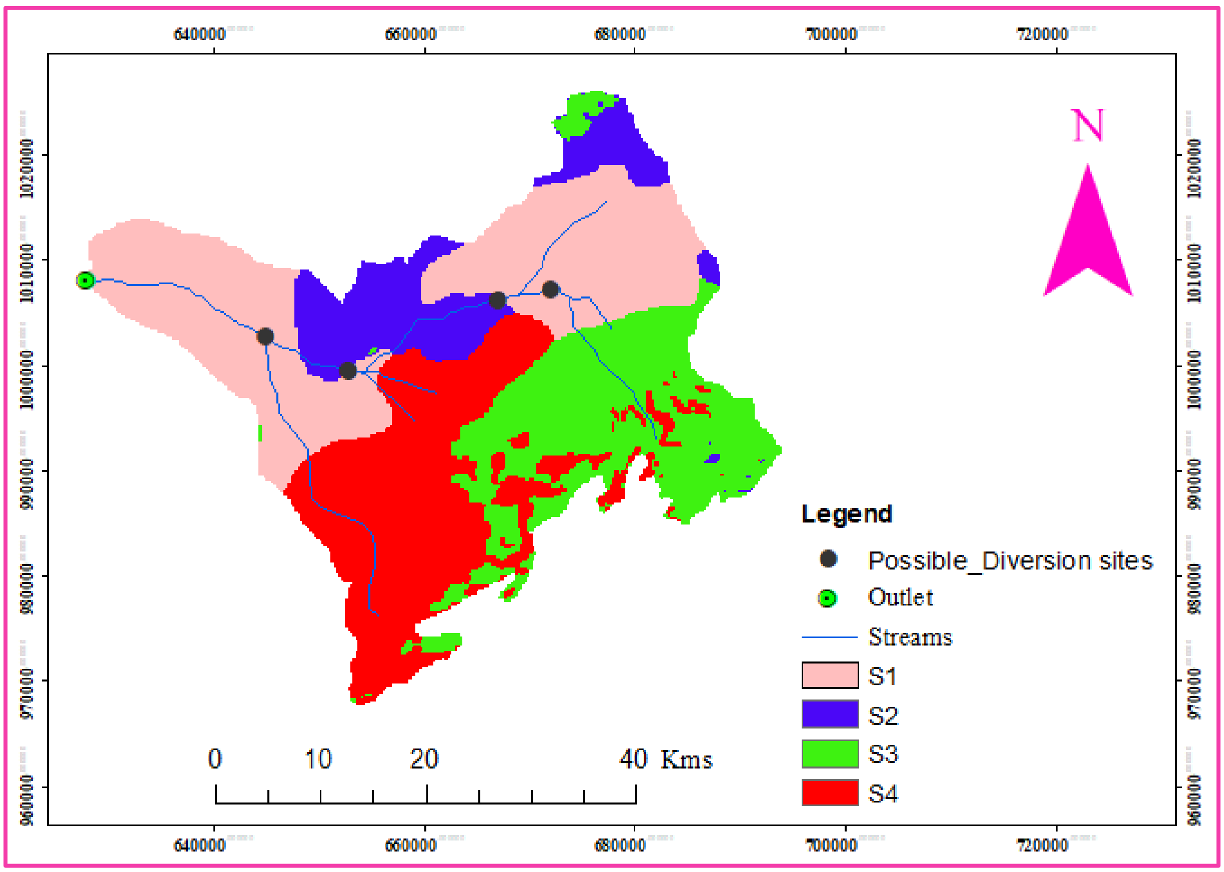

Figure 4.11. Over all land suitability map distribution

4.4. Surface Water Availability

Available Surface water on the study area was evaluated by using stream flow discharge obtained from Ministry of Water, Irrigation and Electricity. Average annual monthly stream flow, maximum and minimum flow was evaluated. But effective irrigable area was calculated based on minimum stream flow. Water available was estimated after little water was released for some ecological purpose Table 4.7 and 4.8 show this result.

Table 4.7. Mean, max, and min annual monthly flow of Awash Arba River at gauged station before 25% released for ecological purpose

Flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Av.flow (m3/s)	0.77	0.77	1.03	1.08	1.01	0.94	1.39	1.54	1.49	1.39	1.04	0.76	13.21
Min.flow (m3/s)	0.02	0.02	0.01	0.03	0.03	0.01	0.14	0.13	0.11	0.03	0.02	0.01	0.56
Max.flow (m3/s)	6.29	3.70	12.73	15.59	5.55	8.97	25.05	27.7	9.84	15.04	9.70	4.63	144.74

Table 4.8. Mean, max, and min annual monthly flow of Awash Arba River at gauged station after 25% released for ecological purpose

Flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Av.flow (m^3s^{-1})	0.58	0.58	0.77	0.81	0.76	0.71	1.04	1.15	1.12	1.04	0.78	0.57	9.91
Min.flow (m^3s^{-1})	0.01	0.01	0.01	0.02	0.02	0.01	0.11	0.10	0.08	0.02	0.02	0.01	0.42
Max.flow (m^3s^{-1})	4.72	2.78	9.54	11.69	4.16	6.73	18.79	20.74	7.38	11.28	7.28	3.47	108.56

Therefore, total average min and max flow was recorded 9.91 m^3s^{-1}, 0.42 m^3s^{-1} and 108.56 m^3s^{-1}respectively. Maximum flow were generate in August.

4.5 Crop water requirement

Table 4.9. Monthly crop water requirement of selected crops on the study area in mm

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Wheat	116.8	108.3	61.1	37.9	7.5	0	0	0	0	0	0	0	331.6
Maize	105.8	145.6	9.9	21.4	94	0	0	0	0	0	0	0	336.7
Onion	84.2	123.6	31.6	101.6	0	0	0	0	0	0	0	0	341
Tomato	116.6	106.2	109	42	14.6	77	0	0	0	0	0	0	465.4
Total	423.4	483.7	211.6	202.9	116.1	77	0	0	0	0	0	0	1514.7

Different crops have not the same crop water need. The crop water requirement of all crops possibly grown in the study area was presented for each month in the Table 4.9 above. From all crops, tomato has needed the highest crop water requirement which recorded 465.4 mm/growing period and wheat has the minimum crop water requirement in the study area was evaluated 331.6 mm throughout the growing period. Total crop water requirement for all possible growing crops were evaluated 1514.7 mm/growing period.

4.6 Gross irrigation water demand

Table 4.10**.**Grosse irrigation water demand for each crop in m3/s

Crop	Area(ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat	38900.00	32	30	17	11	2	0	0	0	0	0	0	0
Maize	35700.00	27	37	3	5	24	0	0	0	0	0	0	0
Onion	21881.86	13	19	5	16	0	0	0	0	0	0	0	0
Tomato	21881.86	18	17	17	7	2	12	0	0	0	0	0	0
Total	118363.72	90	103	42	39	28	12	0	0	0	0	0	0

The maximum gross irrigation water demand was Recorded 96 m^3/s for maize crop and the minimum gross irrigation water demand was recorded 53 m^3/s for onion as per growing period respectively. Total irrigation water demand for the whole irrigable is 314 m/s or 135.648 Mm^3 of water needed to irrigate the whole irrigable area of 118,363.72 ha of land on these specified crops.

4.7 Physical irrigation potential on Awash Arba watershed

Table 4.11. Gross irrigation with the mean available stream flow $\boldsymbol{m^3}$/s

Crop	Area(ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow(m3/s)	0.58	0.58	0.77	0.81	0.76	0.71	1.04	1.15	1.12	1.04	0.78	0.57	0.58
Wheat	38900.00	32	30	17	11	2	0	0	0	0	0	0	0
Maize	35700.00	27	37	3	5	24	0	0	0	0	0	0	0
Onion	21881.86	13	19	5	16	0	0	0	0	0	0	0	0
Tomato	21881.86	18	17	17	7	2	12	0	0	0	0	0	0
Total	118363.72	90	103	42	39	28	12	0	0	0	0	0	0

According to FAO, 1997 Physical surface irrigation potential for surface irrigation was obtained by comparing irrigation water requirement in identified irrigable land and the available stream flow of watershed. From the total stream flow, 25% of the available stream flow on watershed was released to the downstream for ecological purpose. In the whole growing season from January-June irrigation water demand was greater than the available stream flow. Mean monthly stream flow and grosses irrigation water requirement of selected crop such as, maize, wheat, onion, and tomato were present in the Table 4.11 above. The area was assigned for each crop based on their productivity and profitable in traditional farming system in Awash Arba watershed. Based on the minimum available water, the effective irrigable area can be estimated in each month and at different scenario in the following equation.

$$\text{Effective irrigable area} = \frac{\text{Acrop} * \text{e} * \text{Min Q}}{\text{GIWR}} = \frac{38900 * 0.54 * 0.01}{32} = 6.564375\text{ha}$$

6.564375 ha was the effective area can be irrigated at minimum flow of a month January for wheat and the remaining crops with the remaining months can be calculated the same procedure as it shown Table 4.12

Table 4.12. Effective irrigable area with minimum flow

Month	NIR(mm/month)	GIWR(m^3/s)	MinQ(m^3/s)	Area irrigated by min Q(ha)	Un irrigated area due to lack of Q(ha)
Jan	116.8	32	0.01	6.6	38,893.4
Feb	108.3	30	0.01	7.0	38,893
Mar	61.1	17	0.01	12.4	38,887.6
Apr	37.9	11	0.02	38.2	38,861.8
May	7.5	2	0.02	210.1	38,689.9
Total	**331.6**	**92**	**0.07**	**274.3**	

From Table 4.12, effective irrigable area of each month is varies from month to month due to variation of min flow. From table 4.12, the max irrigable area within the min flow for each month Jan, Feb, Mar, Apr and May were 6.6 ,7.0,12.4, 38.2 and 210.1 ha respectively. The actual average irrigable area of land is 54.86 ha out of 38900 ha was irrigated within the total min flow of 0.07 m^3/s and 92 m^3/s gross irrigation water covered by the wheat crop. The remaining effective irrigable area was covered by other crop was calculated on the same procedure. Therefore, to irrigate the whole irrigable land (118,363.72 ha) storage structures should be built.

CHPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Surface irrigation potential was evaluated by assessing land use/cover, soil suitability, and slope suitability. To identify soil suitability soil texture, soil drainage and soil depth were considered. Soil texture was classified into three parts based on textural suitability. The area coverage of textural suitability was categorized into highly suitable which covers the area 35.2%, marginally suitable covers 6.1%, and moderately suitable 26.6 % and 32.1% was not suitable for surface irrigation.

The other suitability factor for surface irrigation is drainage property. Drainage was classified into three category based on permeability well drainage, moderately well drained and imperfect drained. Well drained was categorized 23.3% (S1), imperfect drained 26.6% (S2), 35.2 % poor drained (S3) and 14.9% high drained (S3).

The most determinant factor of soil suitability is soil depth. This parameter was classified into four based on suitability. These are deep, very deep, shallow and very shallow. The reclassified depth suitability was two highly suitable (S1) and not suitable (S4) which covers from the total area 61.8 %(S1) and 38.2 % (S4) respectively.

Land use/cover of the study area is, bush land, grass land, vegetation land, crop land and wet land was identified. This land use/cover was classified into three categories highly suitable, moderately suitable and not suitable with areal coverage of about 55.7% (S1), 37.3 % (S2) and 6.9% (S4), respectively.

Slop suitability is another factor for determining land suitability of the study area. Slop was classified into four parts <2%, highly suitable, 2-5%, moderately suitable, 5-8%, marginal suitable and >8% not suitable for surface irrigation. The area coverage of highly suitable 90,104 ha (S1), moderately suitable 49,748 ha (S2), marginal suitable 18,329 ha (S3) and the area covers 6,088 ha (S4) is not suitable for surface irrigation.

From the total area of the study area 118,363.72 ha (72.0548%) is suitable for surface irrigation and the rest of 45,905.28 ha (27.945%) is not suitable for surface irrigation. Irrigation water demand was assessed by using metrological station which impute for CROPWAT8.0 software. Crops which are identified in the study area are wheat, maize, onion and potato. Physical surface irrigation was identified by comparing available stream flow and grosses irrigation water requirement. Based on the available minimum stream flow, 0.42 m^3/s irrigable potential of the study area, 274.3 ha was irrigated from the total irrigable area 38,900 ha for wheat. Due to lack of the available stream flow, 38,887.6 ha were not irrigated on the study area for wheat and the same was true for other identified crops.

5.2. Recommendation

- Land suitability analysis for irrigation was done by considering only surface irrigation. Furth investigation is recommended to increase suitability of land for irrigation by considering drip and sprinkler irrigation method.
- This study was limited with soil texture, soil depth and drainage to assess land suitability for surface irrigation. Since, other factors probably have their own influence to characterize the suitability of land for surface irrigation. Therefore, further research which will be incorporate additional factors such as soil chemical characteristics of alkalinity, acidity, electric conductivity with the aid of laboratory analysis to assess land suitability over the study area.
- The present irrigation suitability investigation was done based on three physical suitability factors (soil, LULC & slope) and surface water resources of the area alone. However, other section of study should be done like distance to the river, stoniness, salinity hazards, water quality, socioeconomic and environmental aspects and others for sustainable development of irrigation in the study area.
- The study was focused on only five dominant crops to be evaluated for development of surface irrigation. However, crops other than the five may be evaluated for the study area to boost production and productivity of the study area.
- Furthermore, remote sensing and GIS application was found as vital tools in assessing surface irrigation potential in this study. It is therefore hopped that future irrigation development activities will exploit these resources more than the present study for better assessment of land and water resources in the study area and elsewhere.
- The current study was particularly done land suitability investigation and surface water availability for surface irrigation methods. However, investigation of land suitability of

other irrigation methods (pressurized irrigation methods) should be done in order to enhance irrigation development opportunities of the study area.

- To increase irrigation potential of the study area, drip irrigation method is encourage rather than use surface and sprinkler irrigation methods.
- According to the present study investigation much more suitable land was existed for surface irrigation, however, the river potentials were not capable to develop the whole suitable land. Therefore, it is better that water harvesting during the rainy season and develops surface irrigation as dry season.

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7. APPENDIX:

Appendix table 1: Awash Arba monthly precipitation

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total
1997	0.0	11.3	27.8	35.9	7.4	0.0	140.1	109.1	90.5	5.0	0.0	0.2	427.3
1998	0.0	37.2	126.2	24.7	65.4	21.7	85.7	122.4	25.1	31.7	0.0	6.8	546.9
1999	32.3	63.2	0.6	104.0	17.9	51.4	158.2	87.9	73.3	15.2	122.4	50.0	776.4
2000	55.9	70.5	13.6	155.2	38.1	6.2	187.1	376.8	65.6	98.5	7.8	2.6	1077.8
2001	0.0	0.0	10.3	30.9	60.0	24.4	96.7	184.8	65.2	45.3	34.2	12.9	564.7
2002	0.0	17.0	69.4	12.3	72.0	11.0	200.8	162.6	43.0	0.2	0.0	0.2	588.5
2003	3.4	0.0	76.5	17.4	16.6	3.8	105.3	89.1	36.9	0.0	0.0	2.6	351.6
2004	9.5	19.2	82.6	91.0	0.0	7.3	158.6	99.0	42.0	0.0	16.3	21.8	547.3
2005	97.2	0.2	70.8	167.2	0.0	29.7	131.5	133.8	26.5	18.1	12.8	0.0	687.8
2006	55.5	5.4	187.9	97.5	81.9	30.3	167.8	102.4	44.7	0.0	0.0	0.0	773.4
2007	2.2	38.3	67.0	73.6	4.2	6.5	186.3	97.5	33.8	50.0	0.2	35.3	594.9
2008	0.0	0.0	1.0	30.7	0.4	36.1	103.3	60.9	47.3	54.3	96.7	0.0	430.7
2009	80.9	0.6	24.7	58.6	24.2	4.7	54.9	79.1	42.9	13.9	9.4	15.4	409.3
2010	9.0	20.5	74.6	62.8	75.5	21.2	166.7	71.3	19.3	0.0	21.5	1.5	543.9
2011	0.0	0.0	25.0	36.3	54.2	40.2	76.0	186.3	5.0	0.0	5.1	21.5	449.6
2012	0.0	0.0	0.0	1.9	2.5	19.3	119.6	129.9	114.9	5.5	0.0	0.0	393.6
2013	21.8	0.0	63.4	64.8	0.0	46.1	138.3	102.0	61.0	25.0	0.0	0.0	522.4
2014	0.0	78.5	32.9	29.5	35.9	1.3	90.0	77.3	71.6	82.1	0.0	0.0	499.1
2015	0.0	0.0	3.9	2.0	50.7	46.5	22.2	75.3	68.8	0.0	6.5	2.2	278.1
2016	0.0	27.0	27.8	77.2	153.7	36.0	178.7	95.0	75.1	0.0	14.0	0.0	684.5
2017	0.0	0.0	83.5	5.7	73.5	30.0	29.6	76.9	20.4	29.5	0.0	0.0	349.1
2018	0.0	10.6	75.7	34.4	7.9	42.7	129.9	87.8	29.5	20.2	23.5	0.0	462.2
2019	0.0	0.0	7.9	42.7	0.0	14.0	70.4	48.2	87.6	123.1	26.6	43.5	464.0
2020	0.0	0.0	9.0	61.6	28.3	46.2	111.3	88.8	10.3	19.8	41.1	0.0	416.4
2021	76.0	0.0	142.8	67.6	96.3	23.0	120.8	138.4	0.0	0.0	17.6	0.0	682.5
Average	17.7	16.0	52.2	55.4	38.7	24.0	121.2	115.3	48.0	25.5	18.2	8.7	540.9

APPENDIX: Appendix table 2: Bordede monthly precipitation

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total
1997	11.3	104	47.4	58.3	49.4	6.2	105.3	195.8	65.5	23.1	0	25.1	691
1998	105	9.4	51	44.1	42.4	25.3	155.2	97.1	69.8	91.1	0.5	0	690.4
1999	0.4	0	76.2	26	25.5	30.3	143.1	159.3	103	192	0.7	0	756.3
2000	0	0	15.2	36.5	44.7	31	89.6	126.9	131	60.7	26.9	19.5	581.7
2001	0.2	24.6	100.6	40.5	67.5	27.7	137.7	140.7	64.5	1.3	0.3	30.7	636.3
2002	36.3	1.3	4.2	6.4	2.8	3	137.7	20	10.7	8	0	6.5	236.9
2003	2.4	1.7	7.2	283.2	58	62	208	133	340	11	0	0	1106.5
2004	5	0	79	632	0	40	43	68	248	0	48	16	1179
2005	0	0	110	93	176	46.2	73.3	15.2	122	0	0.8	0	636.9
2006	10	8	110	115	46	49	112	165	179	76	20	135	1025
2007	0	31	144.5	112.9	22.4	33.7	240.6	181.1	98.7	21.6	39.7	0.4	926.6
2008	14	0	0	18.3	13.3	23.2	53.1	94.6	72.5	37.6	8.8	0.8	336.2
2009	7.1	19.4	14.8	87.1	78.2	35.6	41.9	35.6	71.4	18.4	30.6	3.9	444
2010	14.3	79	132	108.2	94.3	80	61	98.5	57.9	0	0	0	725.2
2011	0	7.4	12.5	6	46.8	47.4	61.7	135.4	3.4	7.8	24.3	0	352.7
2012	0	0	21.1	25.9	25.9	49.6	96.4	178	79.6	4.6	5.3	10.1	496.5
2013	30.3	0	61.5	90.8	18.5	0	317.4	148.8	22.7	31.1	0	17.9	739
2014	0	28.8	80.4	47.1	206.8	0	7.8	38.9	52	124	27.8	0	613.6
2015	0	0	0	0	9.9	72.2	32.4	127.7	100	0	2.3	0	344.5
2016	2.3	6.8	0.7	83.3	50.6	51.7	171.6	45.4	62.4	37.4	32.4	0	544.6
2017	0	0	11.6	19.1	22.8	14.3	59.1	57.4	77.6	0	32.4	0	294.3
2018	0	0	14.5	43.9	24.5	31.2	76.7	13.7	232	0	0	0	436.1
2019	79.5	118	2.2	136.8	44.1	5.3	77.4	93.8	70.9	22.5	0	0	650.2
2020	0	0	55.8	49.9	48.9	9.5	247.5	89.9	113	3.4	38.7	0	656.8
2021	0	0	98	104.8	26.2	19.3	93.2	102.1	59.5	3.9	0	23.3	530.3
Average	12.7	17.5	50.02	90.76	49.82	31.7	113.7	102.5	100	31	13.6	11.6	625.224

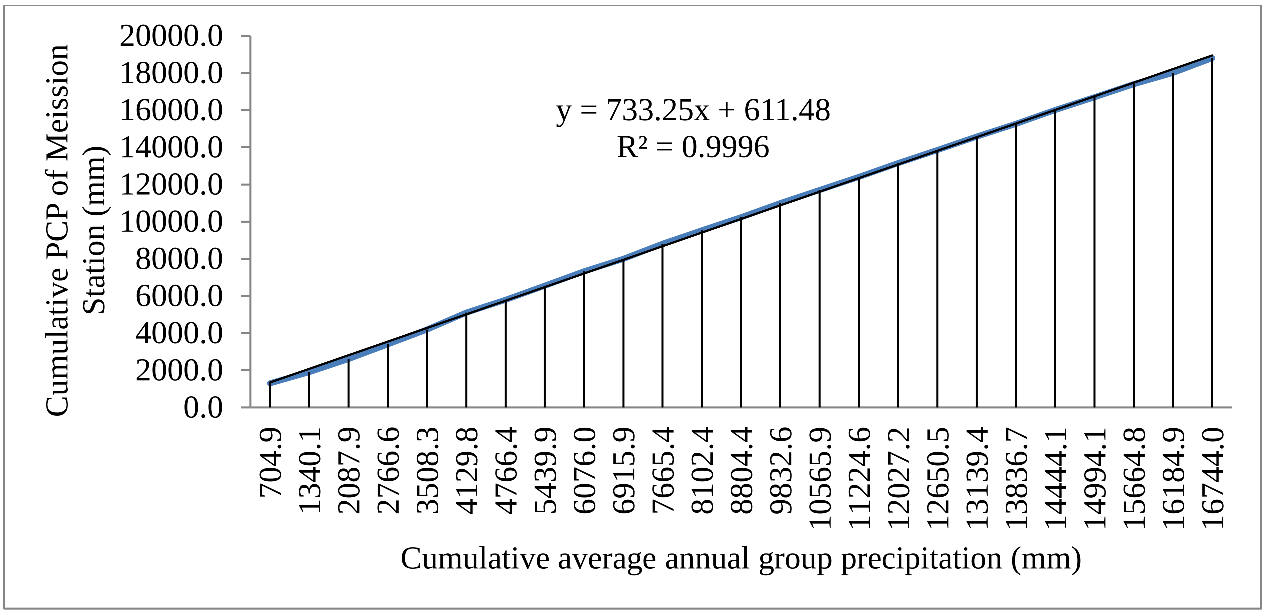
APPENDIX: Appendix table 3: Mesion monthly precipitation

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total
1997	3.7	0	101.6	154	7.6	41.1	104.4	109.2	39.3	360.9	74.2	0	996.4
1998	13.7	32.9	62	26.4	34.7	26.8	114.4	96.4	162	88.7	10.2	0	668.2
1999	0	3.2	131.1	10.8	17.7	33.9	158.1	146	72.9	126.2	10.9	0	710.8
2000	0	0	7.1	83.2	129	56.5	15.3	141.4	113.7	138.1	78.5	0	762.8
2001	1.2	5.4	113.4	24	79.3	60.6	183.8	279	124.7	0.9	0	24.3	896.6
2002	23.9	0	53.2	82.6	4.6	27.5	72.8	80.8	52.7	11.8	0	53.5	463.4
2003	5.5	3.6	37.4	139	25.4	110.2	107.9	182.6	159.9	0	9.1	25.7	806
2004	18.3	0	74.7	142	3.4	37.8	118.6	119.8	115.3	62.8	13.1	1.2	706.5
2005	3.7	8.9	92.9	71.3	97.6	75.6	186.1	96.7	107.7	3.4	18.1	0	762
2006	9.2	26.1	57.5	168	37.5	52.5	146.8	276.2	61.7	12.7	7.9	50.3	906.6
2007	0	19.3	16.8	231	13.4	42.7	158	116.6	168.2	19.9	0	25.1	810.5
2008	23	0	0	59.3	37.8	58.8	112	153.3	14	23.4	96.2	0	577.8
2009	0	3.2	131.1	10.8	17.7	33.9	158.1	146	72.9	126.2	10.9	0	710.8
2010	0	70.4	268.3	163	32.1	72.7	172.9	98.4	90.1	0	16.3	0	984.2
2011	0	0	6.9	86.9	29.4	49.7	124.9	150	103.9	0	0	1.2	552.9
2012	0	0	6.9	86.9	29.4	49.7	124.9	150	103.9	0	0	1.2	552.9
2013	8.5	0	86.2	111	107.4	42	187.9	147	69.9	39	21.9	0	821.2
2014	11.3	103.6	98.8	58.3	48.3	5.3	77.4	195.8	65.5	23.1	0	3.9	691.3
2015	7.1	19.4	14.8	87.1	78.2	35.6	45.9	80.4	101.9	8.1	28.1	0.8	507.4
2016	8	6.6	7.8	137	138	50	191.8	35.6	71.4	0.6	36.8	0	683.4
2017	8	21	24.2	15.8	102.5	9.7	41.9	93.8	186.5	18.4	0	0	521.8
2018	0	26.6	37.4	186	56	67.9	141.2	167.9	44.6	43.3	19.1	0	790.4
2019	0	7.5	56.8	103	84.4	63.1	158.3	68.6	257.3	72.3	70	52.1	993.5
2020	0	1.2	5.7	177	83.1	44.3	225.5	198.6	69.5	6	14.5	0.7	825.7
2021	79.5	0	2.2	49.9	44.1	0	247.5	89.9	70.9	22.5	0	0	606.5
Average	8.98	14.36	59.79	98.6	53.54	45.916	135.1	136.8	100.02	48.332	21.43	9.6	732.384

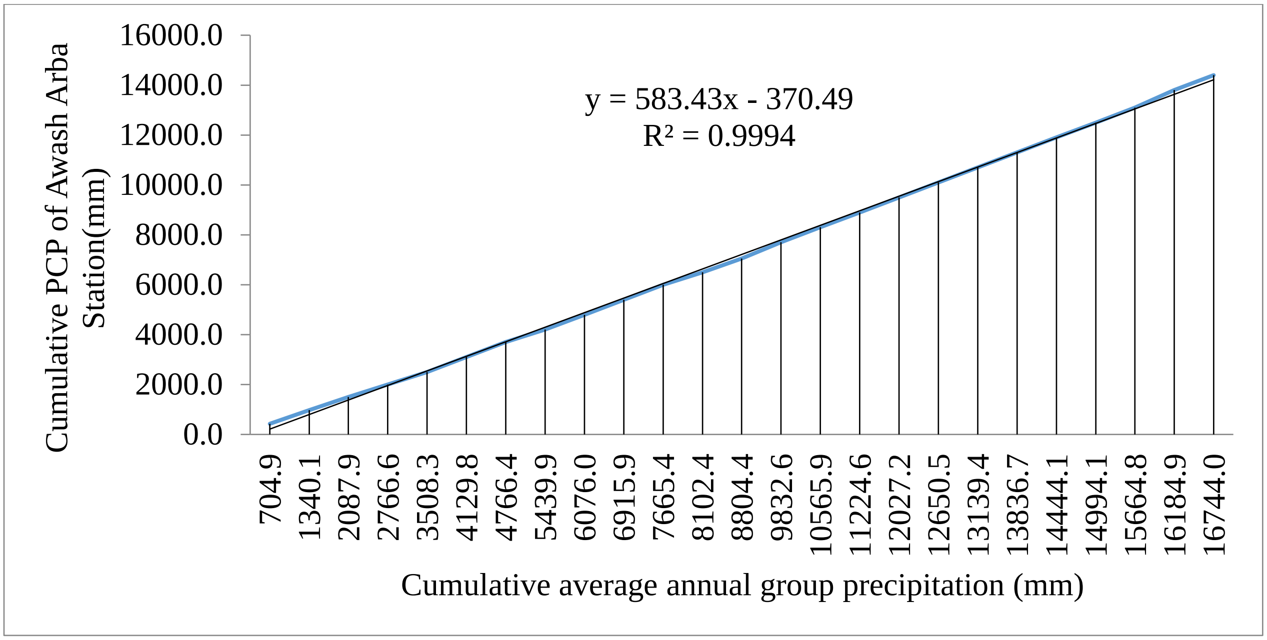
Appendeix table4: Average monthly precipitation of each station

Month	Borede_PCP	AwashArba_PCP	Meission_PCP	Average
Jan	12.7	17.7	9.0	13.1
Feb	17.5	16.0	14.4	16.0
Mar	50.0	52.2	59.8	54.0
Apr	90.8	55.4	98.6	81.6
May	49.8	38.7	53.5	47.3
Jun	31.7	24.0	45.9	33.9
Jul	113.7	121.2	135.1	123.3
Aug	102.5	115.3	136.8	118.2
Sep	100.3	48.0	100.0	82.8
Oct	31.0	25.5	48.3	34.9
Nov	13.6	18.2	21.4	17.7
Dec	11.6	8.7	9.6	9.9

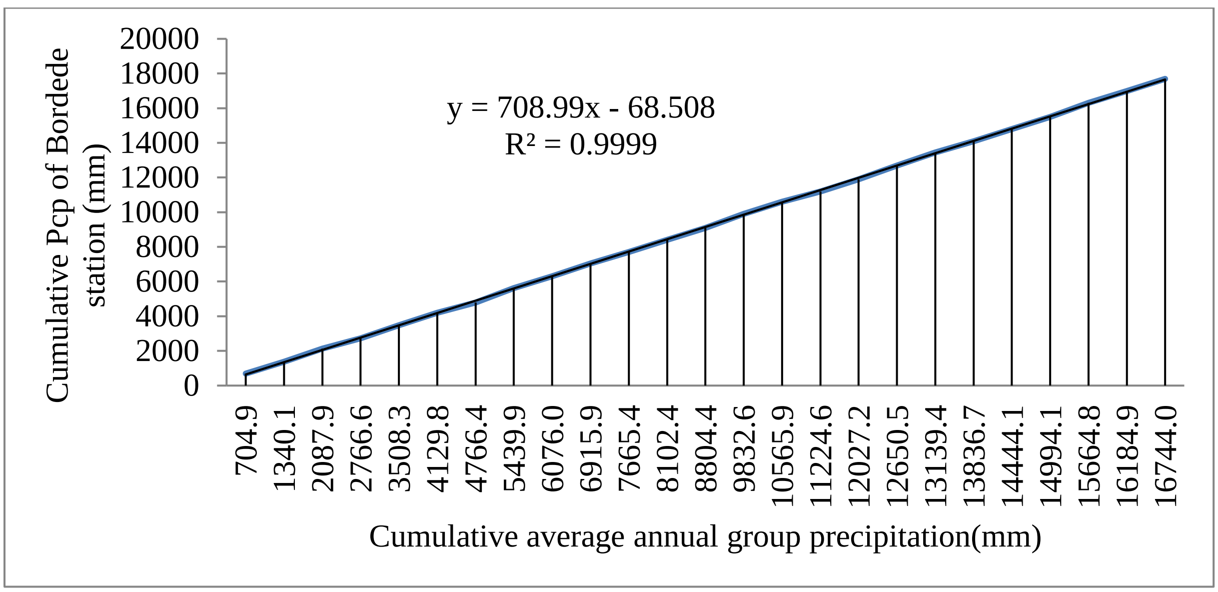
Apendeix figure1:double mass curve Meission station



Apendeix figure2:double mass curve Awash Arba station



Apendeix figure3:double mass curve Bordede station



Appendix table 5: Awash Arba average maximum temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1997	30.8	30.4	35.5	35.1	37.6	38.2	35.6	32.4	33.7	33.0	31.8	31.6	33.8
1998	30.5	30.9	34.4	33.8	34.4	38.0	36.0	35.6	35.3	34.2	32.9	30.9	33.9
1999	28.0	30.4	31.4	31.5	31.2	31.1	29.9	30.7	31.0	32.3	31.7	28.3	30.6
2000	28.7	31.3	30.4	29.8	30.1	34.5	30.9	31.1	31.4	29.7	30.3	29.1	30.6
2001	30.8	33.2	34.5	37.2	38.5	38.9	36.1	32.0	34.4	35.1	33.1	32.3	34.7
2002	31.4	34.1	34.8	37.2	39.9	39.6	38.0	35.1	35.4	35.5	34.3	31.8	35.6
2003	32.3	35.2	36.2	36.7	39.7	38.7	35.9	34.1	35.2	35.0	33.1	31.4	35.3
2004	32.3	32.7	34.8	34.7	38.8	38.3	35.1	34.6	35.5	33.9	32.9	32.4	34.6
2005	31.7	35.4	34.7	36.2	36.1	37.9	34.1	34.6	34.9	34.5	33.0	31.4	34.6
2006	32.3	33.9	34.6	34.9	38.2	39.0	35.0	32.8	34.6	34.2	32.5	30.8	34.4
2007	31.2	34.5	36.2	36.2	39.4	38.5	34.2	32.0	34.3	34.0	32.3	31.6	34.5
2008	31.5	29.8	39.7	36.0	37.9	37.5	35.1	34.3	35.8	34.2	30.3	31.1	34.4
2009	30.5	33.1	35.6	35.2	37.3	39.7	37.4	36.4	37.1	34.6	34.7	32.8	35.4
2010	32.4	33.4	32.8	36.1	37.5	39.4	36.0	35.4	35.5	37.0	33.8	32.4	35.1
2011	32.9	34.9	35.5	38.0	37.5	39.0	36.8	33.9	35.1	37.1	35.7	31.1	35.6
2012	34.4	36.5	38.7	38.5	41.3	41.3	37.7	34.3	34.6	35.4	34.9	33.4	36.7
2013	33.7	35.5	37.3	37.7	39.2	40.0	34.5	33.7	35.5	35.0	33.6	31.8	35.6
2014	32.4	32.7	35.2	35.9	37.2	39.2	36.7	35.0	34.6	33.7	33.9	32.0	34.9
2015	32.0	35.7	37.2	38.2	37.7	38.3	38.7	37.1	37.0	37.2	34.7	32.4	36.3
2016	32.3	34.1	38.7	35.6	35.9	38.2	34.0	34.1	35.3	35.9	33.1	32.3	35.0
2017	33.0	33.6	36.6	37.1	35.8	35.9	36.0	34.5	35.2	36.1	34.2	31.8	35.0
2018	31.8	35.7	32.0	34.4	35.7	38.9	35.0	34.8	36.0	35.8	33.5	33.1	34.7
2019	33.8	35.8	37.2	38.2	37.9	38.3	35.8	34.9	34.5	32.3	33.1	31.6	35.3
2020	32.7	33.1	34.1	35.8	37.9	37.8	33.9	32.4	34.9	33.7	31.9	31.3	34.1
2021	31.0	32.9	35.3	36.2	37.4	37.8	34.0	33.1	33.1	33.7	31.4	30.3	33.8
Average	31.8	33.5	35.3	35.9	37.2	38.2	35.3	34.0	34.8	34.5	33.1	31.6	34.6

Appendix table 6: Bordede average maximum temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1997	31.7	33.4	35.2	33.9	37.9	37.7	35.8	35.1	36.8	33.2	31.5	30.2	34.4
1998	30.9	32.5	33.8	37.3	38.5	39.3	35.8	32.5	34.1	34.0	32.6	31.6	34.4
1999	32.3	35.5	33.8	37.3	38.4	38.5	33.6	34.0	35.0	33.1	31.6	30.9	34.5
2000	32.0	33.5	35.6	36.4	37.9	39.1	35.0	32.3	34.5	33.2	32.0	31.5	34.4
2001	30.8	33.2	34.5	37.2	38.5	38.9	36.1	32.0	34.4	35.1	33.1	32.3	34.7
2002	31.4	34.1	34.8	37.2	39.9	39.6	38.0	35.1	35.4	35.5	34.3	31.8	35.6
2003	32.3	35.2	36.2	36.7	39.7	38.7	35.9	34.1	35.2	35.0	33.1	31.4	35.3
2004	32.3	32.7	34.8	34.7	38.8	38.3	35.1	34.6	35.5	33.9	32.9	32.4	34.6
2005	31.7	35.4	34.7	36.2	36.1	37.9	34.1	34.6	34.9	34.5	33.0	31.4	34.6
2006	32.3	33.9	34.6	34.9	38.2	39.0	35.0	32.8	34.6	34.2	32.5	30.8	34.4
2007	31.2	34.5	36.2	36.2	39.4	38.5	34.2	32.0	34.3	34.0	32.3	31.6	34.5
2008	31.8	32.2	36.1	36.1	36.8	37.0	35.3	34.3	35.3	34.2	30.8	30.7	34.2
2009	31.1	33.9	35.8	36.8	38.5	39.2	36.1	35.0	36.1	33.7	33.6	31.5	35.1
2010	31.7	32.7	32.7	35.9	37.2	38.9	35.7	33.3	34.7	35.3	32.5	30.7	34.3
2011	31.8	34.3	34.8	37.6	37.9	38.8	37.2	33.6	34.8	34.9	33.5	31.9	35.1
2012	33.1	34.5	36.6	36.5	38.6	38.9	35.7	33.4	34.7	33.9	33.6	32.6	35.2
2013	32.4	34.2	36.4	36.8	38.0	39.4	35.0	33.7	35.4	34.6	32.7	31.2	35.0
2014	32.1	33.5	35.3	36.5	37.1	39.0	37.0	34.0	34.9	33.3	33.1	31.9	34.8
2015	31.5	34.9	37.1	37.4	36.7	38.4	37.6	36.7	36.7	37.3	34.4	32.3	35.9
2016	31.7	33.8	37.9	33.2	35.9	35.4	28.5	28.6	29.2	28.9	29.2	30.7	31.9
2017	30.0	35.0	38.5	39.6	33.4	35.7	32.1	30.0	28.1	31.0	33.1	31.1	33.1
2018	30.8	33.0	33.6	35.2	37.1	37.7	35.2	34.2	35.5	34.7	32.8	31.9	34.3
2019	33.5	35.3	36.9	36.6	37.6	37.6	36.1	34.9	34.1	32.6	35.3	35.5	35.5
2020	31.3	33.5	33.2	35.0	38.1	39.3	35.3	34.1	34.7	35.2	32.9	32.6	34.6
2021	31.6	34.6	35.1	35.9	35.7	36.8	34.4	34.5	35.1	34.9	32.7	31.6	34.4
Average	31.7	34.0	35.4	36.3	37.7	38.3	35.2	33.6	34.6	34.0	32.8	31.7	34.6

Appendix table 7: Mession average maximum temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1997	29.9	30.4	32.4	31.1	34.6	32.7	31.3	31.2	33.4	30.3	28.5	27.0	31.1
1998	27.5	29.2	30.3	33.1	33.9	35.1	31.1	29.7	29.2	29.3	28.9	28.3	30.5
1999	28.7	31.3	28.8	32.4	33.6	33.6	30.0	29.5	29.9	27.6	28.4	27.8	30.1
2000	29.0	30.4	32.0	32.1	33.5	33.8	31.7	30.0	29.7	29.0	28.2	27.8	30.6
2001	27.3	30.0	29.9	33.0	33.9	33.1	32.0	28.8	29.5	31.1	29.9	29.0	30.6
2002	27.2	30.7	31.6	32.4	35.1	34.5	33.7	31.7	31.4	32.4	30.9	27.7	31.6
2003	28.7	31.7	32.2	31.8	34.6	33.3	31.4	29.8	30.2	32.1	30.5	28.1	31.2
2004	29.7	29.8	30.6	30.5	34.9	34.0	32.1	31.4	30.9	29.9	30.2	29.1	31.1
2005	29.4	32.2	31.5	32.0	30.8	32.5	30.0	31.0	31.0	31.1	30.1	28.6	30.9
2006	29.3	30.9	30.9	30.0	32.9	34.2	31.9	29.7	30.7	30.4	29.8	27.3	30.7
2007	28.2	30.8	32.6	31.1	34.2	33.4	31.0	29.4	29.6	30.6	29.6	27.7	30.7
2008	29.0	29.0	33.1	32.0	32.9	33.2	32.2	30.9	31.6	31.5	27.3	27.7	30.9
2009	28.1	31.0	32.6	31.7	34.2	34.9	32.6	31.8	32.2	30.3	30.4	28.1	31.5
2010	28.8	29.2	28.7	30.9	33.2	34.5	31.2	31.0	30.4	30.6	29.1	28.1	30.5
2011	31.0	33.6	32.3	33.2	32.3	34.1	32.5	29.9	30.0	31.3	29.8	27.4	31.4
2012	28.8	30.6	32.5	31.9	34.2	33.6	31.3	30.1	30.7	31.4	30.8	29.7	31.3
2013	29.5	31.2	32.6	32.6	32.9	34.2	30.8	29.3	31.0	31.0	29.7	28.5	31.1
2014	29.4	29.2	31.5	31.3	32.4	32.5	30.8	28.7	30.4	29.7	28.6	28.5	30.2
2015	29.5	30.3	31.6	31.2	33.8	33.5	34.0	32.8	32.1	32.8	30.4	29.0	31.8
2016	29.1	30.7	35.3	33.0	31.4	33.4	31.2	28.7	29.5	32.0	29.7	28.7	31.1
2017	26.9	30.0	33.4	33.4	32.0	35.2	29.7	29.3	29.9	31.0	30.3	27.4	30.7
2018	27.9	31.1	30.6	30.1	31.7	32.3	30.9	30.2	31.2	31.4	29.5	29.1	30.5
2019	29.8	31.7	33.5	32.9	32.9	32.4	30.6	29.8	29.7	28.4	28.7	27.1	30.6
2020	28.0	30.4	30.3	33.7	29.7	29.3	29.9	31.8	30.1	29.0	28.6	31.1	30.2
2021	27.4	29.6	30.7	29.2	31.0	34.0	31.6	29.3	30.4	30.3	30.2	28.5	30.2
Average	28.7	30.6	31.7	31.9	33.1	33.5	31.4	30.2	30.6	30.6	29.5	28.3	30.8

Appendix table 8: Awash Arba average minimum temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1997	17.4	13.5	20.4	20.7	21.4	23.6	23.6	22.2	22.3	20.4	17.4	12.9	19.6
1998	19.1	19.8	22.1	21.7	22.3	25.9	23.1	22.6	21.8	20.0	14.2	11.5	20.3
1999	15.0	16.1	20.7	19.8	22.2	24.6	21.9	22.5	21.0	17.5	14.5	14.0	19.1
2000	13.0	14.1	18.3	20.5	23.3	26.1	21.8	21.1	21.0	17.9	15.2	13.7	18.8
2001	14.6	15.1	20.0	19.5	23.2	24.9	21.9	21.2	20.0	18.2	13.8	15.0	18.9
2002	17.1	16.5	20.5	21.0	23.0	24.7	24.2	22.0	21.4	18.0	15.2	19.0	20.2
2003	17.9	19.9	21.5	20.7	20.2	23.8	21.7	21.6	21.2	17.3	16.6	15.4	19.8
2004	19.0	16.3	17.3	20.8	20.6	23.4	21.8	21.8	21.2	17.4	16.0	16.8	19.4
2005	17.7	16.8	20.6	20.1	21.6	24.2	22.2	21.7	21.7	17.5	15.3	12.5	19.3
2006	16.4	19.5	19.1	20.3	21.3	25.2	22.2	21.3	21.5	19.3	15.8	17.3	19.9
2007	17.2	18.4	18.9	20.1	22.8	24.3	21.3	20.2	20.8	16.6	15.0	12.6	19.0
2008	13.4	11.8	15.2	20.0	16.9	21.9	17.9	16.9	18.3	15.5	12.3	9.9	15.8
2009	11.3	13.3	15.9	14.0	13.8	15.7	15.2	13.9	16.3	12.3	7.3	18.7	14.0
2010	17.2	18.8	19.3	22.2	23.2	25.4	22.3	22.1	21.5	20.2	17.2	11.5	20.1
2011	15.3	16.9	16.9	20.2	20.9	21.7	23.2	21.6	22.0	19.0	19.5	8.4	18.8
2012	15.2	15.7	18.2	19.7	23.6	25.0	21.5	20.7	21.8	18.7	17.6	16.9	19.5
2013	16.3	17.6	21.1	23.0	23.9	25.4	21.4	21.3	22.1	20.5	19.4	15.0	20.6
2014	16.8	19.8	20.8	22.1	23.6	25.2	23.2	22.0	22.1	19.9	18.9	15.6	20.8
2015	16.2	17.9	21.1	21.7	23.6	24.8	25.0	22.9	22.7	22.5	20.2	19.3	21.5
2016	19.1	18.6	23.6	22.0	22.4	24.7	22.2	22.1	21.7	19.0	17.6	16.0	20.7
2017	13.4	18.9	20.6	22.8	22.3	24.7	21.8	21.0	22.2	21.3	18.1	14.1	20.1
2018	14.7	12.1	15.7	17.2	17.4	16.8	17.0	20.7	21.7	20.9	19.5	17.1	17.6
2019	15.2	19.8	16.3	16.5	23.4	24.2	21.8	21.9	20.9	18.5	19.3	17.7	19.6
2020	14.3	20.0	19.8	22.6	22.6	24.3	22.4	21.7	20.7	19.2	17.9	15.5	20.1
2021	13.4	18.9	21.8	22.2	22.3	24.1	22.4	22.5	22.4	18.9	17.9	15.8	20.2
Average	15.8	17.0	19.4	20.4	21.7	23.8	21.7	21.2	21.2	18.7	16.5	14.9	19.4

Appendix table 9: Bordede average minimum temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1997	19.1	14.8	22.4	22.7	23.5	25.9	25.9	24.4	24.5	22.5	19.2	14.2	21.6
1998	21.0	21.8	24.3	23.9	24.5	28.4	25.4	24.9	24.0	22.1	15.6	12.6	22.4
1999	16.5	17.7	22.8	21.8	24.4	27.1	24.1	24.8	23.1	19.3	15.9	15.4	21.1
2000	14.3	15.5	20.1	22.6	25.6	28.7	24.0	23.2	23.1	19.7	16.7	15.0	20.7
2001	16.0	16.6	22.0	21.5	25.5	27.3	24.1	23.3	22.0	20.1	15.2	16.4	20.9
2002	18.8	18.2	22.5	23.1	25.4	27.2	26.6	24.3	23.6	19.8	16.7	20.9	22.3
2003	19.7	21.8	23.6	22.7	22.2	26.1	23.9	23.7	23.4	19.0	18.3	17.0	21.8
2004	20.9	18.0	19.0	22.9	22.7	25.7	23.9	24.0	23.3	19.2	17.6	18.5	21.3
2005	19.4	18.5	22.7	22.1	23.7	26.6	24.4	23.8	23.8	19.2	16.8	13.7	21.2
2006	18.1	21.5	21.0	22.3	23.4	27.8	24.4	23.4	23.7	21.3	17.4	19.0	21.9
2007	18.9	20.3	20.7	22.1	25.1	26.7	23.4	22.3	22.9	18.2	16.5	13.9	20.9
2008	15.5	15.4	13.8	20.9	22.2	21.3	22.1	21.4	21.1	17.8	15.5	12.0	18.2
2009	15.5	17.6	19.8	20.8	20.4	23.9	23.3	22.6	22.4	18.9	15.7	18.8	20.0
2010	16.3	19.3	19.3	21.6	23.4	24.8	22.7	22.0	21.5	17.8	16.1	13.5	19.8
2011	16.1	18.9	24.5	25.4	22.1	24.3	23.1	22.3	24.2	21.8	23.1	14.9	21.7
2012	16.0	16.6	19.0	21.9	21.6	24.8	23.3	22.0	22.1	17.8	16.4	15.6	19.7
2013	14.3	16.4	21.4	22.7	23.8	26.4	22.0	22.3	22.3	19.6	17.8	13.3	20.2
2014	15.5	20.1	19.8	21.5	22.2	22.7	23.5	19.3	20.2	18.1	12.9	15.3	19.2
2015	6.9	14.4	13.7	13.3	17.8	18.6	16.8	18.8	19.2	18.2	11.6	12.5	15.1
2016	13.4	11.9	15.9	11.7	13.2	16.0	16.4	16.3	16.1	12.5	8.9	13.4	13.8
2017	12.1	13.9	17.4	20.6	13.6	11.8	11.5	12.1	16.0	14.0	15.5	12.1	14.2
2018	14.3	18.1	19.8	22.6	23.3	24.3	22.4	21.7	20.7	19.2	17.9	15.5	20.0
2019	13.4	18.9	21.8	22.2	22.3	24.1	22.4	22.5	22.4	18.9	17.9	15.8	20.2
2020	13.2	17.9	19.7	21.2	21.1	24.4	22.7	21.6	20.7	17.1	14.6	18.0	19.3
2021	18.2	16.3	21.8	21.0	21.0	23.5	21.1	20.1	19.8	15.8	16.0	13.4	19.0
Average	16.1	17.6	20.4	21.4	22.2	24.3	22.5	21.9	21.8	18.7	16.2	15.2	19.9

Appendix table 10: Mession average minimum temperature

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1997	10.9	8.2	14.7	16.2	18.3	17.4	17.1	16.9	16.2	14.4	13.9	9.7	14.5
1998	12.1	13.7	15.2	16.3	16.9	17.1	16.6	17.5	17.0	15.3	9.7	8.1	14.6
1999	10.6	12.6	15.5	16.2	17.2	17.7	17.4	17.3	16.0	14.7	9.3	8.4	14.4
2000	8.5	10.0	13.6	16.2	17.6	18.1	17.7	17.3	17.0	14.1	11.8	9.7	14.3
2001	9.5	11.7	16.1	16.3	17.5	18.2	18.4	17.7	16.2	14.7	10.8	10.8	14.8
2002	12.8	11.6	16.2	16.7	18.7	18.5	18.8	18.4	17.1	14.3	11.9	15.1	15.8
2003	12.9	13.8	16.0	17.7	17.3	18.5	18.4	18.0	17.2	13.3	12.2	10.7	15.5
2004	13.9	12.6	13.6	17.5	17.2	18.4	18.1	18.5	16.5	13.5	11.5	11.7	15.2
2005	12.1	12.2	16.7	16.4	17.8	18.4	17.7	17.9	17.0	13.3	11.0	8.2	14.9
2006	12.1	14.5	15.4	17.0	16.9	18.4	18.5	17.9	17.4	15.7	12.1	12.8	15.7
2007	12.9	14.7	15.8	17.6	18.6	18.8	18.1	17.8	17.3	12.6	10.8	10.8	15.5
2008	11.5	11.1	12.2	17.6	18.2	18.2	18.3	18.2	17.2	14.6	12.4	9.4	14.9
2009	12.2	13.2	15.7	17.2	17.9	18.6	18.3	17.8	16.8	14.3	10.3	13.8	15.5
2010	10.7	15.2	14.4	16.5	16.6	16.8	15.7	15.7	14.4	11.2	8.7	5.7	13.5
2011	7.9	9.3	10.7	14.4	14.9	16.5	18.9	18.4	16.9	11.6	12.5	8.6	13.4
2012	10.2	10.8	13.5	17.5	17.0	18.9	18.1	17.7	16.3	12.2	11.3	11.4	14.6
2013	11.5	12.0	16.4	17.9	18.3	18.6	18.0	17.5	16.6	14.3	12.8	8.1	15.2
2014	13.9	12.5	13.5	17.5	17.2	18.4	18.0	18.4	16.6	13.7	11.5	11.7	15.2
2015	13.5	14.8	15.8	16.9	17.6	17.9	19.4	18.9	17.9	16.4	14.5	14.1	16.5
2016	14.6	12.9	17.6	17.1	16.6	16.9	16.8	17.3	16.1	13.8	11.9	10.0	15.1
2017	7.2	13.9	15.0	16.5	18.2	19.2	17.7	17.2	17.4	15.3	11.5	9.0	14.8
2018	9.2	13.4	15.5	17.8	17.4	18.2	18.2	17.7	16.5	15.3	14.1	11.2	15.4
2019	10.4	15.1	17.3	18.6	18.6	19.5	18.7	18.5	18.3	14.6	14.2	12.2	16.3
2020	13.8	14.8	17.4	18.5	18.4	18.9	18.6	18.8	17.0	12.7	12.2	10.8	16.0
2021	10.0	12.8	18.8	15.4	17.2	18.0	17.9	17.7	17.0	15.2	11.2	12.3	15.3
Average	11.4	12.7	15.3	16.9	17.5	18.2	18.0	17.8	16.8	14.0	11.8	10.6	15.1