JIMMA UNIVERSITY
SCHOOL OF POSTGRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULITY OF CIVIL AND ENVIRONMENTAL ENGINEERING
CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING
MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

GIS-BASED PHYSICAL LAND SUITABILITY ASSESSMENT FOR SURFACE IRRIGATION: CASE OF KATAR RIVER WATERSHED, ETHIOPIA

BY: DESU MEGRA HIRPO

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING.

JANUARY, 2020

JIMMA, ETHIOPIA

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MAIN ADVISOR: Dr.-ING. FEKADU FUFA (PhD)
CO-ADVISOR: Mr. NASIR GEBI (MSc.)

JANUARY, 2020

JIMMA, ETHIOPIA

DECLARATION

I hereby declare that the Thesis entitled "**GIS-BASED PHYSICAL LANDASSESSMENT FOR SURFACE IRRIGATION:** CASE OF KATAR RIVER WATERSHED, ETHIOPIA**"** is my original work which I submit for partial fulfillment of the degree of Master of Science in Hydraulic Engineering to school of graduate studies of Jimma University; Jimma Institute of Technology; Hydrology and Hydraulic Engineering Chair. The Thesis was conducted under the guidance of main advisor, Dr.-Ing. Fekadu Fufa (PhD) and Co-Advisor, Mr. Nasir Gebi (MSc.)

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This Thesis has been submitted for examination with my approval as a university supervisor.

Main Advisor	Signature	Date
Dr.-Ing. Fekadu Fufa (PhD)	-----------------------	-------------------

Co-Advisor	Signature	Date
Nasir Gebi (MSc.)	-----------------------	------------------

APPROVAL

The thesis entitled “**GIS-BASED PHYSICAL LAND SUITABILITY ASSESSMENT FOR SURFACE IRRIGATION:** CASE OF KATAR RIVER WATERSHED, ETHIOPIA” submitted by Desu Megra Hirpo is approved and accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering at Jimma Institute of Technology.

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Advisor: Dr.-Ing Fikadu Fufa (PhD)	____________	___________
Co-Advisor: Mr. Nasir Gebi (MSc.)	____________	___________

As members of the examining board of MSc. thesis, we certify that we have read and evaluated the thesis prepared by Desu Megra Hirpo. We recommend that the thesis could be accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

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External Examiner:	________________	_____________
Internal Examiner:	________________	_____________
Chairman:	________________	_____________

ABSTRACT

The is study aimed to assess the physical land suitability for surface irrigation in Katar River watershed by using Geographic Information System (GIS). Watershed delineation, identification of irrigable land, and estimation of surface runoff and irrigation water requirements were the steps followed. Irrigation suitability factors such as slope, characteristics of soil such as type, texture, depth, drainage and land use/cover were classified based on the Food and Agricultural Organization guideline for land evaluation in to highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and marginally not suitable (N) suitability classes independently, where the final potentially irrigable land was identified by weighting the factors of suitability. Irrigation water requirement of four commonly grown crops (Tomato, potato, Cabbage and small vegetables) were computed from climate, crop and soil data inputs using Crop Water Requirement *(CropWat8.0) software and the capacity of low flow (90% time of exceedance flow of Katar River) were estimated. The suitability analysis of the parameters indicated that 45.33% of slope, 99.6 % of soil, and 79.9 % land use/cover of the study area were classified as potentially suitable for irrigation development. By weighing analysis of all parameters 93.47 % of the study area was found in a range highly suitable to that of marginally suitable whereas about 6.53 % was restricted for irrigation developments. By comparing the required water and available monthly flow of the river, the river had insufficient capacity for irrigation application of the command area.*

Key Words: *CROPWAT; GIS; Irrigation potential; Katar River Watershed;*

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ACRONYMS

AHP	Analytical Hierarchy Process
CROPWAT	Crop Water Requirement
CRV	Central Rift Valley
DEM	Digital Elevation Model
ESRI	Environmental System Research Institute
ET_o	Potential Evapotranspiration
FAO	Food and Agriculture Organization
GIS	Geographic Information System
IWMI	International Water Management Institute
Kc	Crop coefficient
Mha	Million hectares
MoA	Ministry of Agriculture
MoWIE	Ministry of Water, Irrigation & Electricity
NGO	Non-Governmental Organization
NMSA	National Meteorological Agency
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission
UTM	Universal Trans-Mercator

1. INTRODUCTION

1.1. Background

The definition of irrigation potential is not straightforward and involves 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 water. However, to assess the information on land and water resources at the river basin level, knowledge of physical irrigation potential is necessary (Ganole, 2010). The area which can potentially be irrigated depends on the physical resources such as soil, slope, LULC 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).

Currently, the population of the planet is increasing radically. Today's world population of 7.5 billion is expected to reach about 8.5 billion by 2030, an increase of 50 % (Ababa, 2005). The growing population resulted in considerable additional demand for food. A current FAO analysis of 93 developing countries expects agricultural production to increase over the period 1998–2030 by 49 % in rain-fed systems and by 81 % in irrigated systems (Playan and Mateos, 2006). Therefore, much of the additional food production are expected to come from irrigated land, three quarters of which are located in developing countries (Alexandratos and Bruinsma, 2012).

Although irrigation in Africa has the potential to boost agricultural productivity by at least 50 %, food production on the continent, it is almost entirely rain-fed. The area equipped for irrigation, currently slightly more than 13 million hectares, makes up just 6% of the total cultivated area. More than 70 % of Africa's poor live in rural areas and mostly depend on agriculture for their livelihoods. As a result, agricultural development is key to ending poverty on the continent **(**You et al., 2011**).**

Ethiopia is home to approximately 96.6 million people, which makes it the second most populous country in Africa only after Nigeria with an annual growth rate of 2.89 percent and the country is projected by the UN to be among the world's most populous countries by 2050 (WHO/UNICEF, 2014).

About 85 % of the population in the country lives in rural and dependent on agriculture with a low level of productivity. 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 (Ganole, 2010). As a result of this, the country continues to receive food aid for about 10% of the population who are at risk annually (Wale et al., 2013). Moreover, the country has a large potential of land and water resources that could be easily developed for irrigation. In Ethiopia, irrigable land potential is estimated to be 6 million hectares with which 8 % can be irrigated using ground water (Worqlul, *et al*., 2017). The rest of irrigable land (3.8 Mha and 0.6 Mha) can be irrigated with Surface Water Potential and Rain Water Harvesting respectively (Awulachew *et al*., 2010). The country is endowed with ample water resources with 12 river basins with an annual runoff volume of 124.4 billion m^3 of water and an estimated 30-40 billion m^3 of groundwater potential (Ayalew, 2018). In developing supplementary irrigation, evaluating and assessing the potential and suitability of the land area is to provide a comprehensive and integrated economic viability and sustainability of water resource development. Therefore, the planning process for irrigation has to integrate information about the suitability of the land and water resources availability

Katar watershed is a part of Ziway–Meki Sub-basin which is internal drainage basin located in the northern part of the Main Ethiopian Rift Valley. Katar River and its tributaries drain from south east highland area of Ethiopia to North West and enter Lake Ziway. This River is the biggest perennial river in Ethiopian central Rift valley and has a total watershed area more than 3,500km^2. Even though the area is rich in water and land resources, irrigation potential of the area had not been identified. Hence, the aim of this study is to assess physically suitable land for surface irrigation, to identify Crop Water Requirement and compere with existing Surface water by evaluating previous river discharges using available data for Katar River Watershed.

1.2. Statement of the Problem

Proper assessment of the suitability of a command area plays a significant role in the subsequent sustainability of an irrigation scheme. Attempt to evaluate the suitability of an irrigation land has been a growing interest by researchers and development partners. For instance, Abraham, et al., (2015) revealed that, in developing supplementary irrigation, evaluating and assessing the potential and suitability of the land area is important for better utilization of land resources. However, in Ethiopia, this is almost ignored and any type of irrigation is practiced without proper investigation on the potential of the area for irrigation purpose. Irrigation planning process requires integration of information about the suitability of the land, water and climatic conditions. Irrigation water supplies and their requirements are important physical factors in matching the available supply to the requirements. The physical and chemical land resources that have great contribution on evaluation of land suitability for specific use must also be evaluated on condition that water can be supplied to it. Land evaluation is related with the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable (FAO, 1985). Dagnenet (2013) revealed that, irrigation land suitability assessment and mapping play an imperative role for sustainable utilization of scarce physical land resources. Sound information on soils, water and other land characteristics provide a basis for decision making on proper utilization and management of natural resources. The importance of land evaluation points to opportunities for influencing future developments of soils in the region using management techniques that are tailored to the characteristics of the landscape elements. The factors that are involved for irrigation potential assessment such as soil, land use/cover and slope gradient could be weighted and evaluated. AHP method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix, in which all relevant criteria identified are compared against each other based on preference factors. The weights can then be aggregated. 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.

The climatic condition of East-Arsi zone is changing from time to time and crop production through rain-fed agriculture has become uncertain. To overcome such difficulties, irrigation is a sole option. Irrigation is important there by assisting the rainy season and also by creating an opportunity to produce without rain. Katar River discharges water from the plateaus found at eastern and south-eastern from Ziway-Meki Sub-basin into Lake Ziway. Even though the watershed has abundant water and land resources, it is not yet fully assessed to what extent it can be irrigated. Hence, the aim of this study is to assess physically suitable land for surface irrigation, identify Crop Water Requirement for dominant crops cultivated in the Watershed and compere with existing Surface water by evaluating previous river discharge using available data for Katar River Watershed.

1.3. Objectives

1.3.1 General Objective

The general objective of this study is to assess physical land suitability for Surface irrigation in Katar River watershed.

1.3.2. Specific Objectives

Based on the statement of the problem, the following specific objectives were proposed which were evaluated and achieved by the research out puts.

1. To delineate main river catchments using GIS from digital elevationmodel (DEM)
2. To compare total irrigation water requirement and potential of katar river flow
3. To develop map of irrigable land in the watershed.

1.4. Research Questions

To achieve the research objectives, it is necessary try to answer the following research questions based on the data collection and analysis out puts.

1. How was the distribution of the river catchment?

2. How much are the exploitable river flow potential and irrigation water requirement in the area?

3. What portions of the lands are suitable for irrigation in the river watershed?

1.5. Justification of the study

The information that was generated by this study will help development practitioners and the community in the area to design good irrigation strategies and based on the findings, to improve irrigation practices and capability of utilizing. The finding of the study will also assist in identifying the challenges, alternatives in policy formulation and planning of appropriate programs regarding utilization of large and medium-scale projects. Besides, the finding of this study will be used, by individual researchers, the community, governmental and NGOs in the Catchment and as a baseline data for further study.

1.6. Scope of the Study

This study was, essentially a watershed level study with an areal extent of 3,580.1 km^2 upstream the gauging station (Abura) and focused mainly on the assessment of irrigable land, total irrigation water requirement and potential of katar river flow. physically irrigable land was evaluated by implementing a digital elevation model (DEM) to develop slope map, land use/cover and soil data on ArcGIS. In addition, estimation of irrigation water demand was carried out using Cropwat8.0 and River flow potential was evaluated. AHP method was used to calculate the required weights associated with the respective criterion map layers with the help of a preference matrix.

1.7. Limitations of the study

Data availability and accuracy were very important to conduct the thesis. Wrong and incomplete data lead to incorrect result.

The important data for GIS such as soil and land use/cover map which were taken from MoWIE did not contain sufficient information which were necessary for conducting the thesis. The calculation of irrigation water requirement and assessment of river flow potential needs the correct meteorological and flow data. However, most of meteorological stations from which those data were collected were not correctly recorded. Availability of flow data for the study area in gaging station with high missing can affect the final output if not filled appropriately.

2. LITERATURE REVIEW

2.1. General

Different documents reviewed for this Thesis which can help to develop knowledge about surface Water potential, land suitability assessment, Surface irrigation potential assessment and application of GIS and remote sensing in irrigation networks management, application AHP and MCA.

2.2. Irrigation Potential

Irrigation may be defined as the science of artificial application of water to the land in accordance with the crop requirements throughout the crop period for full-fledged nourishment (Garg, S.K., 1980).

The definition of irrigation potential is not straightforward 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. (Ganole, 2010). However, to assess the information on land and water resources at the river basin level, knowledge of physical irrigation potential is necessary. Therefore, physical irrigation potential represents a combination of information on gross irrigation water requirements, area of land suitable for irrigation and available water resources by basin (FAO, 1997).

2.3. Irrigation Potential in Ethiopia

If successful, irrigation in Ethiopia could represent a cornerstone of the agricultural development of the country, contributing up to ETB 140 billion to the economy and potentially moving up to 6 million households into food security. Ethiopia comprises 112 million hectares (Mha) of land. Cultivable area estimates vary between 30 to 70 Mha (Awulachew *et al*., 2010). Currently, the MoWR (Ministry of Water Resources) has identified 560 irrigation potential sites on the major river basins

Different studies estimate that over the next two decades, Ethiopia could irrigate over 5 Mha with existing water sources (Awulachew *et al*., 2010). Medium- and largescale schemes were an important strategy to achieve this aspiration, in combination with exploring and developing groundwater potential, especially given that an estimated 85 percent of Ethiopia’s total surface water irrigation potential is estimated to be in large-scale schemes. Moreover, large-scale schemes will play a critical role in helping Ethiopia overcome the correlation between rainfall and agricultural growth, a goal no country has achieved without large-scale irrigation interventions (Yihdego et al., 2015)

2.4. Water Resources

Ethiopia is blessed with ample water resources in central, western and south western parts, while most of North Eastern and Eastern parts of the country are relatively dry. The distribution and availability of water is erratic both in space and time. Hence, despite abundance in some parts the country is highly water-scarce due to lack of water control infrastructure (Kitila *et al*., 2014).

2.4.1. Surface Water Resource

2.4.1.1. Major river basins and lakes

Ethiopia constitutes 99.3% of land area and the remaining 0.7 % is covered with water bodies (MOWE, 2013). The country is divided into 12 basins; 8 of which are river basins; 1 lake basin; and remaining 3 are dry basins, with no or insignificant flow out of the drainage system. Although it needs update and further detailed investigation, the country's surface water potential as identified and estimated in different integrated river basin master plans is 124.4 billion cubic meter (BCM) (Berhanu, *et al*., 2014).

Ethiopia has 11 fresh and 9 saline lakes, 4 artificial lakes and over 12 major swamps or wetlands. These lakes are distributed in different parts of the country especially in the central, south and south west areas (Ayalew, 2018). Majority of the lakes are found in the Rift Valley Basin. The total surface area of these natural and artificial lakes in Ethiopia is about 7,500 km^2 (Makombe *et al.,* 2007). They store sufficient volume of water that can be used for different purposes. The country has about 70 BCM lake water and part of this water (5.7 billion cubic meter) is exposed to evaporation (Ayalew, 2018).

The majority of Ethiopian lakes are rich in fish. Most of the lakes except Ziway, Tana, Langano, Abbaya and Chamo have no surface water outlets. Lake Shala and Abiyata have high concentrations of chemicals and Abiyata is currently exploited for production of soda ash (Awulachew, 2019).

2.4.2. Ground Water Resources

As compared to surface water resources, Ethiopia has lower ground water potential. However, by many countries' standard the total exploitable groundwater potential is high (Makombe *et al*., 2007).

Based on the available data on groundwater resources, the potential is estimated to be about 30-40 Billion m^3 (Ayalew, 2018). Annually rechargeable resources estimated that at least 13.2 billion m^3 infiltrates into the groundwater system of which 50 percent could be extractable (Makombe et al., 2007).

As demonstrated above, Ethiopia has sufficient surface water and groundwater potential for irrigation development. However, this potential is not fully utilized and translated into development because of many factors including limited financial resources, technical challenges, and lack of water control infrastructure (Berhanu, *et al*., 2014).

2.5. Previous Studies

2.5.1. Assessment of Land Use/Land Cover Change Impact on Stream Flow Using SWAT Model (The Case Study of Katar Catchment) by Tolera Kabeto March, 2018)

The Katar watershed, which is the major contributor of runoff for Lake Ziway is very sensitive to land use and land/cover change. The dominant land use in the Katar watershed is agriculture. The basin is as a whole intensively cultivated and different crops are grown in the basin using both rain and irrigation. The Katar irrigation Scheme was established by government in Tiyo Woreda, Oromia Region in 1987. The main crops produced in this scheme are onion, cabbage, potato, sugarcane, carrot Crops like teff, maize and bean are also cultivated during the rainy season. The catchment provides water for domestic (rural and urban water supply) and agriculture sectors.

In general, from this study the impact of land use/land cover change on hydrological components of Katar stream flow showed that the base flow and surface flow have been changed in the study period. The base flow decreased while surface runoff increased as a result of urbanization, agricultural land expansion and decrease of forest evergreen.

2.5.2. SWAT Based Hydrological Modeling of Ketar Watershed, Lake Ziway Catchment, Ethiopia (Damtew Fufa, 2015).

According to the study, seven different LU/LC have been identified in the Katar catchment. The identified LU/LC types are: Agriculture, Wetlands (Area that is saturated with water, either permanently or seasonally), Grass (Pasture) land, Forest land, Afro Alpine (Areas covered with vegetation on high land areas and every year green), Settlement areas and Water bodies.

2.5.3. Groundwater–Surface Water Interaction and Analysis of Recent Changes in Hydrologic Environment of Lake Ziway Catchment (Alemu Dribssa June, 2006)

According to the study, Katar River originating from the highlands of Arsi, has drainage area of 3,302 km^2. The average seasonal discharge of the river varies from 7 m^3/s during the months of December to February; and 140 m^3/s in August based on hydrologic data of 1970-2004 obtained from Ministry of Water Resources. The average annual discharge of the river is 409 m^3/s.

In order to quantify net loss of river to groundwater in the stretch of 36.2 km between Fite and Abura stations, the inflow from Fite, Chufa (gauged tributary of Katar River) and ungauged tributaries as well as outflow at Abura station were used. Abura, Fite and Chufa have monthly discharge records of 1970-2004, 1982-2000 and 1981-1999 respectively. Due to establishment of irrigation projects since 1986 in this stretch and absence of well-established abstraction data, mean monthly pre irrigation records of each station was considered in the analysis. Ungauged tributaries between the stations have flows only during wet season from June to October. The monthly contribution from these tributaries (769 km^2) to the river was estimated based on rainfall-runoff relationship for each month of adjacent gauged rivers. Annual channel evaporation loss is less than one million cubic meters and the possibility of change in bank storage could also be very small in annual base; and both are assumed to be negligible in this analysis. Accordingly, the net loss due to the occurrence of fault belt is found to be 86 m^3 annually.

2.5.4. Estimating the Sediment Flux and Budget for a Data Limited Rift Valley Lake in Ethiopia (Aga and Chane, 2019)

According to the study, Katar River is the biggest perennial river in CRV and has a total watershed area of 3,350 km^2. Analysis of the streamflow data indicated that the river's average annual runoff volume is 401.6 Mm^3, it attains a maximum discharge of 110 m^3/s in the month of August and a minimum discharge of 1.6 m^3/s in the month of January.

2.6. Land Suitability Classification for Irrigation

Land suitability is the fitness of a given type of land for a defined use (FAO, 1976). The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 2001). Land evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land. It is a vital link in the chain leading to sustainable management of land resources by considering the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use (FAO, 1976). For irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, slope, land use/cover and distances the land from available water sources as well as terrain conditions in relation to methods of irrigation considered (FAO, 1976).

2.6.1 Structure of the Suitability Classification

In Food and Agriculture Organization Framework for Land Evaluation FAO (1976), the structure of the suitability classification is described recognizing qualitative, quantitative and of current or potential suitability in four categories of decreasing generalization. Each category retains its basic meaning within the context of the different classifications and as applied it different kinds of land use (FAO, 1976). Accordingly, Structure of the suitability is classified as follows:

1. **Land Suitability Orders:** reflecting kinds of suitability.
2. **Land Suitability Classes:** reflecting degrees of suitability within Orders.
3. **Land Suitability Subclasses:** Reflecting kinds of limitation or main kinds of improvement measures required, within Classes.
4. **Land Suitability Units:** reflecting minor differences in required management within Subclasses.

1. Land Suitability Orders

Land suitability order is an indicative for land whether it is Appropriate or not for specific use. Land Suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders Suitable and not suitable represented by the symbols S and N respectively.

Order S suitable: Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.

Order N not suitable: Land which has qualities that appear to preclude sustained use of the kind under consideration.

2. Land Suitability Classes

Land suitability classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic number, in sequence of decreasing degrees of suitability within the Order.

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

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

Class S3 Marginally Suitable: Land having limitations which in aggregate are severe for sustained application of a given use and is so reduce productivity or benefits, or increases required inputs, that this expenditure is only marginally justified. With the order not suitable, there are normally two classes.

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

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

3. Land Suitability Subclasses

Land suitability subclasses reflect kinds of limitations, such as moisture deficiency and erosion hazard. The number of subclasses recognized and the limitations chosen to distinguish them is differ in classifications for different purposes. Subclasses are indicated by lower-case letters like S2m, S2e, and S3me. There are no subclasses in Class S1.

4. Land Suitability Units

Land suitability units are subdivision of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. Suitability units are distinguished by Arabic numbers following a hyphen, for instance, S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass. Depending on the purpose, scale and intensity of the study, either the full range of suitability orders, classes, subclasses and units may be distinguished, or the classification may be restricted to the higher two or three categories.

2.7. Irrigation Land Suitability Factors

The basic physical factors in determining the suitability of land for irrigation are soil, topography, drainage, water quality and quantity, and climate. Water and climate differ from the others in that they are usually uniform throughout the specific area to be investigated (Stanhill, 2002.). For irrigation land suitability analysis, particular attention is given to the physical properties of the soil, the distance from available water sources and the terrain conditions in relation to methods of irrigation considered (Godfray *et al.,* 2010). In addition to these factors, land use / land cover types are considered as limiting factors in evaluating suitability of land for irrigation (Kebede *et al.*, 2017).

Soil

The soil is a major factor in the suitability of land for sustained irrigation. Its primary influence is in the productive capacity, but it may also influence production and development costs. A number of soil factors affect farm irrigation system selection. These are soil texture, soil type, soil depth and profiles, soil drainage and soil salinity (*Tariku*, 2017).

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 and erosion. The slope gradient of the land has also great influence on selection of the irrigation methods (FAO, 1990).

Land use / land cover

Land use and land cover can be defined as how land is utilized. For example, residential and industrial land use would be considered one type of developed land use. Land cover is slightly different. A park could be forest, in this land use is a park and land cover is a forest (Tolera, 2018).

Water availability

Water is the most important resource for any country and of the entire society as a whole, since no life is possible without water. The availability of water largely determines the spatial pattern of the Earth's terrestrial biomes (forest, grasslands and deserts): it covers 71% of the Earth's surface providing habitat for fresh and saltwater ecosystems. Water is a major controlling element of the

Earth's climate, and it is water that is largely responsible for sculpting the Earth's surface into the infinitely complex associations of erosion and depositional landforms (Garg, 1980).

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

2.8. Overview of Geographical Information System and Remote Sensing

Work on GIS began in late 1950s, but first GIS software came only in late 1970s from the lab of the Environmental System Research Institute ESRI. Canada was the pioneer in the development of GIS as a result of innovations dating back to early 1960s. Much of the credit for the early development of GIS goes to Roger Tomlinson. Evolution of GIS has transformed and revolutionized the ways in which planners, engineers and managers conduct the database management and analysis (Tariku, 2017).

There was development of GIS in the function of many program computer software which could manipulate for geographic information in many aspects as following:

a) **Weighted overlay**: Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from water supply (Yang, 2003).

b) **Watershed Delineation**: A watershed can be defined as the catchment area or drainage basin that drains into a common outlet. Simply, watershed of a particular outlet is defined as an area, which collects the rainwater and drains through gullies, to a single outlet (Winchell et al., 2008).

c) **GIS in Mapping**: Mapping is a central function of Geographic Information System, which provides a visual interpretation of data. GIS store data in database and then represent it visually in a mapped format. People from different professions use map to communicate. It is not necessary to be a skilled cartographer to create maps. Google map, Bing map, Yahoo map are the best example for web based GIS mapping solution.

Remote sensing is a technology that has close ties to GIS. Remote sensing can provide timely data at scales appropriate to a variety of applications. As such many researchers feel that the use of GIS and RS can lead to important advances in research and operational applications. Merging these two technologies can result in a tremendous increase in information for many kinds of users. Remote sensing is the technique of obtaining information about an object, area, or phenomenon through the analysis or data acquired by a device that is not indirect contact with the object, area, or phenomenon under investigation (Tariku, 2017).

Geographical 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 use/cover, 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.

2.9. AHP Application Concept for Land Suitability Analysis

The Analytic Hierarchy Process (AHP), introduced by Saaty (1980), is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker’s evaluations, thus reducing the bias in the decision making process.

The AHP method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix, in which all relevant criteria identified are compared against each other based on preference factors. The weights can then be aggregated. GIS based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria (Feizizadeh and Blaschke, 2011).

2.10. Overview of CROPWAT Model

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation practice in water resource development (FAO, 1985). CROPWAT is meant as a practical tool to carry out standard calculations for reference evapo-transpiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes (Tariku, 2017). According to FAO (1985) calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop and soil data.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study area, Katar River watershed is sub catchment of Ethiopian Central Rift valley (CRV) Lakes basin.

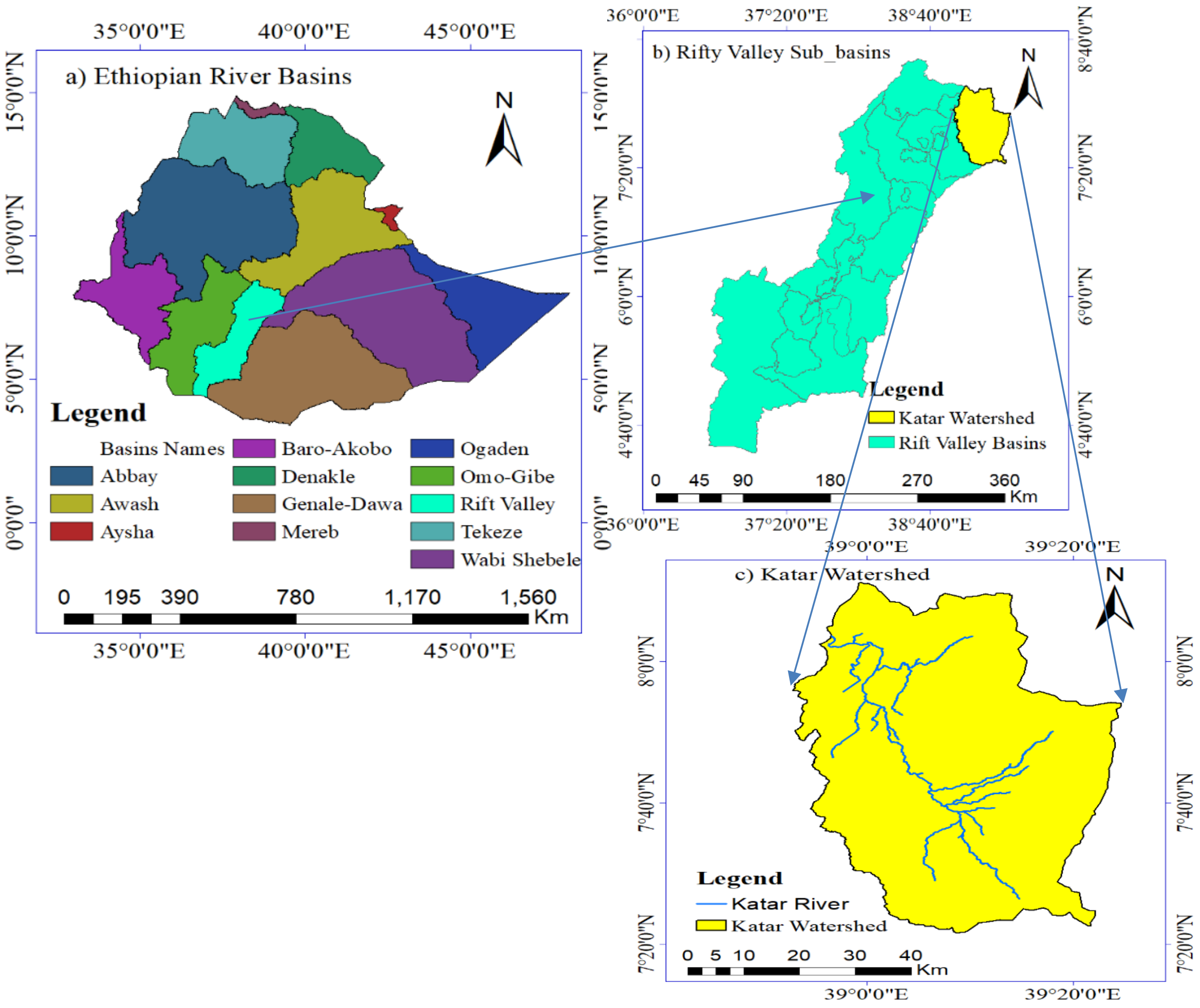

Figure 3. 1: Location map of the study area

The watershed is located in Oromia Regional State at northern part of Ethiopian CRV basin in the part of Ziway-Meki sub- basin. In terms of geographic coordinate system, the watershed lies between

7º21’34’’ to 8º9’55’’ North latitudes and 38º53’57’’ to 39º24’46’’ East longitudes. Katar River and its tributaries start from the eastern parts of mountains Chilalo, Galema and Kakka of Arsi Zone and drains to Lake Ziway. The over flow of Lake Ziway drains to Lake Abiyata. The total area of the watershed, upstream the gauging station (near abura) is estimated to be 3,580 .1 km^2.

3.1.2. Climate

According to Koppen’s climate classification system of Ethiopia, the dominant climatic types are the Hot Arid Climate, the Hot Semiarid Climate, and Tropical Climate with distinct dry winter and Tropical Monsoon Rainy Climate with short dry winter, Warm Temperate Rainy Climate with dry winter and Warm Temperate Rainy Climate without distinct dry season(Tolera, 2018).

The most common Ethiopia climate classification system is traditional classification system mainly relies on altitude and temperature. This shows the presence of five climatic zones. These are, Wurch (cold climate at more than 3000 Mts. altitude), Dega (temperate like climate-highlands with 2500-3000 Mts.altitude), Woina Dega (warm at 1500-2500 Mts. altitude), Kola (hot and arid type, less than 1500m in altitude), and Bereha (hot and hyper-arid types) climates (NMSA, 2001). Katar Watershed falls into Wurch and woindega(warm) according to traditional classification system (Tolera, 2018).

3.1.3. Soil

Soil is a key factor in determining the suitability of an area for agriculture in general and irrigation in particular (Worqlul *et al.*, 2017). Soil data were a major component in study of Land suitability assessment for irrigation. According to previous study (Makin, 1976) the soil type in the study Area, is closely related to parent materials, degree of weathering and the relief that has significant influence on the development of soil types. The main parent materials are basalt, ignimbrite, acid lava, volcanic ash and pumice. According to the FAO/UNESCO soil classification system the study area comprises of Six major soil types, such as Rhodic Nitisol, HaplicLuvisols, Vitric Andosol, Calcaric Fluvisol, Eutric cambisol and Eutric vertisol. The soil raster data set was taken from Ethiopian MoWIE.

3.1.4. Topography

Topographically, the Katar watershed shows variation with altitude ranging from around 1,673 m Near Abura (at gauging Station) to about 4,181 m above mean sea level on the high volcanic ridges along the eastern watershed.

3.1.5. Water Resources Available

The main rivers that flow in study area are Gonde, Kulumsa, Bolkasa, Hadama, Ashebeke, Katar, Dergo and Dima. Katar River is the biggest perennial river in the watershed as well as in Ethiopian central Riftvelly and has a total watershed area of 3,580.1 km^2. The rainfall distribution in the Katar River watershed varies from higher altitudes in the mountainous regions to the low land areas. According to Aga *et al.*, (2019), the Katar River's average annual runoff volume is 401.6 Mm^3, it attains a maximum discharge of 110 m^3/s in the month of August and a minimum discharge of 1.6 m^3/s in the month of January. This shows that there is abundant surface water to apply irrigation practice in the area.

3.2. Materials

Different softwares were used to effectively execute the research. These are:

ArcGIS10.6: was used for Watershed Delineation, finding optimal site for irrigation using weighting of factors such as slope, soil and land use/cover, by weighting overlay in AHP.

CROPWAT 8.0: for estimating ETo, and irrigation water requirement.

Microsoft office Excel: Microsoft Excel is a spreadsheet program used to record and analyze numerical data. The average/mean monthly maximum and minimum Temperature, wind speed, relative humidity and solar radiations data for CropWat8.0 input to calculate ET_o were prepared using the Microsoft Excel 2016 pivot table application. Microsoft Excel 2016 pivot table application was also used to prepare Tables and graphs in the report and also AHP was done in Microsoft exceel.

3.3. Data Collection

To achieve the objectives of the study, different data inputs were collected from different sectors such as National Metrological Service Agency (NMSA), Ministry of Water Resources Irrigation and Electricity of Ethiopia and Ethiopian Mapping Agency (EMA). From those sectors Meteorological data, Hydrological data and spatial data were obtained.

Table 3. 1: Data Types and Sources:

Data types	Data sources
1.Spatial Data	
Digital elevation model	Website: https://vertex.daac.asf.alaska.edu/
Soil map	Ethiopian Ministry of Water, Irrigation and Electricity
Land use/land cover (2013)	Ethiopian Mapping Agency (EMA)
2. Meteorological	
Precipitation, Maximum and Minimum temperature, relative humidity, wind speed and solar radiation	National Meteorological Agency of Ethiopia
3.Hydrological data	
Stream Flow	Ethiopian Ministry of Water, Irrigation and Electricity

1. Spatial Data

Digital elevation model (DEM)

Digital elevation model was one of the essential inputs required for GIS to delineate watershed of the study area. DEM is also required to simulate specific properties of the real world that obstruct or conduct the flow of water such as flow velocity and direction (Haile and Rientjes, 2005). For this study, 12.5 m by 12.5 m meter grid resolution DEM was used to delineate the katar watershed and to develop slope map for reclassification as one of irrigation suitability factors.

Soil Data

Soil data was an input data for GIS as a factor in Land suitability assessment for irrigation. Soil data was also used as input data in CropWat8.0 to calculate irrigation water requirement.

According to the FAO/UNESCO soil classification system the study area comprises of six major soil types, such as Rhodic Nitisol, HaplicLuvisols, Vitric Andosol, Calcaric Fluvisol , Eutric cambisol and Eutric vertisos.

Land use/Land cover

Land use/Land cover is one of the most important factors that affect land suitability for irrigation.

Land use/cover (2013) of the study area was taken from Ethiopian Mapping Agency.

2. Meteorological Data

The meteorological data are daily data that collected from the meteorological station and used as an input for CROPWAT Software. The meteorological data used were daily precipitation, maximum and minimum air temperature, relative humidity, wind speed, and solar radiation.

The selected meteorological station was based on the availability of the data and representative of the total study area. The selected meteorological stations were Sagure, Kulumsa, Bekoji and Assela.

3. Hydrological Data

Stream flow

Sixteen years daily discharge data of Katar River (1995 to 2010) were recorded at Abura gauging station at the downstream of the river near to its outlet to Lake Ziway (Danbal). The measured stream flow data was required to determine river flow potential to determine whether it can satisfy the irrigation requirement of selected crops cultivated in the watershed.

3. 4. Methods

3.4.1. Data Pre-processing and Quality Checking

The continuity of a recorded data may be broken with missing data due to many reasons such as damage or fault in gauging station during a measuring period. So, before starting any model simulation, it is important to check whether the data were consistence, sufficient and complete with no missing data.

3.4.1. Missing data analysis

Both consistency and continuity may be disturbed due to change in observational procedure and incomplete records (missing observations) which may vary in length from one or two days to decades of years. The existing missing data estimated using the data filling methods. Some of the techniques which are used to estimate missing rainfall data are the normal ratio method, arithmetic mean method, inverse distance method, areal precipitation ration method and multiple regression analysis methods (De Silva *et al.*, 2007). For this study, Normal Ratio method was used to fill missing metrological data.

3.4.2. Meteorological Data Analysis

Four meteorological stations such as Assela, Bekoji, Kulumsa and Sagure were selected. The selected meteorological stations were those which found within the watershed and relatively have full weather data (Figure 3.2)

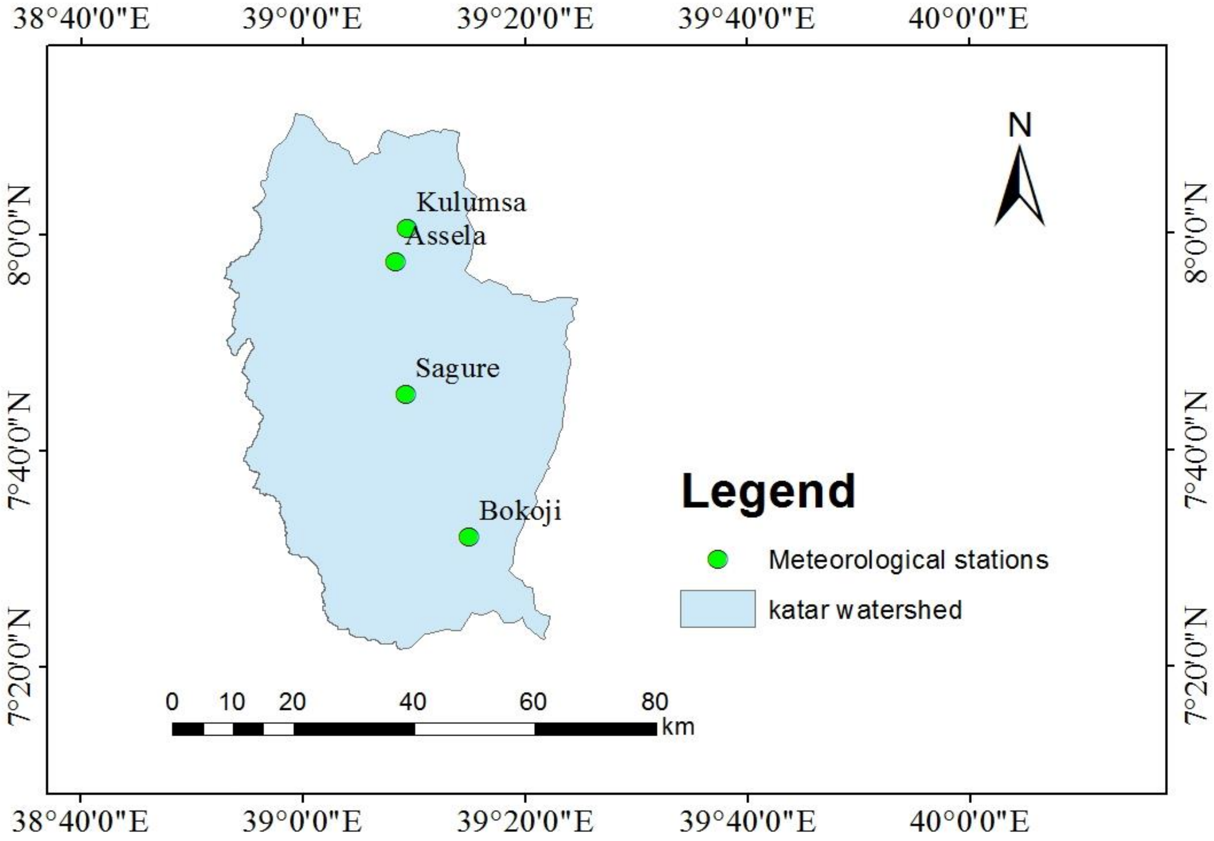

Figure 3. 2: meteorological stations of katar watershed

Climate data which was used in this study consist of daily rainfall, maximum and minimum temperature, wind speed, Relative humidity and solar radiation.

1. Precipitation

The monthly rainfall distributions of the study area indicate that July, August and September are the wettest months of the year in all selected stations except for Sagure. The mean monthly rainfall of Assela, Bokoji, Kulumsa, and Sagure stations for 20 years (1998-2017) were shown in Figure 3.3

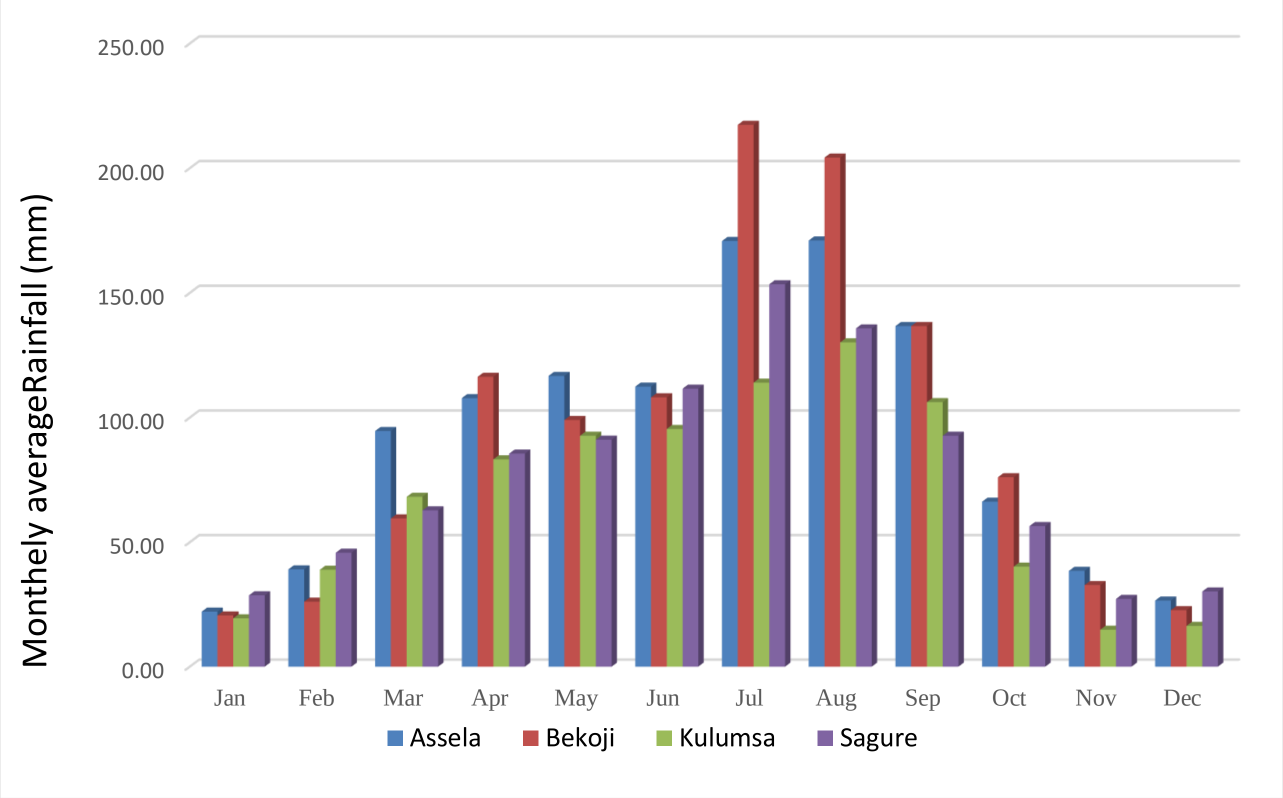

Figure 3.3: Monthly average rainfall for all meteorological stations

The Annual average rainfall of 20 years (1998-2017) for Assela, Bekoji, Kulumsa and Sagure stations were found to be 2009.5, 1119.64, 819.68 and 921.31 mm respectively figure 3.4. The detail was provided in Appendix Table 1

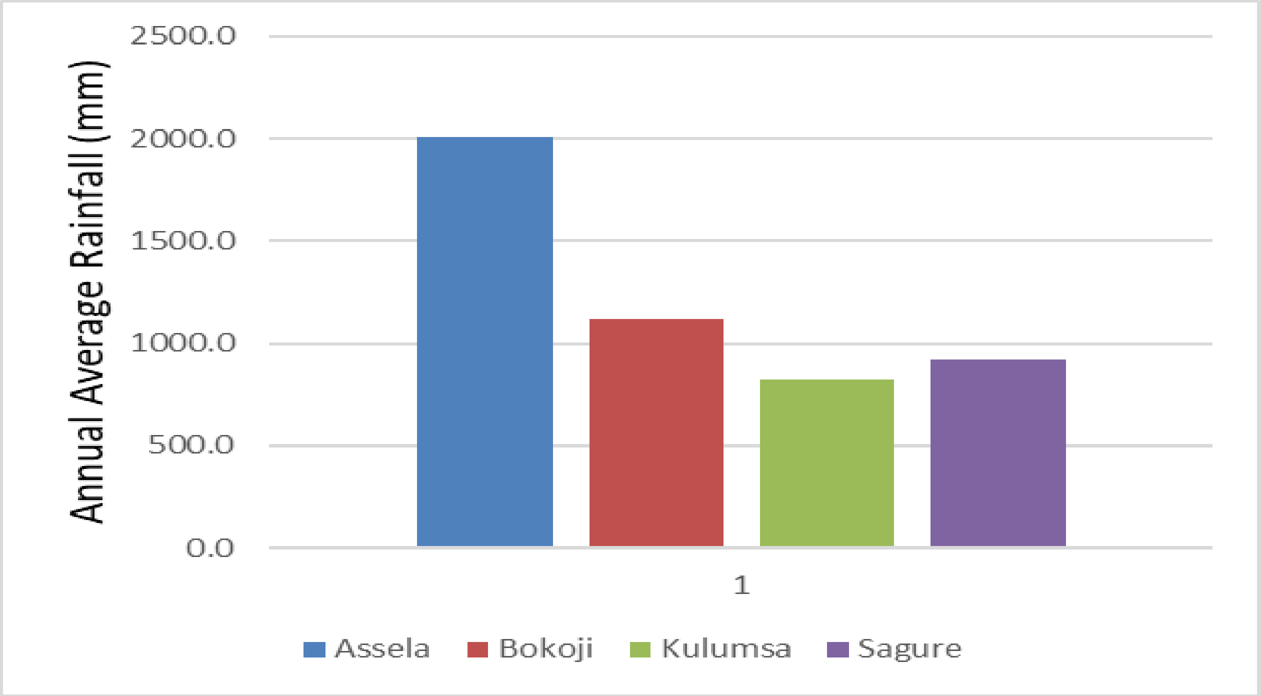

Figure 3.4: Annual average rainfall for all meteorological stations

2. Temperature

The mean annual maximum temperatures over four selected meteorological stations was 25.58 °C. Whereas the mean annual Minimum temperature was about 4.97°C. The maximum monthly average temperature recorded over selected stations was 29.86^{o}C. It is recorded at Kulumsa meteorological station where as the minimum monthly average temperature recorded was 2.10^{o}C at Bekoji meteorological station (Figure 3.5 - 3.8).

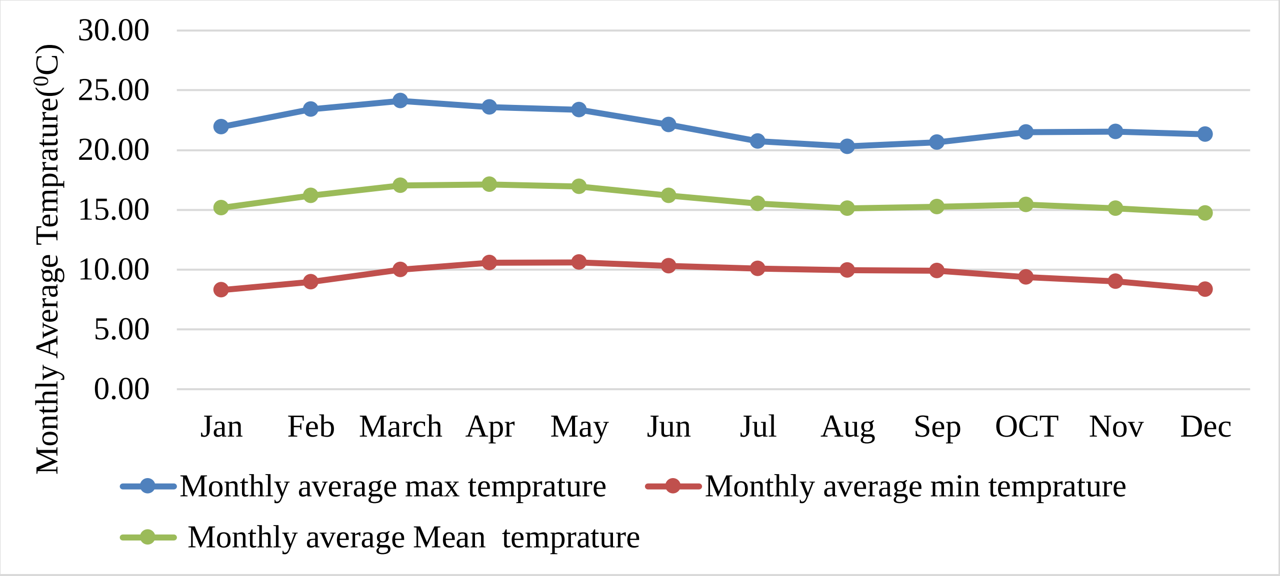

Figure 3.5: Monthly average temperature for Assela Station

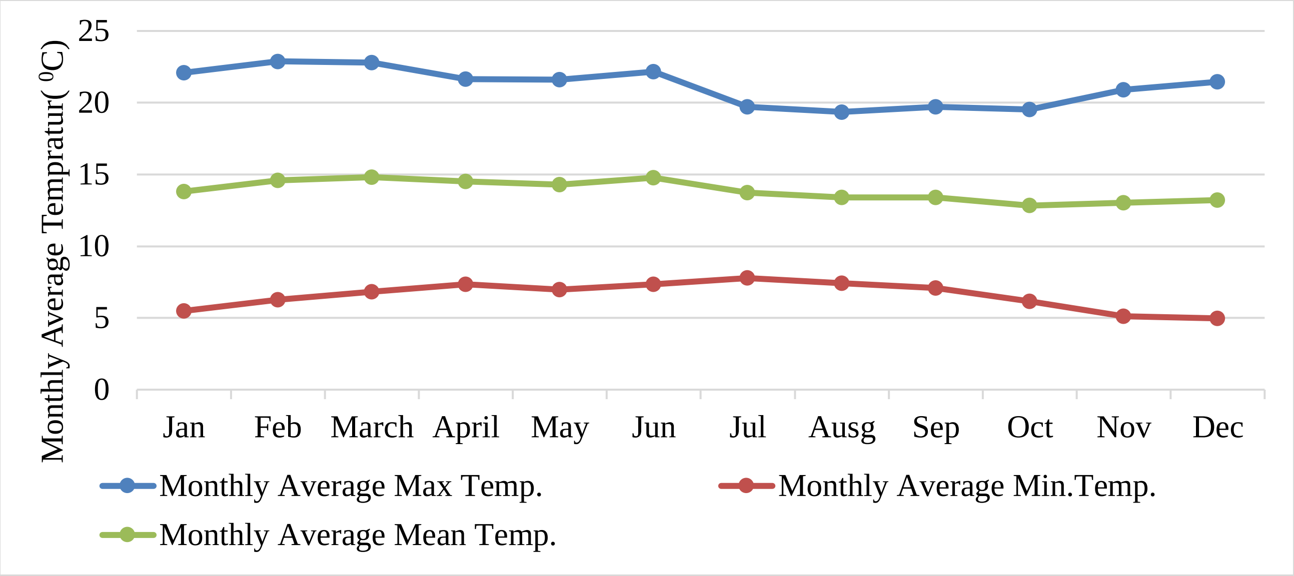

Figure 3.6: Monthly average temperature for Bekoji station

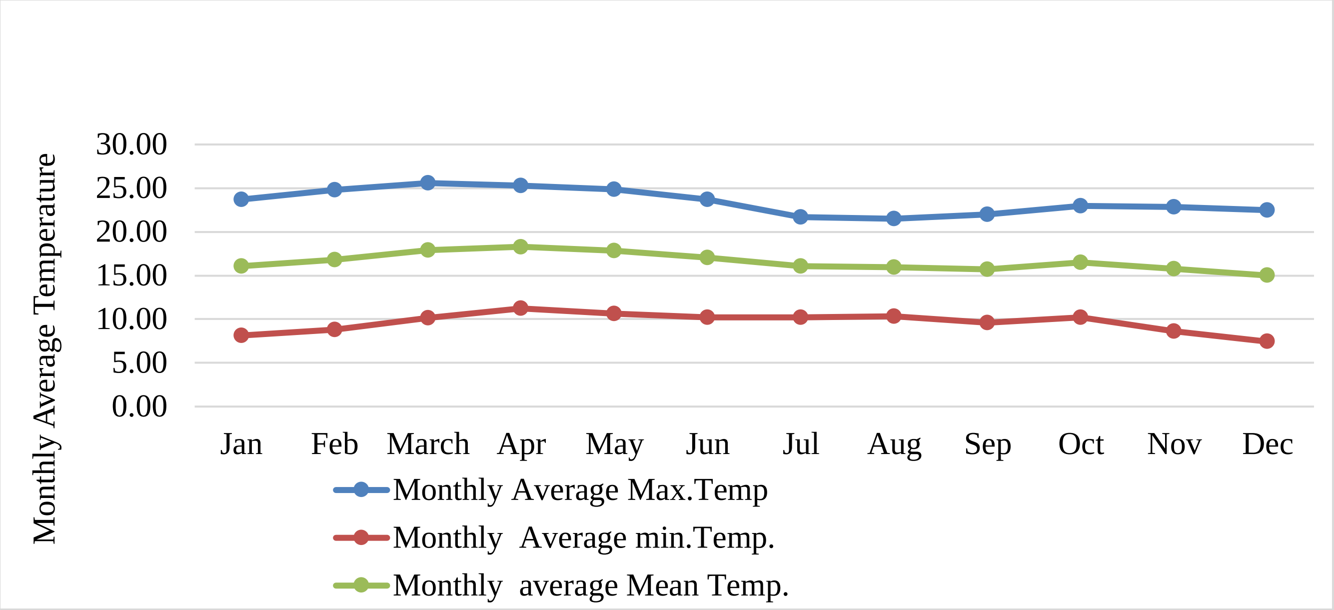

Figure 3. 7: Monthly average temperature for kulumsa station

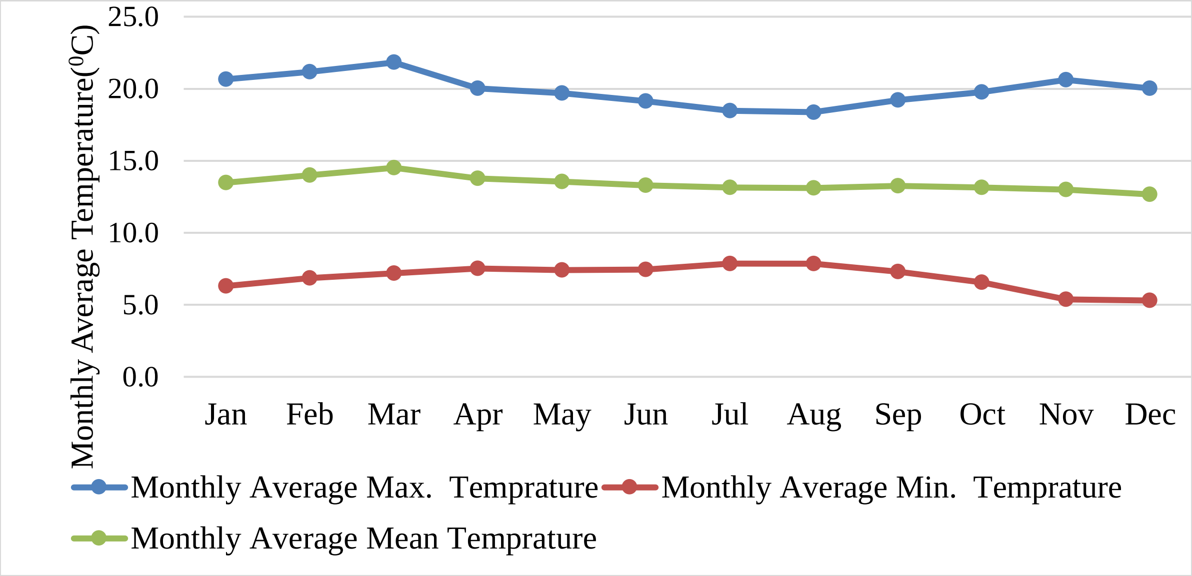

Figure 3. 8: Monthly average temperature for Sagure station

3. Wind speed

Wind characteristics such as wind velocity, frequency and direction of winds are important regarding to selection of irrigation methods and the rate of transpiration of crops. The average wind speed taken at 2 m height was observed as 147.42 Km/day.

4. Relative humidity

Relative humidity data were one of data which was used as input data for CROPWAT8.0 to calculate ETo. The average daily relative humidity for twenty years period (1998-2017) which was taken from Kulumsa meteorological station was found to be 65.35%.

5. Sunshine hours

The average maximum and minimum sunshine hours recorded at kulumsa meteorological station were 7.2 hours, which is occurred at the Month of December, and 4.93 hours at the Month of September respectively (Table 3.2).

Table 3.2: Metrological data of kulumsa station

Month	Max. Average Temperature	Min. Average Temperature	Wind speed (km/day)	Relative Humidity (%)	Sunshine hour
Jan	23.67	8.16	164.4	59.88	6.97
Feb	24.82	8.78	180	56.7	6.83
Mar	25.58	10.13	148.4	58.32	6.62
Apr	25.3	11.23	143.7	61.85	6.27
May	24.89	10.65	131.5	65.74	6.13
Jun	23.69	10.23	120.7	70.38	6.11
Jul	21.71	10.23	130.7	76.59	5.07
Aug	21.5	10.33	111.5	78.3	5.14
Sep	22	9.62	94.55	75.3	4.93
Oct	22.94	10.2	168	62.4	6.58
Nov	22.87	8.6	186.2	59.17	6.82
Dec	22.47	7.44	189.4	59.6	7.2
Average	23.45	9.63	147.4	65.35	6.22

3.4.3. Checking the Consistency of Rainfall Data

Estimating missing precipitation is one problem that hydrologists need to address. A second problem occurs when the catchment rainfall at rain gauges is inconsistent over a period of time and adjustment of the measured data is necessary to provide a consistent record. Double-Mass Curve (DMC) analysis is a graphical method for identifying or adjusting inconsistencies in a station record by comparing its time trend with those of other nearby stations (*Abera, 2011*). All four rainfall stations checked within the watershed and double mass curve was plotted for each station against three other stations.

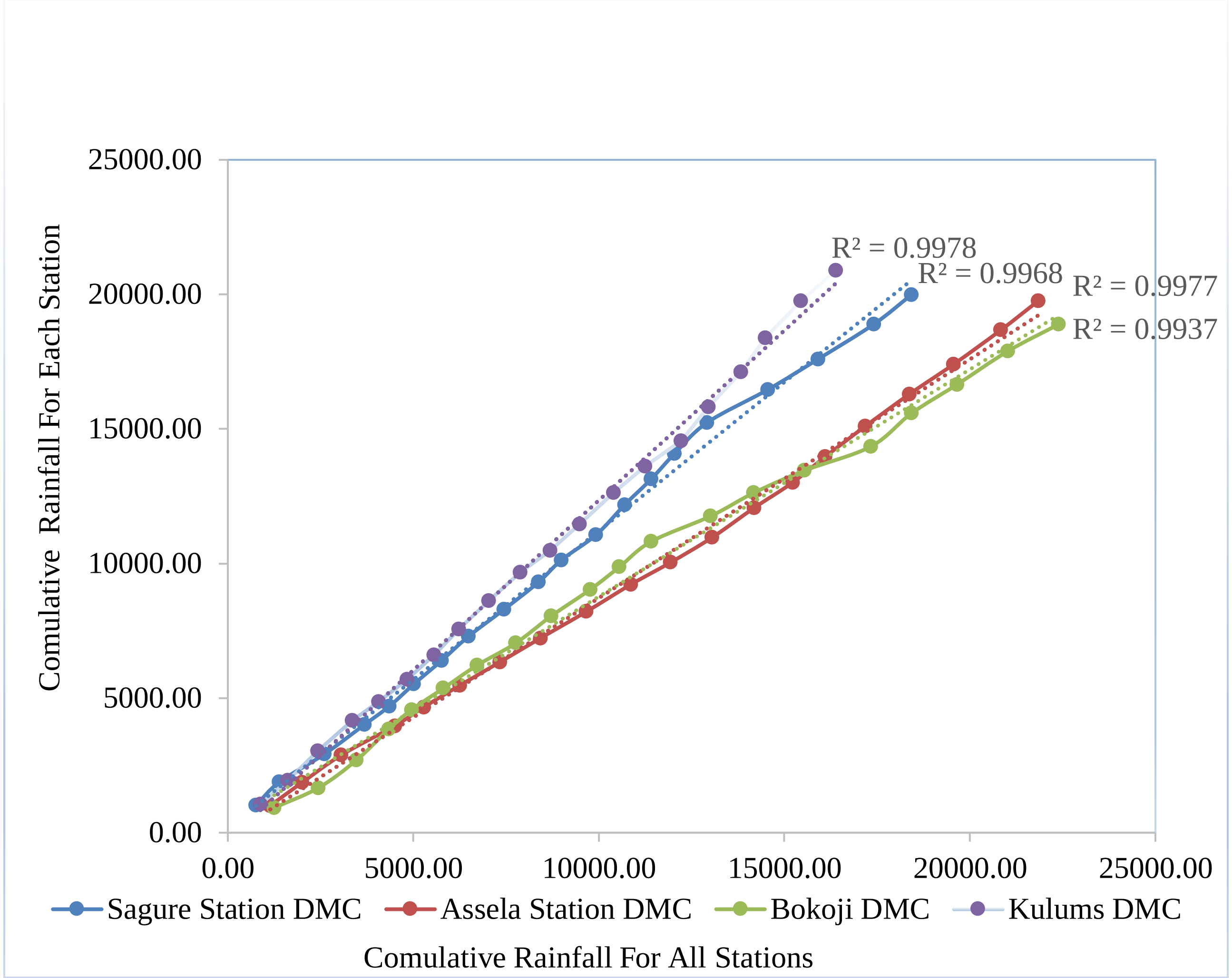

Figure 3.9: DMC for all Rain gage stations against three other near stations.

3.4.4. Watershed delineation

Katar Watershed is found at North Eastern part of Ziway-Meki sub-basin which is the sub-basin of Ethiopia Centeral Riftvelly Lakes Basin. It covers a total area of 3,580.1km^2.

In watershed delineation, the Digital Elevation Model (DEM) with 12.5-meter pixel size, which provides topographic information of the watershed, was used. The DEM properties were set to verify the projection, with a projection Adindan UTM zone 37N and datum WGS_1984.The projected DEM is used to delineate the watershed for the study area.

To delineate watershed using ArcGIS10.6 the following steps were adopted:

1. Load the DEM/importing DEM data which was already downloaded from Website: https://vertex.daac.asf.alaska.edu/
2. The DEM of the watershed was projected to UTM coordinate system using Arc Catalog in ArcGIS10.6
3. The DEM projection setup was done.
4. With this DEM watershed was delineated by using Arc Catalog tools in ArcGIS 10.6. Filling, flow direction, flow accumulation, Raster calculation, stream link, stream order, stream to feature, outlet selection are processes in watershed delineation.

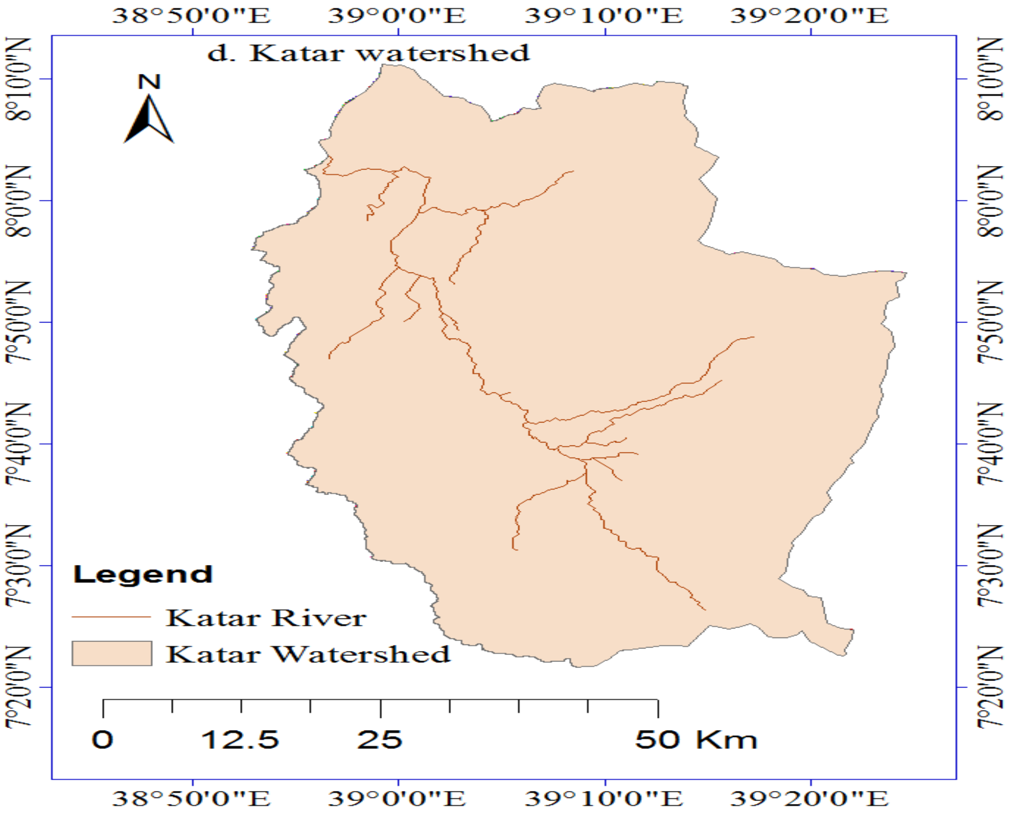

Figure 3.10: Katar River Watershed

3.5. Identification of Potential Irrigable Sites

Identification of suitable sites for irrigation was carried out by considering the slope, soil physical characteristics and land cover/use as factors. The individual suitability of factors was first analyzed and finally weighted to get potential suitable land for surface irrigation found within the watershed area. According to FAO, 1976 framework suitable land for irrigation is classified from highly suitable to not suitable.

3.5.1. Slope suitability analysis

Land slope is the most important topographical factors influencing land suitability for surface irrigation. The slope map of the specified watershed was derived from SRTM-DEM of 12.5 m spatial resolution using the spatial analysis tool in ArcGIS. The slope derived from the DEM was classified based on the classification system of FAO (1990) using the “Reclassification” tool in to four suitability classes S1 (highly suitable, 0-2%), S2 (moderately suitable, 2-5 %,), S3 (marginally suitable, 5-8%), and N (marginally not suitable,>8%) for surface irrigation.

3.4.2.1. Soil suitability analysis

The soil is a major factor in the suitability of land for sustained irrigation. Its primary influence is on the productive capacity, but it may also influence production and development costs depending on irrigation system. Soil survey is regarded as a necessary prerequisite for all agricultural developments, particularly where irrigation is concerned (Tariku, 2017).

For this particular study, four physical properties of the soil were reclassified by “reclassify” tool in Spatial analysis of ArcGIS; then those reclassified physical properties of the soil were used as inputs with slope and land use/cover for weighting overlay process in ArcGIS to identify irrigable land in the study area by Analytical Hierarchy Process (AHP).

3.5.1.1. Soil type

The soil map of the specified watershed was taken from MoWIE of Ethiopia. The major soils in katar watershed were found to be Rhodic Nitisol, EutricVertisols, HaplicLuvisols, Vitric Andosol, Calcaric Fluvisol, Eutric cambisol and Eutric vertisol. The soil map was converted from polygon to raster by conversion tool in ArcGIS10.6 and the map of siol type was developed. The major soil type and their distribution were presented in figure 3.11

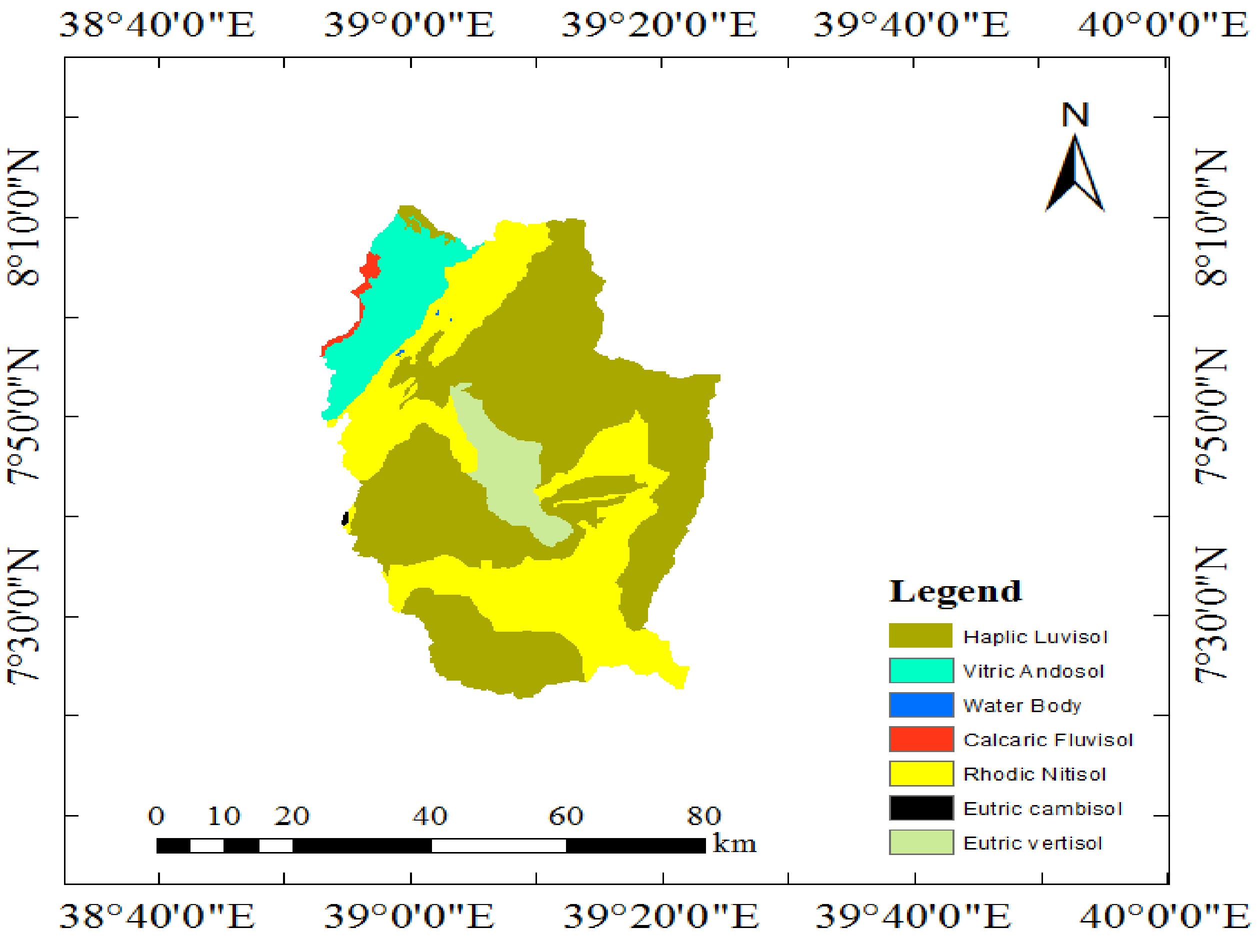

Figure 3.11: Map of Soil Type distribution of The Study area

3.5.1.2. Effective Soil Depth

Soil depth can restrict root penetration and the effective volume of soil that can be utilised by plants. Soil depth is a crucial element in most agricultural activities, and can play a key role in the determination of vegetation communities and species composition (Napier & Hill 2012). The soil depth that can be effectively exploited by plant roots is an important criterion in selecting land for irrigation purposes. Effective soil depth is the depth of soil at which root growth of crops is strongly inhibited. The effective depth of soil is governed by such factors as the presence of cemented, toxic, compacted or indurated layers; hard rock or gravel layers. A high permanent water table may also control the effective soil depth, but may change after drainage. FAO guideline for soil depth classification was given in table 3.2 based on FAO (1979)

The soil depth of the watershed was found to be moderately deep to very deep. It was ranging from 50 cm to 200 cm (Figure 3.12)

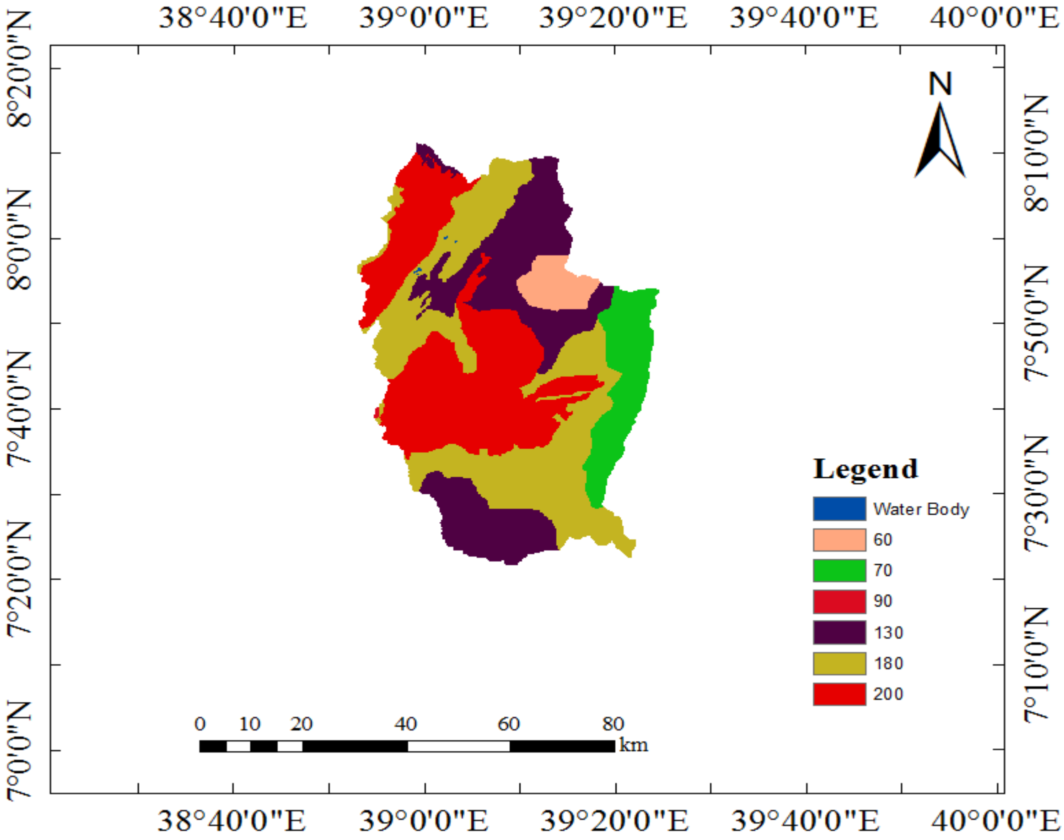

Figure 3.12: Map of soil depth distribution of the study area

3.5.1.3. Soil Texture

Texture is one of the most essential soil characteristics for consideration in soil appraisal for irrigation. It influences infiltration, moisture and nutrient retention, drainage, tilt hand susceptibility to erosion. Its effect on these qualities can be modified by soil structure, nature of clay minerals, organic matter and lime. The watershed is dominated by fine textured soils. Fine textured soils have high water holding capacity and low infiltration rate, whereas coarse textured soils have low water holding capacity and a high infiltration rate.

The proportions of sand, silt and clay are used to determine the textural class of the soil. It is important in that, it helps determine the capacity of a soil to retain moisture and air, both of which are necessary for plant growth. Soils with a greater proportion of larger particles are well aerated and allow water to pass through the soil more quickly, sometimes so quickly, that plants are unable to make use of the water.

The soils of the watershed show various size ranges such as, fine, fine and medium, medium and coarse texture. The Vertisols, Nitisols, and Luvisols are dominantly fine and medium texture while the Andosols, Cambisols, and Fluvisols are dominantly medium to coarse textured soils. Map of soil texture distribution was developed (3.13). Soil texture classification was given in table 3.2 based on FAO guideline. (FAO, 1991)

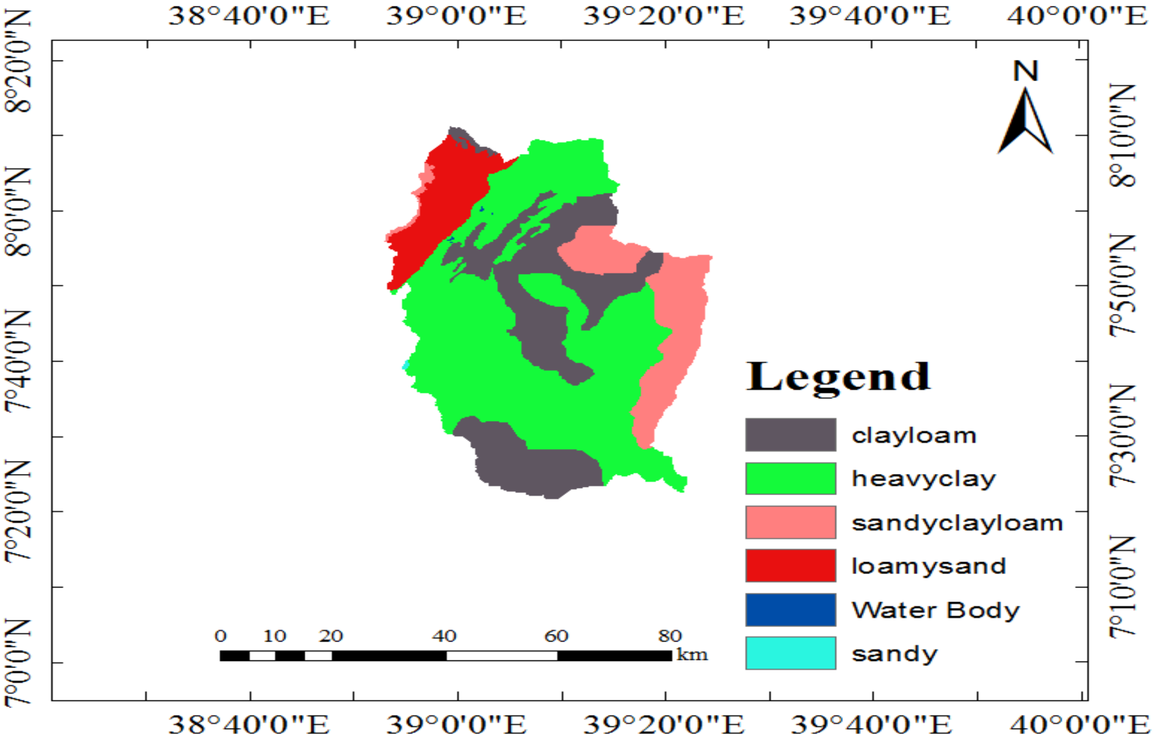

Figure 3.13: Soil Texture distribution Map of Katar watershed

3.5.1.4. Soil Drainage

Soil drainage relates the frequency and duration of periods when the soil is free of saturation or partially saturated. The classes of internal soil drainage that are used are; Excessively drained, Somewhat excessively drained, well drained, moderately well drained, imperfectly drained and poorly drained (FAO, 1976). The soils of the watershed are excessively, well, imperfectly and poorly drained (Figure 3.14).

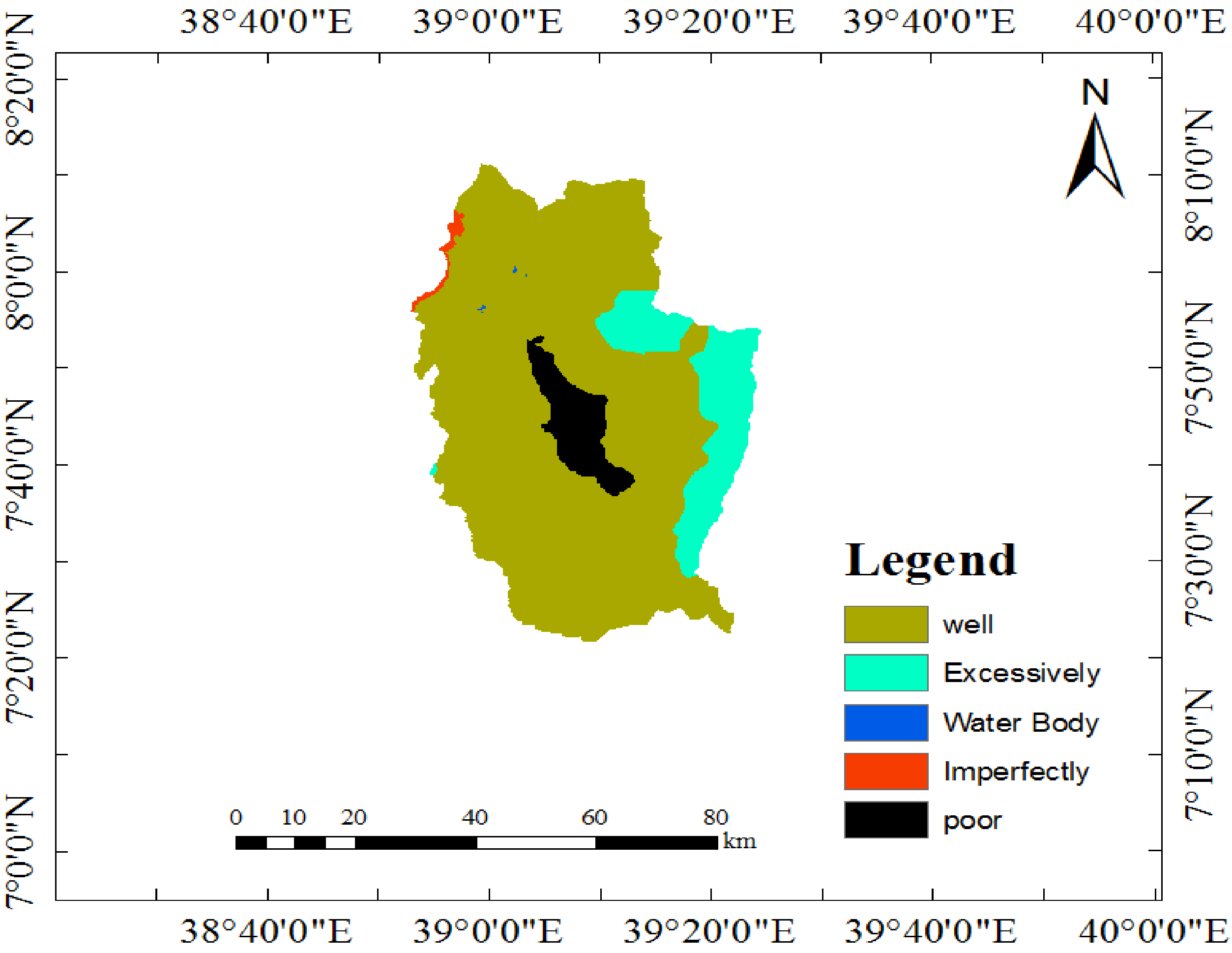

Figure 3.14: Soil Drainage distribution Map of Katar watershed

To classify soils of the study area for surface irrigation suitability, soil suitability rating was used based on the FAO guidelines for land evaluation (FAO, 1974, 1976, 1979, 1990, 1991) and FAO (1997) land and water bulletin.

3.5.2. Land cover/use suitability analysis

These two terms, land cover and land use, are often used interchangeably, but the difference between land use and land cover is an important one. Land use refers to the actual economic activity for which the land is used such as food production, commercial forestry, parking. Land cove refers to the cover of the earth’s surface such as vegetation (by type), bare soil and urban development, without reference to how that cover is used. The raster Land use/cover map of the study area was masked from Ethiopia Land use/cover map of 2013 which was taken from Ethiopia mapping agency. From land use/cover map of the study area, eight primary land-use/cover classes were recognized. These classes include: grass land, forest land, cultivated land, settlement area, wet land, woodland, and shrub land and water body (Figure 3.15)

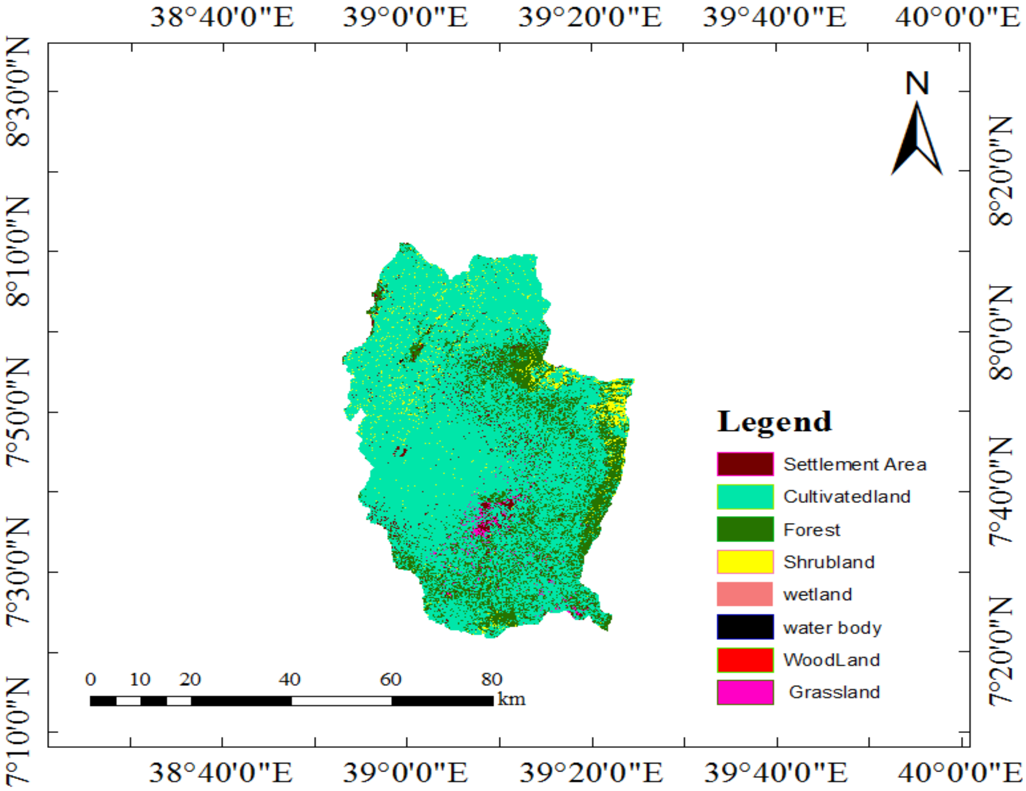

Figure 3.15: LULC distribution Map of Katar watershed

These Land use/cover types were ranked based on FAO guideline of LULC suitability for irrigation as given in table 3.4.

Table 3.3: FAO classification of irrigation suitability factors

Slope	Soil type	Soil Depth	Soil Texture	Soil Drainage	LULC	Factors Rating
0 – 2	Haplic Luvisol, Vitric Andosol, Rhodic Nitisol	>100	Clay Loam, Clay	Well	Cultivated	S1
2 – 5	Calcaric Fluvisol, Eutric Fluvisol, Eutric Vertisol	80-100	Sandy clay loam, heavy clay	Moderately well	Seasonally Wetland, Grassland	S2
5 – 8	Vertic Stagnosols, Haplic Luvisol	50-80	Loamy Sand, Sand	Imperfectly	Shrub land, Wood Land	S3
> 8	Stagnic Vertisols, Vertic Stagnosols	< 50	Very course soil	Excessively, Somewhat excessively, poor and very poor	Settlement Area, Forest, water body	N

Source: (FAO, 1974, 1976, 1979, 1990, 1991, 1997)

3.6. Developing Pairwise Comparison Matrix

According to Mendoza et al, (2008) AHP (Analytic Hierarchy Process) Pairwise Comparison Matrix is a Matrix in which the Rows and Columns have the same parameters. Once the matrix was arranged a score range of 1 to 9 is selected based on number of irrigation suitability factors and allocated for each factor. Team where a maximum score implies that the row was more important than the column. The diagonal of the matrix was allocated a score of 1. Now proceeding Column wise the value in the corresponding column just below the diagonal was just inverse of the scores in the corresponding row. Consistency Ratio calculation was described with formula from the matrix goal calculation.

$CR=CI/RI$………………………………………………………………………………………..3.1

Where: - CI = Consistency Index and RI = Random Consistency Index.

$CI = (\lambda_{ave.} - n) / (n-1)$ …………………………………………………………………….....3.2

Where: - $\lambda_{ave.}$ = the average of Eigen values and n = numbers of criteria or sub-criteria in each pair wise comparison matrix. As stated by Mendoza et al. (2008) the bigger the matrix is the higher the inconsistency level will be. The average random consistency index is given in Appendix table 13

3.7. Weighting of Irrigation Suitability Factors to find Potential Irrigable Sites

The irrigation suitability factors which were considered in this study, such as slope, soil (type, texture, depth and drainage) and land cover/use, were used as the input for irrigation suitability model to find the most suitable land for surface irrigation. Weighting of irrigation suitability factors which were already classified individually was conducted and the overall suitable land for surface irrigation was identified. To do that, irrigation factors were compared pair wisely.

A suitability model was created using model builder in Arc tools box and tools from spatial analysis tool sets (Figure 3.11) and Flow chart showing the processes of surface irrigation potential assessment in the watershed was developed (Appendix Figure 15).

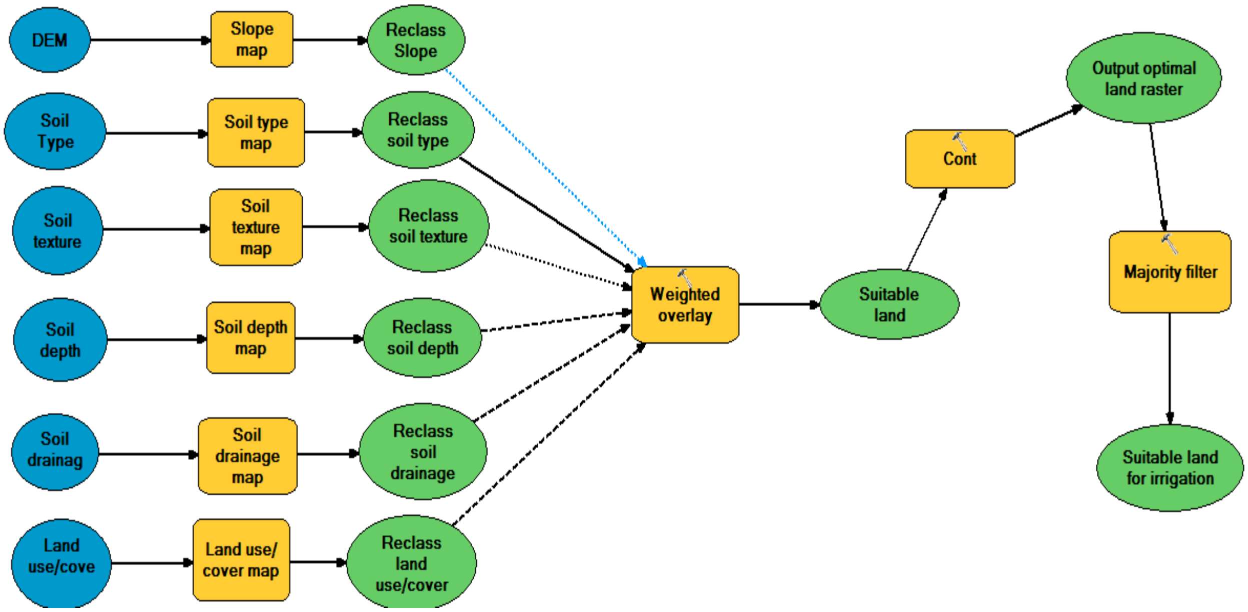

Figure 3.16: Irrigation suitability model

3.8. Surface water availability

The 90-percentile time of exceedance flow of the available flow was determined by making flow-duration curve (FDC). FDC provides the percentage of time (duration) of a daily or monthly stream flow is exceeded for certain year period (Vogel and Fennessey, 1994). For this particular study, the FDC was developed using sixty years (1995-2010) katar river discharge.

3.9. Irrigation Water Requirement

Irrigation water requirement for major crops grown in the study area was computed using the CROPWAT 8.0 software. Crop types which are commonly grown in the study area are Tomato, cabbage, potato and small vegetables. The respective crop coefficients for these crops were selected based on (FAO, 1998). Climate data such as temperature (maximum and minimum), rainfall, wind speed, sunshine hour, and relative humidity were used as data input in CROPWAT 8.0 software. In addition to climate data inputs the software was used crop and soil data to compute crop water requirements (CWR).

Reference Evapotranspiration (ETo): This is rate from a reference Evapotranspiration for plant like grass or alfalfa, not short of water. Reference Evapotranspiration Estimated from input data such as monthly average maximum and minimum temperature, relative humidity, sunshine duration and wind speed of the study area using the Penman-Monteith method with the help of CROPWAT 8.0 computer programming (FAO, 2002).

Crop Evapotranspiration (ETc): The crop evapotranspiration is the crop water requirement (CWR) for a given cropping pattern during a certain time period. Crop evapotranspiration was calculated by multiplying the kc values at each growth stage of the specific crops by the corresponding ETo values (FAO, 2002).

$$ET_C=ET_O*K_C \qquad \text{3.3}$$

Where**:** ETc= Crop evapotranspiration (mm/day), ETo = Reference evapotranspiration (mm/day), Kc = Crop coefficient

Effective rainfall: Is parts of the rainfall that can be effectively used by the crop, depending on its root zone depth and the soil storage capacity. It was calculated on a daily soil balance based on the imperially determined formula from CROPWAT model (Smith, 2000).

Cropping Pattern: The major crops grow in the area and their areal coverage was first identified from regional agricultural sector. Since each crop had its own water requirements, crop patterns such as the planting date, crop coefficient data files including Kc values, growth stage, root depth and depletion fraction was used as an input to estimate crop water requirement (FAO, 2002).

Irrigation water requirement (IWR): Using the climate, rainfall, crop and soil data inputs, crop water requirement and irrigation water requirement of each crop was calculated in CROPWAT 8.0 software.

Net irrigation water requirement (NIWR): The sum of individual crop water requirements (CWR) calculated for each irrigated crop (FAO, 2002).

$$\mathrm{NIWR}\ \frac{\sum_{i=1}^{n}\mathrm{NIWRi}*\mathrm{Ai}}{\mathrm{A}} \qquad \text{3.4}$$

Where:

NIWR = Net irrigation water requirement (mm), Ai= the area cultivated with the crop i (ha)

A = the area of the scheme

Gross irrigation water requirement (GIWR): Gross irrigation water requirement refer to the amount of water diverted from source for irrigation purpose. According to FAO (2001) GIWR of crops at the identified potential irrigable sites were estimated by considering efficiency of 50% for surface irrigation as follows.

Irrigation efficiency accounts for losses in storage and distribution systems, losses in application systems as well as conveyance losses.

$$\mathrm{GIWR} = \frac{\mathrm{NIWR}}{\mathrm{E}} \qquad \text{3.5}$$

Where: GIWR = Gross irrigation requirements (mm), NIWR = Net irrigation water requirement (mm), E = Over all irrigation efficiency (%)

Over all irrigation efficiency (E) = water conveyance efficiency (E_c)*water application

Efficiency (E_a)* water distribution efficiency (E_d)* water storage efficiency (E_s).

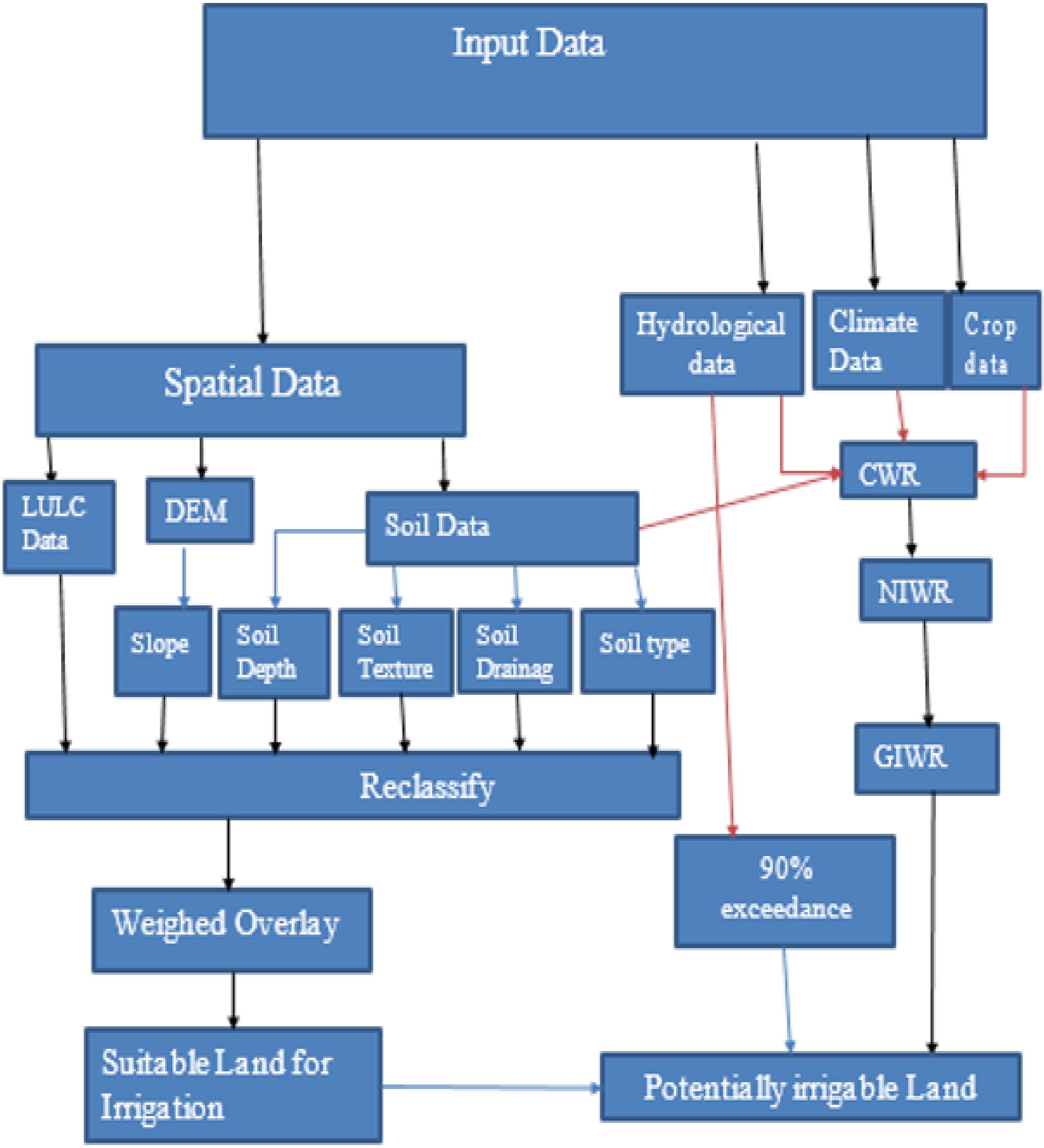

Figure 3.17: General Conceptual Frame Work of the Study

4. RESULTS AND DISCUSSION

The study consists of two parts. The first one is assessment of physically suitable land for surface irrigation, by assigning weights (or ranks) to the factors that likely affect the irrigation suitability of land. These factors were soil (type, Depth, Texture and drainage), land use/cover and slope. Then calculating growth irrigation water requirement for dominant crops cultivated in the area and comparing with available water flowing in the river during the dry season (March) by analyzing sixty-year (1995-2010) discharge records for Katar River.

The suitability classes used in this particular study were considered as four levels: highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). Six criterias were chosen, for suitability evaluation. These criterias were slope, Soil (type, Depth, Texture and Drainage) and Land use/cover.

4.1. Slope Suitability

The slope map of the specified watershed was derived from SRTM-DEM of 12.5 m spatial resolution using the spatial analysis tool in ArcGIS. The slope derived from the DEM was classified using the “Reclassification” tool, slope was classified in to four suitability classes S1 (highly suitable, 0-2%), S2 (moderately suitable, 2-5 %,), S3 (marginally suitable, 5-8%), and N (not suitable >8%) for surface irrigation. From reclassified raster slope map of the watershed, area of each suitable class was calculated. Slope classification, suitability classes, area covered by each suitability class in hectare and in percent was provide in Table 4.1. The result from slope suitability analysis shown that about 45.33% (covering an area of 162,118.15 ha) of the watershed was covered with less than 8% slope class where this land was fall under highly suitable to marginally suitable for surface irrigation. About 54.67% (covering an area of 195,507.97 ha), of the watershed area having a slope of greater than 8%, which is not suitable for surface irrigation.

Table 4.1: Slope suitability classes and their area coverage

Slope (%)	Suitability Class slope	Area (ha)	Area (%)	Description
0-2	S1	23,893.55	6.68	Highly suitable
2-5	S2	58,205.44	16.28	Moderately suitable
5-8	S3	80,019.16	22.37	Marginally suitable
> 8	N	195,507.97	54.67	Not suitable

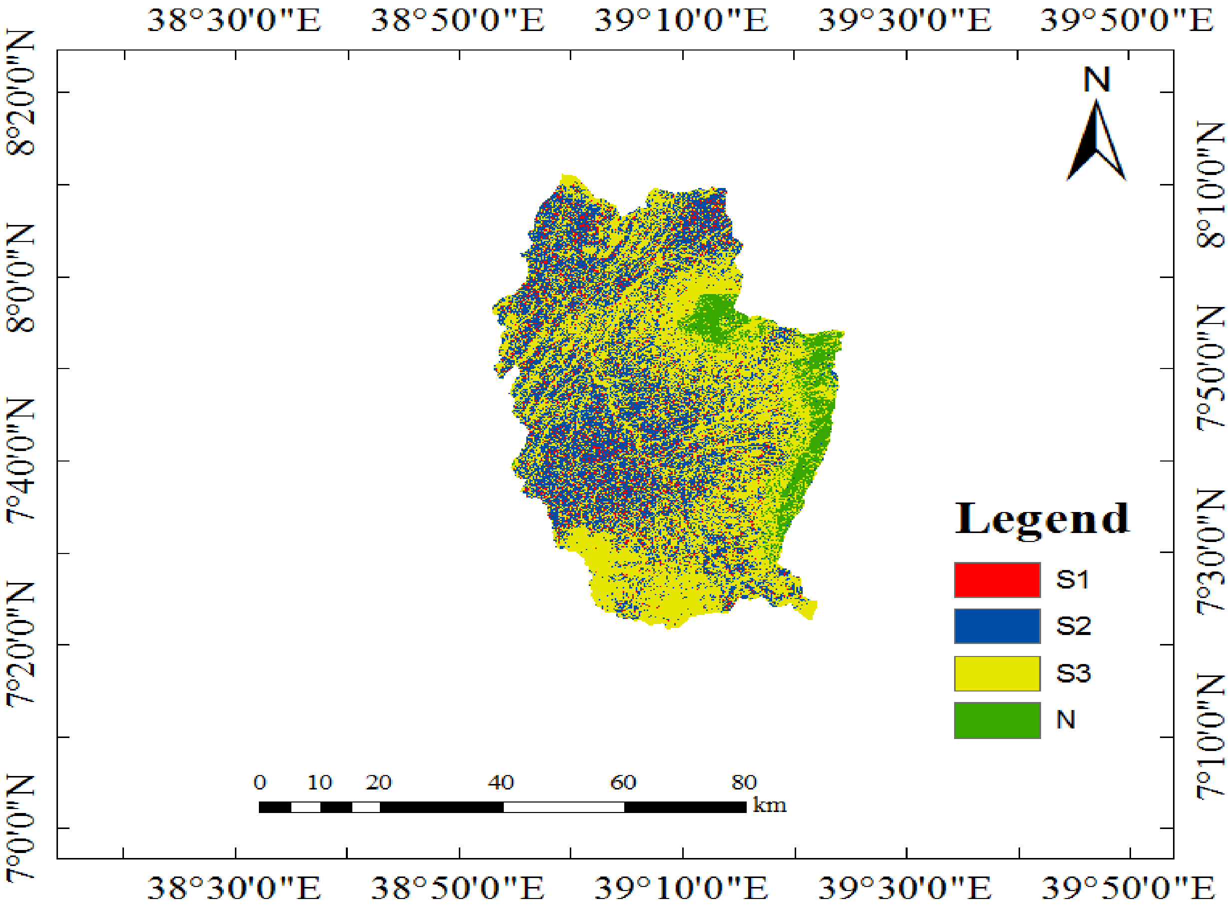

Figure 4.1: Slope suitability Map for katar watershed

From fig 4.1 reclassified slope map in percentage rise, the green color represent area with high slope rise which is not suitable for surface irrigation whereas red, blue and yellow parts in the slope map represent areas with low to moderate slope rise which is from highly suitable to marginally suitable for surface irrigation respectively.

From the result, more than half of the watershed area is not suitable for surface irrigation due to low work efficiency and high cost for land leveling, erosion control, canal construction and pumping system (FAO, 1976).

4.2. Soil Suitability

Four physical properties of the soil (type, depth, texture and drainage) were reclassified by “reclassify” tool in Spatial analysis of ArcGIS; then those reclassified physical properties of the soil were used as inputs with slope and land use/cover for weighting overlay process in ArcGIS to evaluate irrigable land in the study area by Analytical Hierarchy process(AHP).

4.2.1. Soil type suitability

Soil type was taken as one input to develop irrigation suitability map for the Watershed. Irrespective of their depth, texture, drainage, all types of soils are not suitable for crop production through irrigation. The soil map of the specified watershed was taken from MoWIE of Ethiopia from which soil raster data was developed.

The soil type raster was reclassified using the “Reclassify” tool in ArcGIS and Soil types of the study area was generally classified into two irrigation suitability classes based on soil suitability, such as S1 (highly suitable), S2 (moderately suitable), (figure 4.2). Soils with natural fertility and the suitability for a wide range of agricultural uses (Luvisols) and very productive soils, Nitisols and Andosol were classified as S1; Vertisols, Fluvisols and Cambisols with good natural fertility and considerable agricultural potential were classified as S2. From reclassified raster soil map of the watershed, area of each suitable class was calculated. The result from soil Type suitability analysis shown that about 80.96% (covering an area of 289,847.1 ha) of the watershed was enclosed with land covered by suitable soil class for irrigation. Whereas about 19% (covering an area of 68,028.03 ha), of the watershed area having a soil type classified under moderately suitable for irrigation agriculture. The rest of the land in the study area is covered by water body. (Table 4. 2). This indicated that most of soils types covered the study area was highly suitable.

Table 4.2: Soil type suitability classes and their areal coverage.

Soil Type	Suitability Class	Area (ha)	Area (%)	Description
Haplic Luvisol, Vitric Andosol Rhodic Nitisol,	S1	289,847.10	80.96	Highly suitable
Calcaric Fluvisol, Eutric Cambisol, Eutric vertisol	S2	68,028.03	19	Moderately suitable
Water Body	Water Body	150.9219	0.04	-

Soil Type Suitability map was developed and two suitability classes were separate in color. The red part of the map represented highly suitable whereas the green one indicated moderately suitable (Figure 4. 2).

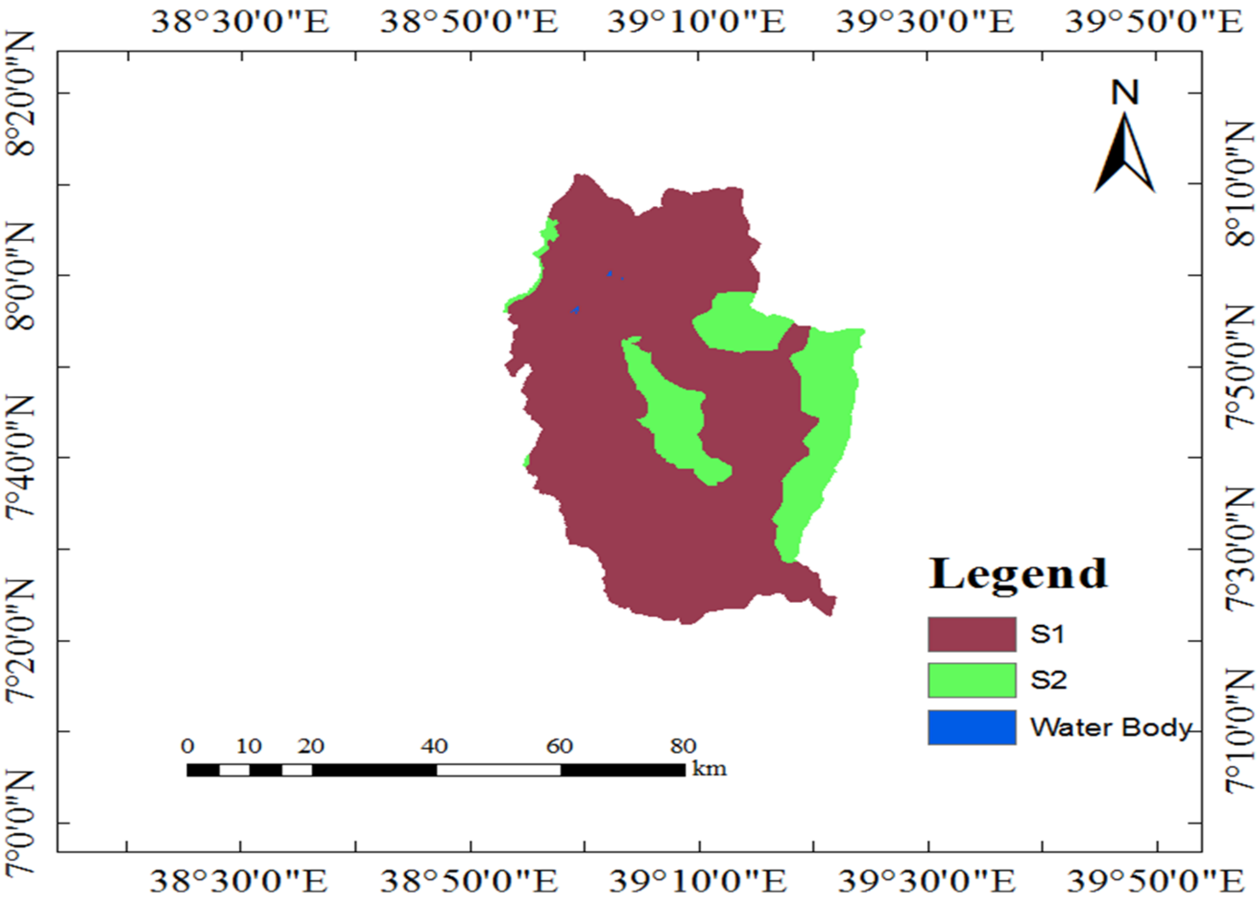

Figure 4.2: Reclassified Soil Type Map of The Study area

4.2.2. Soil depth suitability

Based on soil depth requirement of most common crops, soil depth of the study area was divided in to suitability classes to select surface irrigation potential. Rating factor was given for the value of soil depth and weighting them to evaluate the suitability of surface (gravity) irrigation potential of the study area. Rating factor was adopted from FAO guidelines (FAO, 1991). Soils having soil depth greater than 100 cm was classified as highly suitable for irrigation. It covered most part of the study area (about 87.133%) whereas the rest part of the land (0.05%) with soil depth between 80 to 100 cm and (12.77%) with soil depth between 50 to 80 cm was classified as S2 (moderately suitable) and S3 (marginally suitable) respectively.

Table 4.3: Soil depth suitability classes and their area coverage

Depth(cm)	suitability class	Area (ha)	Area (%)	Description
100-200	S1	311,959.30	87.13313	Highly suitable
80-100	S2	194.6563	0.054369	Moderately suitable
50-80	S3	45,721.16	12.77034	Marginally suitable
Water body	Water body	150.9219	0.042154	-

Thus, generally effective soil depths of these soils would not be a limiting factor for crop production through application of irrigation technology. The map of soil depth suitability class was developed from ArcGIS (Figure 4.3.)

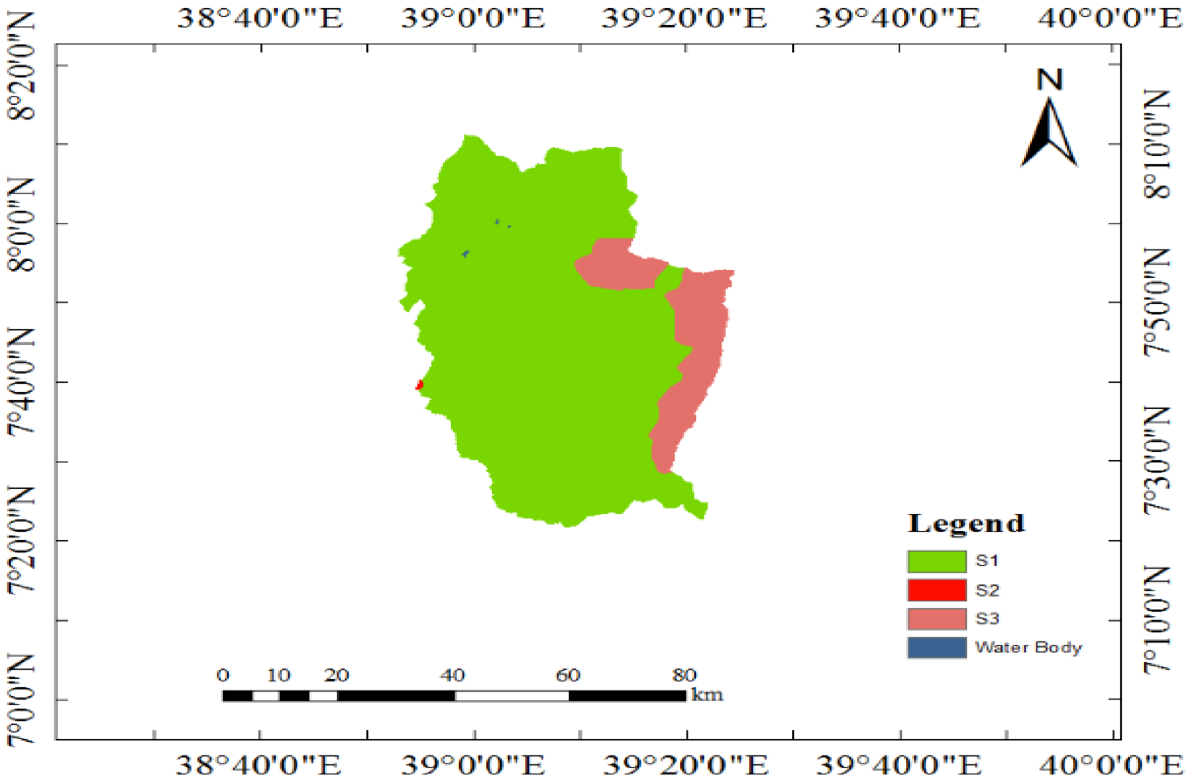

Figure 4.3: Map of Reclassified Soil Depth for katar watershed

4.2.3. Soil texture suitability

The soil textural classes, clay and clay loam (77.73 % of study area) were classified as highly suitable (S1) for irrigated agriculture whereas the rest part of the land (22.20 %) with soil texture of Fine and Medium, Medium, Fine, and Coarse (Heavy clay Sandy clay loam) was classified as S2 (moderately suitable) and (0.05%) with soil texture of Coarse (Loamy Sand, Sand) were classified as S3 (marginally suitable) (Table 4.4)

Table 4.4: Soil Texture suitability classes and their area coverage

Soil Texture	Suitability Class	Area (ha)	Area (%)	Description
fine and Medium and fine (Clay Loam, Clay)	S1	278,294.8	77.73	Highly suitable
Fine, Medium and Medium and Coarse (Sandy clay loam)	S2	79,385.73	22.17	Moderately suitable
Coarse (Loamy Sand, Sand)	S3	194.6563	0.05	Marginally suitable
Water Body	Water Body	150.9219	0.04	-

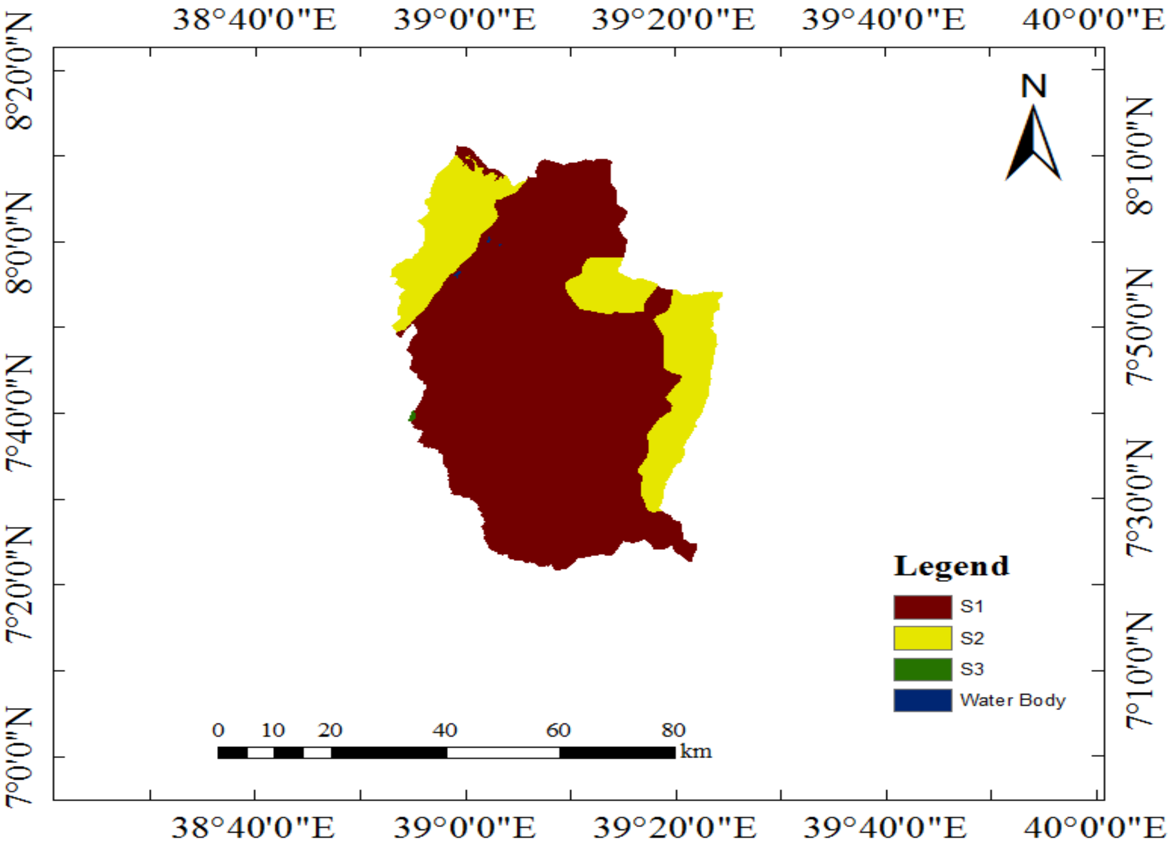

Figure 4.4: Map of reclassified soil Texture for Katar watershed

From the result, all of the textural classes of the soil in the watershed area is suitable for surface irrigation with some limitation.

4.2.4. Soil Drainage suitability

Soil drainage is one among very important parameter of evaluation of the area for surface irrigation. The well drained soils are good for agriculture in general.

From reclassified raster soil drainage map of the watershed, area of each suitable class was calculated and area covered by each suitability class in hectare and areal coverage in percent was provide in Table 4.5. The result from soil drainage suitability classification shown that about 80. 96% (covering an area of 289,847.1 ha) of the watershed land was fall under highly suitable (S1) for surface irrigation whereas about 0.62% (covering an area of 2,214.13, ha) is marginally suitable (S3). About 18.4% (65,813.91 ha) of the watershed area is not suitable (N) for surface irrigation.

Table 4.5: Soil Drainage suitability classes and their areal coverage

Class name for Soil Drainage	Suitability class	Area(ha)	Area (%)	Description
Well	S1	289,847.10	80.95699	Highly suitable
Imperfectly	S3	2,214.13	0.618426	Marginally suitable
Excessively/poor	N	65,813.91	18.38243	Marginally not suitable
Water Body	-	150.9219	0.042154	-

The final soil drainage suitability map was developed from reclassified soil raster. Accordingly, most of the study area is covered with highly suitable soil drainage whereas the eastern (hilly sides) and central parts of the of the watershed which represent by brown color is not suitable for surface irrigation development (Figure 4.5)

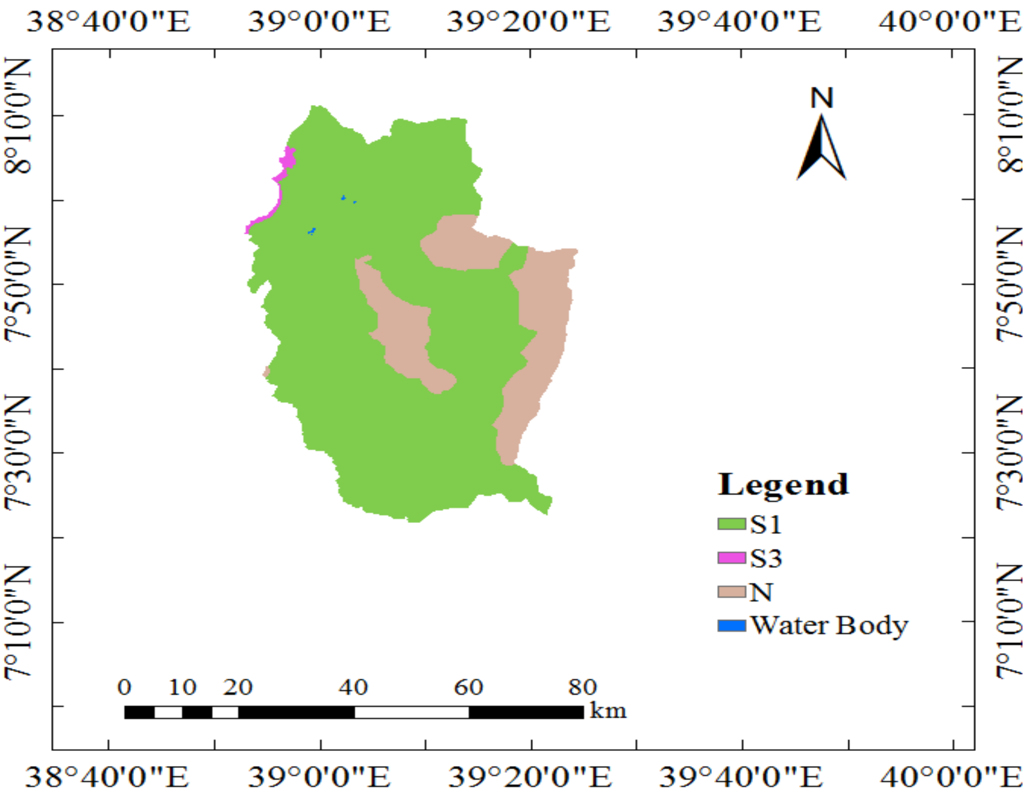

Figure 4.5: Reclassified Soil Drainage Map

4.3. Land use/cover suitability

Land use/cover was taken as one input for the evaluation of land suitability for irrigation in the study area. Land use/cover types of the study area were ranked based on their suitability for irrigation potential, such as working efficiency, costs to land clearing or land preparing for cultivation and environmental impacts. After rank was given for the land use types, reclassified map of the study area was developed (Fig.4. 11). The land use type was reclassified in to four suitability classes and given value from 1 to highly suitable, 2 moderately suitable, 3 marginally suitable and 4 marginally not suitable. From land use/cover classification, cultivated land was classified as highly suitable (S1) for surface irrigation which accounts 267,321.70 ha (74.67 %) of the watershed with the assumption that these land cover class could be irrigated without or with limited cost for land clearing and farm preparation. Seasonally Wetland and Grassland were classified as moderately suitable (S2) which accounts an area of 7,749.74 ha (2.17 %). Woodlands and shrub lands were classified as marginally suitable (S3) which cover an area of 11,545.69 ha (3.23 %). This is due to their work efficiency, cost for land clearing and land preparation for irrigation. Water body, forest and settlement areas were classified as marginally not suitable (N) which accounts an area of 71,915.77 ha (20.10 %). (Table 4. 6 and Figure 4.6).

Table 4.6: Land use/cover suitability classes and their areal coverage

Class name for LULC	Suitability	Area (ha)	Area (%)	Description
Cultivated land	S1	267,321.70	74.67	Highly suitable
Seasonally Wetland/Grassland	S2	7,749.74	2.17	Moderately suitable
Shrub land/Wood Land	S3	11,545.69	3.23	Marginally suitable
Settlement Area/Forest/water body	N	71,915.77	20.10	Marginally Not suitable

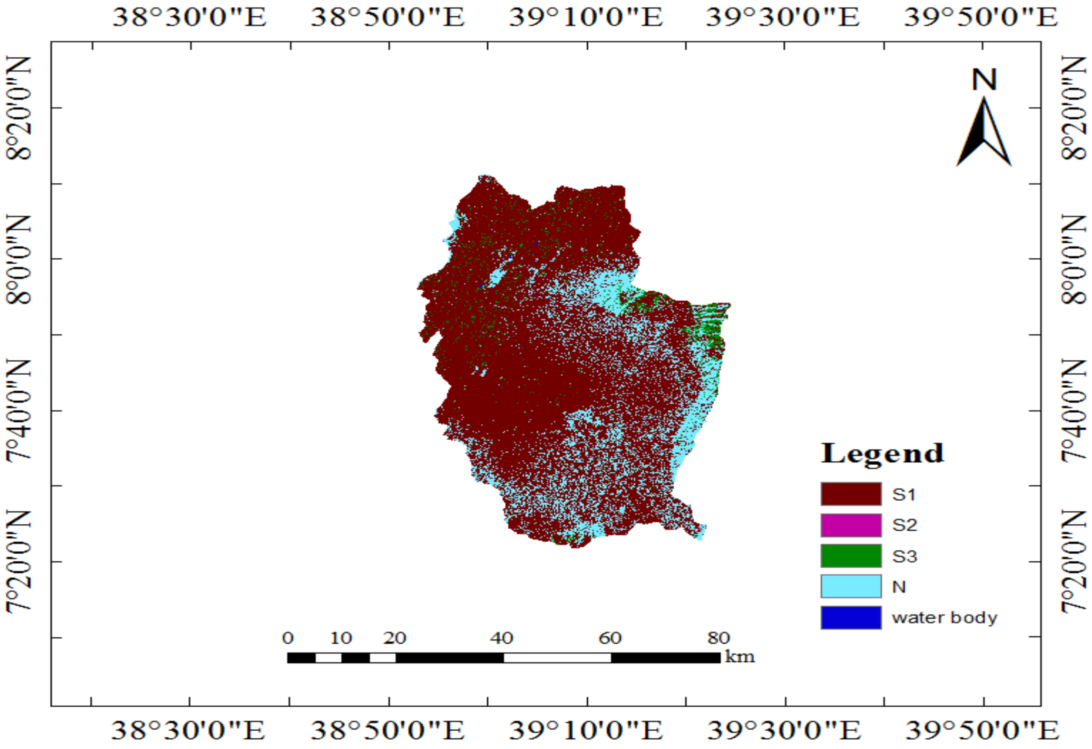

Figure 4. 6: Reclassified LULC Map of the study area

4.4 Weighting of Factors and Identifying Suitable Areas for Irrigation

To find the potential irrigable land, weighting of irrigation suitability factors which were already classified individually was needed. To do that, irrigation factors were compared pair wisely as given in the following steps.

1. Developing pairwise matrix comparisons

The pairwise matrix consists of the first six rows. Suitability factors were listed ranging from slope to land use/cover. Based on the relative importance of each factor the scoring was given as follow in table 7

Table 4.7: Pairwise comparisons Matrix

Factors	Slope	Soil Depth	Soil Texture	Soil Drainage	Soil Type	Landover
Slope	1	2	2	3	4	5
Soil Depth	0.5	1	1.5	2	2	1.667
Soil Texture	0.5	0.667	1	1	0.5	1.5
Soil Drainage	0.333	0.5	1	1	1.333	1.2
Soil Type	0.25	0.5	2	0.75	1	1.5
Landover	0.2	0.6	0.667	0.8333	0.667	1
Sum	2.783	5.267	8.167	8.5833	9.5	11.867

In the pairwise matrix comparison, the importance of each of factor for surface irrigation was given. Thus, for example in Table 7 slope is much more important factor than soil (type, depth, texture and drainage) and LULC to determine the suitability of land for surface irrigation. Hence the values in the first row were integers. Conversely, land use on the bottom of Table 7 is less important than other factors.

2. Developing Standardized Matrix

This table was developed by dividing each value of a cell of a column by the column total in pairwise matrix comparisons (Table 4.7**)**. Likewise do for all columns. Average of each rows of this new table was the weight of each factor. The weight percentage was calculated by multiplying the average of each row by100.

Table 4.8: Standardized Matrix

Factors	Slope	Soil Depth	Soil Texture	Soil Drainage	Soil Type	Land Cover	Weight	Weight in %
Slope	0.359	0.380	0.245	0.350	0.421	0.421	0.363	36.264
Soil Depth	0.180	0.190	0.184	0.233	0.211	0.140	0.190	18.953
Soil Texture	0.180	0.127	0.122	0.117	0.053	0.126	0.121	12.071
Soil Drainage	0.120	0.095	0.122	0.117	0.140	0.101	0.116	11.583
Soil Type	0.090	0.095	0.245	0.087	0.105	0.126	0.125	12.478
Landcover	0.072	0.114	0.082	0.097	0.070	0.084	0.087	8.650

3. Computing lamda (λ)

The first row (R1) was calculated as, the score of slope in the first row was multiplied by the weight of slope was added to the score of soil depth in the first row was multiplied by the weight of the soil depth was added to the score of soil texture in the first row was multiplied by the weight of the soil texture was added to score of soil Drainage in the first row was multiplied by the weight of the soil was added to score of soil type in the first row was multiplied by the weight of the soil type was added to the score of land use in the first row was multiplied by the weight of the land use. This calculation was continued for all rows.

R1=1*0.363+2*0.1895+2*0.12071+3*0.11683+4*0.12478+5*0.0865 = 2.2623

Likewise,

R2	1.1773
R3	0.7364
R4	0.7222
R5	0.7683
R6	0.5330

The computed value of Rows was divided by the weight of respective rows.

2.2623/0.363 = 6.2383

1.1773/0.1895 =6.2118

0.7364/0.1207 1=6.1006

0.7222/0.11683 =6.2351

0.7683/0.12478 =6.1568

0.5330/0.0865 =6.1619

Here lamda (λ) was computed by dividing the summation of the above results by the number of factors.

$$\lambda_{ave} = 6.1841$$

4. Calculate consistency index (CI)

CI = (λ - n)/ (n-1) ……………………………………………………………………………4.1

Where n is the number of irrigation factors

CI= 0.0368

5. Calculate consistency ratio (CR)

Where, RI= 1.24 (from appendix table 13)

CR=CI/RI, = 0.0368/1.24 = 0.0297

According to Saaty. (2008) the calculation for consistency ratio which was found to be 0.0297 was said to be consistent pair wise comparison since the maximum allowable is 0.1.

The overall results of irrigation suitability were tabulated (Table 4.9) from Weighting of all factors in ArcGIS. The area which is highly suitable (S1) for surface irrigation covered 6.37% (22,781.64 ha) of the study area; moderately suitable (S2) area covered 34.64 % (123,863.581ha) of the study area; marginally suitable (S3) area covered 52.46788% (187,633.55 ha) whereas 6.53 % (23,337.23 ha) of the study area was grouped as not suitable (N) for surface irrigation (Table4.9 and Figure 4.12).

Table 4. 9: overall suitability

Area of overall suitability (ha)	Area (%)	Suitability class	Description
22,781.64	6.37	S1	Highly suitable
123,863.58	34.64	S2	Moderately suitable
187,633.55	52.47	S3	Marginally suitable
23,337.23	6.53	N	Marginally not suitable

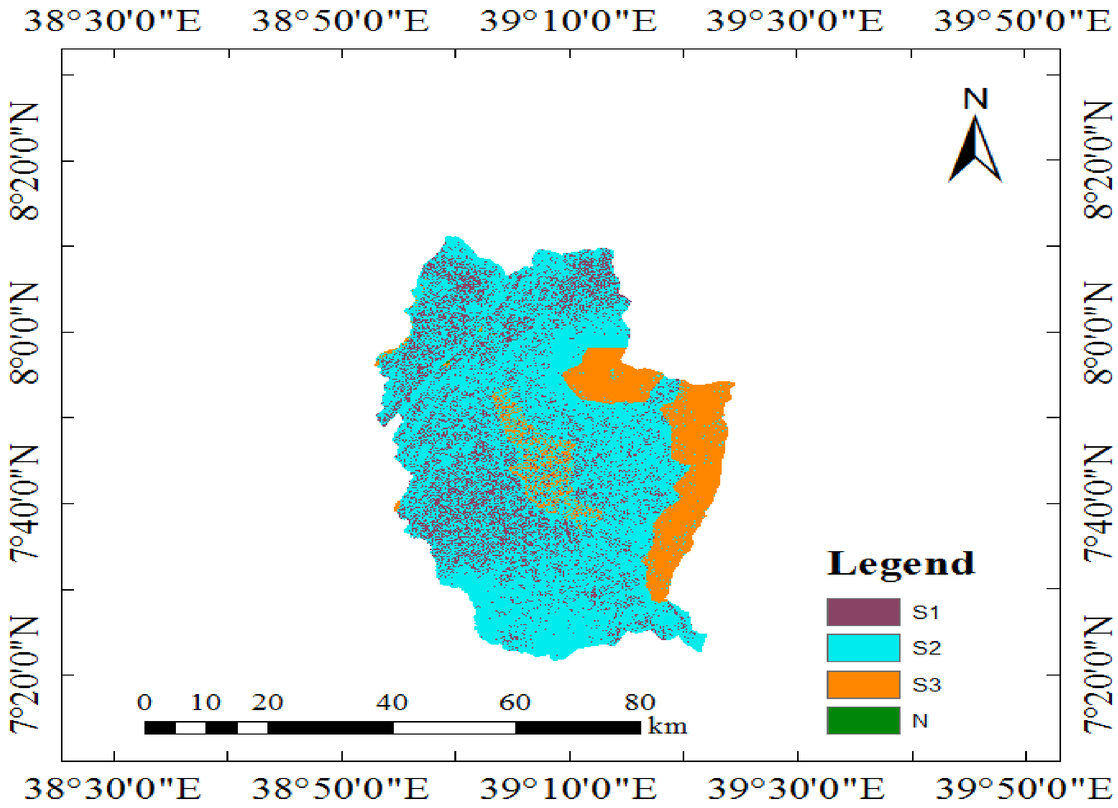

Figure 4.7: Overall irrigation Suitability Map of Katar River watershed

From overall irrigation Suitability Map of the study area most of the land in katar watershed is in the range of highly suitable to marginally suitable for surface irrigation development whereas few parts of the land in the study area (6.53 %) is restricted for surface irrigation development.

4.5. Irrigation Water Requirements

To compute irrigation water requirement, first a potential evaporation rate was calculated by Penman Moenteith approach. Appendix table 14 Shown that the minimum potential evaporation was 3.19 mm/day in September and the maximum potential evaporation was 4.24 mm/day in March.

Net irrigation water requirement for each Month was computed. Gross Irrigation Water Requirement (GIWR) was calculated by considering 50% efficiency for surface irrigation (Table 4.11).

4.6. Irrigation Potential of Katar Watershed

Irrigation Potential Refers to Areas suitable for irrigation vs. surface water availability. Irrigation potential of the river Watershed was obtained by comparing irrigation water demand of the four crops commonly grown in the study area (Tomato, Potato, cabbage and small vegetables), in considering to the identified suitable land for surface irrigation and the 90% dependable monthly flow of Katar River which was developed from flow duration curve (Appendix B (4 -14) and Figure 4.8).

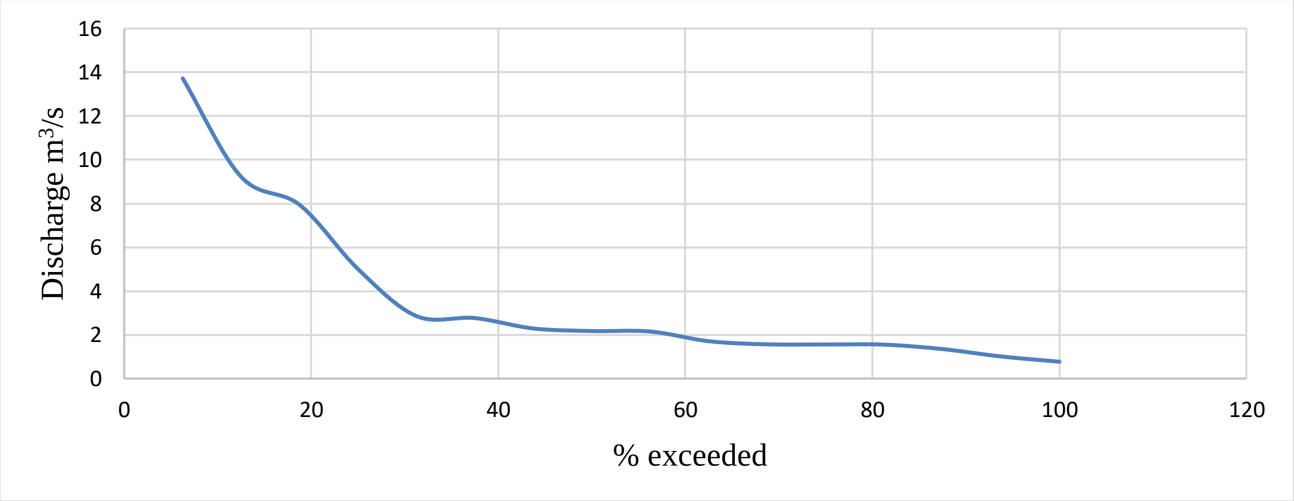

Figure 4.8 Flow Duration Curve for Month of March

Potential irrigable Land was computed by dividing 90% dependable monthly flow of Katar River for total Gross Irrigation Requirement in each month of all crops (Table 4.11)

Table 4.10: Comparison of Gross Irrigation requirement and 90% exceedance of Katar River flow

Month	GrossIrrigation Requirement (m^3/s /h)	90% exceedance Katar river flow (m^3/s)	Irrigation Potential (ha)
Jan	0.00074	1.49	2,015.56
Feb	0.00078	1.31	1,677.22
March	0.00054	1.21	2,243.12
Apr	0.00008	1.72	21,532.94
May	0	2.23	_
Jun	0	2.65	_
Jul	0	11.45	_
Aug	0	14.35	_
Sep	0	13.44	_
Oct	0	5.18	_
Nov	0.00016	2.07	_
Dec	0.00026	1.64	6,300

The result indicated that, in April and February the katar river irrigation potential is maximum (21,532.94 ha) and minimum (1,677.22 ha) respectively. In the month of March, the river discharge is minimum and only 2,243.12 ha of suitable area can be irrigated with available low flow.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The assessment of physical land suitability for surface irrigation for Katar River watershed, was conducted in East-Arsi Zone, Oromia regional state, Ethiopia. The watershed area was found to be 3,580.1 km^2.

Physically irrigable land of the River watershed was mapped based on irrigation factors such as slope, soil physical characters and land use/cover of the study area. Irrigation land suitability was evaluated based on FAO guideline such as S1, S2, S3 and N1. Based on the analysis, 45.33% of slope, 99.6 % of soil, and 79.9 % of land use /cover of the study area were identified to be in the range of highly suitable to marginally suitable for irrigation.

By weighing values of irrigation factor in ArcGIS, irrigation suitability map was developed and potential irrigable land which range from highly suitable to marginally suitable was found to be 93.47 % whereas 6.53% is not suitable.

Based on the data from meteorological station, the irrigation water requirement was calculated using FAO-Penman-Monteith methods. By using CropWat8.0 model, the irrigation requirement of the selected crops was calculated and the result implies that irrigation water requirement was higher than 90% exceedance flow at driest month. As a result, only 6.36% (2,243.12 ha) of the highly suitable land could actually be irrigated with the available low flow in the river in the driest Month.

In conclusion, the main limitation for surface irrigation in Katar River watershed is the available surface water and not physically land suitable for irrigation.

5.2. Recommendations

The following recommendations are forwarded based on the result obtained in this study

The land suitability assessment for surface irrigation in this research was carried out by considering only physical characteristic of land. But effects of other factors Such as soil chemical characteristic, Elevation, River proximity, urban proximity and Road proximity and water quality should be assessed to get more comprehensive and reliable result.

The calculation of irrigation water requirement and assessment of water potential needs the correct meteorological and flow data so that those data should be carefully recorded at their specific stations.

From the result, the main limitation for surface irrigation in the study area was the available surface water and not physical land suitability for irrigation. So, to meet crop water demand for commonly grown crops in the area, building of dam to store the run off river in rainy season, or sustainable use of groundwater if available is necessary.

Spatial data such as Soil and land use should contain all necessary information which researchers need to assess land suitability for irrigation in a certain area.

Physical land suitability analysis result indicates that most of the study area (93.47%) of is suitable for surface irrigation. further assessment on pressurized irrigation systems should be carried out to know how much land is suitable for irrigation.

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APPENDIX

1. APPENDIX A TABLES

Appendix Table 1: Annual Rainfall for all Metrological Stations

Year	Annual Rainfall for Assela Station	Annual Rainfall for Bekoji Station	Annual Rainfall for Kulumsa Station	Annual Rainfall for Sagure Station
1998	1142.10	1249.37	876.08	756.50
1999	857.20	1194.71	745.50	631.00
2000	1061.80	1022.43	799.10	1213.80
2001	1438.80	871.66	938.90	1077.07
2002	779.50	613.31	708.40	678.00
2003	978.70	858.19	758.60	658.60
2004	1077.20	903.59	728.00	743.60
2005	1088.70	1051.65	678.70	727.10
2006	1242.52	951.29	807.20	957.90
2007	1194.10	1055.20	835.90	933.44
2008	1072.86	780.78	817.35	614.60
2009	1118.62	861.80	787.90	934.10
2010	1139.10	1599.54	917.80	771.70
2011	1037.19	1163.45	849.70	709.10
2012	875.83	1359.25	961.20	639.20
2013	1071.70	1798.14	749.80	875.00
2014	1196.60	1095.82	876.02	1632.14
2015	1187.47	1223.79	650.34	1355.06
2016	1278.50	1376.59	951.15	1506.31
2017	1008.62	1362.24	955.87	1011.89
Average	**1092.36**	**1119.64**	**819.68**	**921.31**

Appendix Table 2: Monthly average maximum temperature for Assela Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	24.61	26.19	25.19	27.35	26.83	26.24	21.71	20.50	20.72	22.32	24.59	24.12
1999	25.26	27.43	26.04	27.91	27.05	24.99	21.82	22.14	23.17	21.83	22.73	24.37
2000	25.29	25.29	26.71	26.80	24.64	23.10	20.83	20.85	21.15	22.83	21.98	21.77
2001	23.14	25.57	24.24	24.28	22.01	20.36	19.57	19.45	19.96	21.16	20.82	21.00
2002	20.47	23.17	23.00	23.09	24.29	21.99	21.26	20.00	20.30	21.93	22.16	20.85
2003	21.39	22.53	22.48	21.99	24.07	21.82	19.09	19.88	20.01	21.56	20.91	20.15
2004	21.84	21.62	23.03	21.45	23.56	20.49	19.27	19.90	19.47	19.58	20.48	20.21
2005	21.03	23.13	22.22	22.93	22.80	21.00	19.53	19.28	19.27	20.64	21.01	19.88
2006	21.95	21.85	22.08	22.39	22.77	21.00	19.53	19.28	19.27	20.64	21.01	19.88
2007	21.54	22.45	28.46	22.28	22.48	20.74	19.20	18.39	19.07	20.56	20.46	20.25
2008	21.82	22.18	24.68	23.49	21.49	20.76	19.40	18.73	20.04	20.96	19.71	20.49
2009	20.82	21.86	23.95	23.25	23.68	23.32	21.86	22.00	22.31	22.20	22.09	21.73
2010	21.81	21.24	20.79	22.59	21.75	21.47	20.00	20.77	20.26	21.72	21.52	21.05
2011	21.94	23.32	22.14	24.20	23.10	22.61	21.28	20.61	19.48	21.65	20.47	20.49
2012	22.26	23.17	24.08	22.58	23.62	22.36	20.06	20.52	22.06	22.09	22.55	21.57
2013	22.21	24.39	23.94	22.84	22.10	21.28	20.16	19.66	20.39	20.61	20.64	21.62
2014	22.33	23.22	23.25	22.39	22.77	22.87	20.69	19.63	19.05	20.30	21.72	21.05
2015	21.78	24.57	24.60	23.37	22.07	21.73	21.07	21.07	23.10	23.07	21.70	22.12
2016	22.44	23.09	25.58	22.53	22.35	22.24	22.22	21.30	21.50	22.11	22.66	21.81
2017	14.68	22.08	25.77	24.06	23.71	21.90	26.64	22.30	22.10	22.15	21.58	22.15
Average	21.93	23.42	24.11	23.59	23.36	22.11	20.76	20.31	20.63	21.49	21.54	21.33

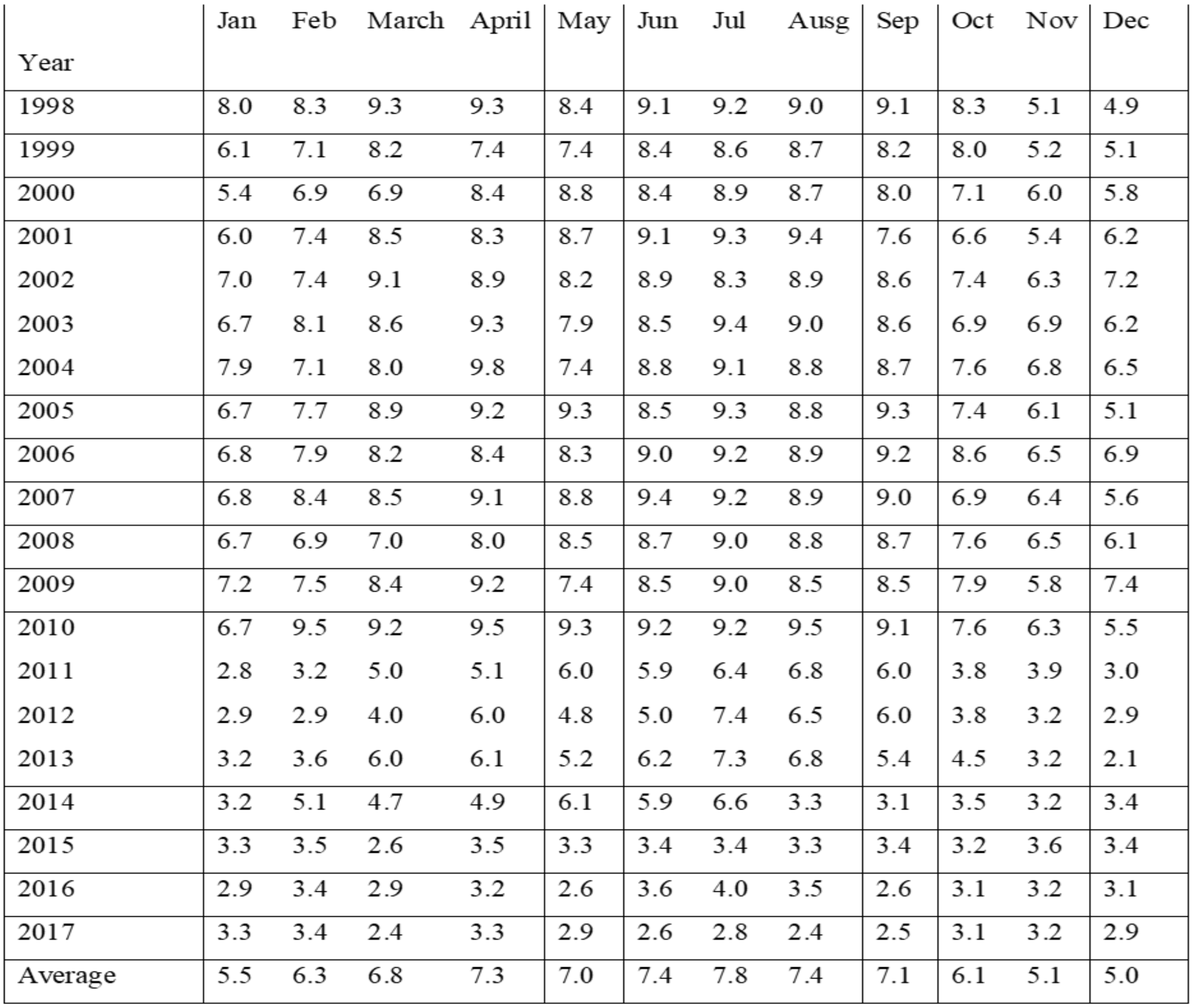
Appendix Table 3: Monthly average minimum temperature for Assela Metrological station

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	OCT	Nov	Dec
1998	8.84	10.34	10.92	11.58	11.89	11.39	11.61	11.32	10.47	9.51	6.80	5.02
1999	7.89	8.49	10.78	11.50	11.37	11.53	11.59	11.35	10.93	10.09	7.98	6.41
2000	6.56	7.47	8.87	11.40	10.79	11.14	11.23	11.48	10.69	9.93	7.99	5.35
2001	7.04	10.05	11.11	11.41	10.14	10.57	10.50	10.81	9.24	9.34	6.63	6.10
2002	6.93	7.10	9.76	10.21	10.39	10.77	10.64	10.18	9.94	10.48	8.76	9.36
2003	8.77	9.36	10.29	11.47	10.89	10.39	10.67	10.42	10.38	10.58	10.93	12.14
2004	10.74	10.70	10.58	10.59	9.96	10.06	9.25	9.94	10.15	10.05	10.54	11.53
2005	11.56	11.68	9.37	9.61	8.73	8.99	9.21	9.16	9.05	9.58	11.55	6.97
2006	8.15	8.30	8.45	8.25	9.24	9.11	9.13	9.53	11.69	6.66	11.30	10.60
2007	10.60	11.09	10.81	9.97	9.67	8.27	7.64	10.59	10.53	10.34	9.46	7.30
2008	5.01	6.45	7.24	8.48	10.73	11.37	10.78	11.01	10.87	10.74	10.80	7.88
2009	7.38	8.04	9.53	10.79	10.49	10.54	8.20	8.41	8.38	8.25	8.02	8.93
2010	10.08	9.76	11.10	11.18	10.63	11.32	11.81	10.25	10.75	7.41	6.52	7.58
2011	8.39	9.81	10.69	11.46	11.44	10.99	10.93	10.28	10.40	8.79	7.12	7.22
2012	6.74	5.99	8.09	10.95	9.82	10.48	10.44	10.52	9.63	8.11	8.52	8.32
2013	8.21	8.51	10.39	11.31	10.83	10.72	9.31	5.91	6.81	8.83	9.91	10.57
2014	11.05	11.19	11.50	10.42	10.95	10.62	8.25	6.02	7.78	9.55	11.02	11.38
2015	5.61	8.43	9.77	8.04	11.14	11.32	10.92	11.21	10.57	10.37	8.04	8.31
2016	10.68	8.59	11.73	12.12	11.73	8.79	8.18	11.96	11.72	8.39	9.18	7.81
2017	5.62	8.32	8.59	10.47	11.21	8.03	11.51	8.80	8.58	10.55	8.90	7.79
Average	8.29	8.98	9.98	10.56	10.60	10.32	10.09	9.96	9.93	9.38	9.00	8.33

Appendix Table 4: Monthly average maximum temperature for Bekoji Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1998	21.70	23.50	23.30	24.08	22.18	21.82	17.52	17.01	18.58	17.18	20.48	21.81
1999	22.71	24.27	22.76	23.15	22.82	22.87	18.07	19.77	20.04	17.57	20.66	21.59
2000	22.79	23.58	24.49	23.29	22.83	24.08	19.78	19.05	20.72	19.96	21.48	23.06
2001	22.99	24.69	23.03	23.76	24.52	24.32	20.84	18.95	20.31	20.85	22.76	23.39
2002	22.20	25.04	23.72	23.83	24.87	24.96	25.08	21.48	21.06	21.51	23.57	23.18
2003	23.28	25.07	24.42	23.62	24.46	24.02	20.21	19.27	20.27	21.48	22.51	21.80
2004	22.67	23.59	24.95	21.80	24.83	24.03	21.48	20.36	20.90	20.42	22.05	22.59
2005	22.59	25.22	24.12	22.84	20.15	21.70	19.62	20.76	20.63	20.52	21.61	21.73
2006	23.05	23.67	24.59	21.91	23.63	24.30	21.04	19.89	20.18	19.60	21.75	21.44
2007	23.13	23.70	24.34	23.25	23.27	21.74	20.38	20.48	19.32	20.56	21.40	21.89
2008	23.02	23.19	24.70	22.01	22.69	23.26	21.84	19.37	20.64	20.78	20.75	22.35
2009	21.17	23.59	24.69	21.87	23.49	24.54	20.60	20.63	20.40	18.83	21.41	20.84
2010	22.66	20.56	20.32	21.37	21.58	22.73	18.16	17.43	18.03	19.42	20.46	20.85
2011	21.60	22.05	20.84	20.16	16.43	19.73	17.02	16.57	16.16	16.39	17.71	19.14
2012	20.53	20.58	22.24	16.52	17.47	19.55	16.19	16.32	16.19	16.28	17.96	19.70
2013	21.63	22.08	20.61	17.94	16.11	17.88	15.27	14.94	16.31	15.21	16.27	19.15
2014	20.67	20.59	19.37	18.04	17.05	18.79	17.99	21.26	20.60	21.01	21.08	21.62
2015	21.26	21.02	21.10	21.36	20.74	20.97	21.09	21.33	21.50	20.95	21.57	21.03
2016	20.71	20.98	21.85	21.35	21.68	21.36	21.25	21.36	21.43	20.80	21.44	20.83
2017	21.65	20.80	20.77	20.83	21.25	20.93	20.96	20.95	21.15	20.95	21.36	21.02
Average	22.10	22.89	22.81	21.65	21.60	22.18	19.72	19.36	19.72	19.51	20.91	21.45

Appendix Table 5: Monthly average minimum temperature for Bekoji Metrological station



Year	Jan	Feb	March	April	May	Jun	Jul	Ausg	Sep	Oct	Nov	Dec
1998	8.0	8.3	9.3	9.3	8.4	9.1	9.2	9.0	9.1	8.3	5.1	4.9
1999	6.1	7.1	8.2	7.4	7.4	8.4	8.6	8.7	8.2	8.0	5.2	5.1
2000	5.4	6.9	6.9	8.4	8.8	8.4	8.9	8.7	8.0	7.1	6.0	5.8
2001	6.0	7.4	8.5	8.3	8.7	9.1	9.3	9.4	7.6	6.6	5.4	6.2
2002	7.0	7.4	9.1	8.9	8.2	8.9	8.3	8.9	8.6	7.4	6.3	7.2
2003	6.7	8.1	8.6	9.3	7.9	8.5	9.4	9.0	8.6	6.9	6.9	6.2
2004	7.9	7.1	8.0	9.8	7.4	8.8	9.1	8.8	8.7	7.6	6.8	6.5
2005	6.7	7.7	8.9	9.2	9.3	8.5	9.3	8.8	9.3	7.4	6.1	5.1
2006	6.8	7.9	8.2	8.4	8.3	9.0	9.2	8.9	9.2	8.6	6.5	6.9
2007	6.8	8.4	8.5	9.1	8.8	9.4	9.2	8.9	9.0	6.9	6.4	5.6
2008	6.7	6.9	7.0	8.0	8.5	8.7	9.0	8.8	8.7	7.6	6.5	6.1
2009	7.2	7.5	8.4	9.2	7.4	8.5	9.0	8.5	8.5	7.9	5.8	7.4
2010	6.7	9.5	9.2	9.5	9.3	9.2	9.2	9.5	9.1	7.6	6.3	5.5
2011	2.8	3.2	5.0	5.1	6.0	5.9	6.4	6.8	6.0	3.8	3.9	3.0
2012	2.9	2.9	4.0	6.0	4.8	5.0	7.4	6.5	6.0	3.8	3.2	2.9
2013	3.2	3.6	6.0	6.1	5.2	6.2	7.3	6.8	5.4	4.5	3.2	2.1
2014	3.2	5.1	4.7	4.9	6.1	5.9	6.6	3.3	3.1	3.5	3.2	3.4
2015	3.3	3.5	2.6	3.5	3.3	3.4	3.4	3.3	3.4	3.2	3.6	3.4
2016	2.9	3.4	2.9	3.2	2.6	3.6	4.0	3.5	2.6	3.1	3.2	3.1
2017	3.3	3.4	2.4	3.3	2.9	2.6	2.8	2.4	2.5	3.1	3.2	2.9
Average	5.5	6.3	6.8	7.3	7.0	7.4	7.8	7.4	7.1	6.1	5.1	5.0

Appendix Table 6: Monthly average maximum temperature for kulumsa Metrological station

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	22.06	24.00	25.01	25.98	24.87	24.23	21.43	20.80	20.80	21.84	21.59	21.68
1999	22.98	25.66	24.14	25.93	25.27	23.48	20.51	20.67	21.51	20.66	21.12	21.50
2000	23.09	24.34	25.86	25.13	23.95	23.07	20.65	20.43	21.23	21.60	21.81	21.79
2001	22.21	24.33	22.58	24.36	23.77	21.79	21.30	21.12	21.95	23.36	22.67	22.87
2002	21.59	24.62	24.81	25.41	26.25	24.27	23.85	21.77	22.56	24.15	24.08	22.56
2003	23.24	25.66	24.77	24.27	26.54	23.18	20.74	21.04	21.24	23.33	22.91	21.31
2004	23.88	23.89	25.37	23.85	26.55	23.69	21.49	21.74	21.57	21.53	22.82	22.03
2005	23.35	25.70	25.07	25.63	23.25	23.43	21.19	22.06	22.12	23.24	22.95	22.76
2006	24.13	26.01	24.49	23.20	24.79	23.69	21.28	20.95	21.27	22.82	22.51	21.65
2007	23.02	24.42	26.19	25.05	25.39	22.59	21.33	20.67	21.60	22.58	22.17	22.07
2008	23.54	23.97	26.98	25.88	24.26	23.07	20.91	20.64	22.06	23.24	21.26	22.69
2009	22.84	24.45	26.49	25.61	26.59	25.63	22.01	21.42	22.79	22.68	23.72	22.37
2010	23.70	23.79	23.18	24.45	23.97	23.55	21.40	21.53	21.39	23.79	23.59	23.12
2011	23.78	25.34	24.35	26.39	24.24	23.96	22.24	20.99	21.38	23.27	22.87	21.96
2012	23.70	24.93	26.44	24.89	25.85	24.48	20.99	20.90	21.19	23.23	23.94	23.20
2013	23.97	25.90	26.30	25.15	24.14	23.77	21.27	20.95	21.76	22.73	23.21	22.84
2014	29.86	25.83	25.93	25.69	24.23	23.22	23.29	23.50	23.64	23.06	23.52	23.46
2015	23.68	23.65	27.31	27.09	25.74	24.43	23.66	23.36	22.83	24.92	23.68	23.45
2016	24.73	26.47	29.21	24.74	23.93	23.51	22.15	21.87	23.61	23.17	23.39	22.60
2017	24.08	23.46	27.20	27.22	24.25	24.77	22.50	23.56	23.42	23.61	23.48	23.55
Ave.	23.67	24.82	25.58	25.30	24.89	23.69	21.71	21.50	22.00	22.94	22.87	22.47

Appendix Table 7: Monthly average minimum temperature for kulumsa Metrological station

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	9.50	10.44	11.40	11.77	11.27	10.93	10.91	10.66	10.19	10.46	8.05	8.45
1999	8.02	8.65	11.84	12.72	12.07	12.21	11.77	11.79	11.39	11.55	11.11	9.09
2000	8.50	9.75	10.61	13.49	12.23	12.15	12.64	12.23	11.55	12.20	10.68	9.06
2001	9.95	10.41	9.45	10.09	9.52	8.75	7.73	9.70	8.51	8.90	7.43	6.02
2002	7.93	6.69	8.73	10.36	9.59	9.45	9.31	9.21	8.52	9.12	8.19	8.27
2003	7.33	8.44	8.70	9.41	9.55	9.16	9.16	9.38	8.43	9.60	7.65	6.39
2004	7.85	7.34	8.71	10.46	9.35	8.90	8.78	9.20	8.90	8.07	8.16	6.95
2005	7.22	6.95	9.33	10.06	10.41	9.12	9.22	9.03	9.15	9.32	8.12	5.01
2006	6.23	7.83	9.13	9.66	9.50	9.28	9.45	9.21	8.69	8.93	8.50	7.97
2007	7.36	8.81	8.42	9.51	9.77	9.61	9.40	8.54	8.24	8.66	7.51	6.10
2008	6.08	6.79	7.67	10.11	9.65	8.75	8.87	8.67	8.71	9.25	6.79	4.55
2009	5.76	6.10	8.41	10.09	10.02	9.03	9.61	9.19	9.20	7.67	7.00	7.42
2010	6.24	9.40	9.03	9.86	9.90	9.07	9.37	9.49	8.20	9.35	6.25	5.81
2011	5.95	7.33	8.55	9.42	9.99	9.33	9.07	9.08	8.06	8.99	9.20	6.41
2012	8.33	9.53	11.27	13.02	12.57	11.98	12.42	12.24	11.12	12.44	10.98	9.75
2013	9.67	10.41	12.55	12.36	9.37	9.35	9.32	10.70	10.88	10.20	7.60	8.49
2014	9.67	10.41	12.55	12.36	9.37	9.35	9.32	10.70	10.88	10.20	7.60	8.49
2015	12.64	12.02	12.21	12.97	12.49	12.30	12.34	12.17	11.73	12.81	11.26	9.36
2016	9.79	7.64	12.23	13.42	13.01	13.43	12.85	12.70	12.32	13.61	12.15	7.69
2017	9.14	10.70	11.85	13.51	13.32	12.49	13.08	12.68	7.66	12.58	7.88	7.43
Average	8.16	8.78	10.13	11.23	10.65	10.23	10.23	10.33	9.62	10.20	8.60	7.44

Appendix Table 8: Monthly average maximum temperature for Sagure Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	13.2	14.3	15.8	15.9	14.6	15.7	14.6	15.0	15.3	14.4	14.5	15.1
1999	14.9	14.7	15.5	16.0	15.3	14.8	15.4	14.4	16.7	14.4	14.5	17.1
2000	14.8	13.5	15.6	15.7	14.9	16.0	21.9	19.3	21.2	22.5	22.0	22.5
2001	22.6	24.0	23.1	15.6	21.7	19.6	19.4	18.9	20.7	22.4	23.5	23.4
2002	23.1	24.6	23.1	23.5	23.0	21.3	20.7	19.4	21.4	23.4	24.4	23.3
2003	24.0	25.5	25.1	23.3	24.0	20.2	18.8	19.3	20.4	23.0	22.7	21.8
2004	23.1	24.4	24.2	22.0	23.0	20.7	18.8	19.7	20.5	22.2	22.9	22.8
2005	23.0	25.1	24.0	24.0	20.6	20.9	19.5	20.4	20.6	21.7	22.6	22.9
2006	24.0	25.0	23.7	22.0	22.2	21.4	19.0	18.9	20.3	21.2	22.4	22.0
2007	23.2	23.9	25.0	22.7	22.5	20.5	19.4	13.9	20.4	13.4	23.0	20.4
2008	23.6	24.0	25.4	23.2	22.6	22.7	19.4	20.9	20.3	22.9	22.0	22.3
2009	22.5	13.9	25.6	23.8	23.5	23.0	20.5	19.5	21.0	22.3	23.9	22.4
2010	23.4	23.4	22.9	22.5	22.1	21.5	19.1	19.3	20.8	22.9	23.0	22.5
2011	23.1	24.7	24.3	24.8	21.7	21.4	19.5	18.7	19.7	23.4	22.6	15.4
2012	23.1	24.8	25.8	22.4	23.6	23.6	19.1	19.2	21.3	21.8	24.3	21.8
2013	25.2	27.0	26.9	23.5	21.8	21.2	19.1	19.2	21.1	22.5	23.3	22.7
2014	23.5	16.0	24.7	14.9	14.1	13.4	13.9	19.5	15.7	15.1	14.7	16.1
2015	13.5	14.7	15.5	15.1	13.8	15.0	21.2	21.2	15.4	15.7	15.6	14.7
2016	14.7	25.2	15.4	16.3	14.2	14.8	13.9	15.7	15.9	15.3	15.6	16.3
2017	14.7	14.8	14.9	13.5	14.7	15.3	15.8	15.0	15.5	15.1	14.4	15.0
Ave.	20.7	21.2	21.8	20.0	19.7	19.1	18.5	18.4	19.2	19.8	20.6	20.0

Appendix Table 9: Monthly average minimum temperature for Sagure Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	5.1	5.2	5.0	5.4	5.0	5.6	5.6	4.7	5.4	4.7	5.2	5.0
1999	5.7	5.9	7.7	5.0	6.0	5.4	5.2	5.2	5.1	5.3	5.4	5.3
2000	5.0	5.6	5.4	5.9	5.2	5.8	6.7	7.8	7.5	6.4	4.8	3.5
2001	5.5	5.5	4.9	5.6	5.1	5.4	5.1	5.4	5.2	5.4	5.3	5.4
2002	5.7	5.9	5.5	5.1	5.1	5.2	5.2	5.2	5.5	5.9	5.6	5.0
2003	5.6	5.8	5.1	5.4	5.3	7.2	8.0	10.0	8.7	6.8	6.2	5.1
2004	7.1	6.8	7.9	10.1	8.5	8.8	9.3	9.4	8.5	6.9	5.4	4.9
2005	5.8	5.2	8.9	9.4	10.4	9.5	9.7	9.4	9.3	7.1	4.7	2.2
2006	5.2	6.6	8.6	9.3	9.2	9.2	10.3	9.6	9.4	8.5	5.4	5.7
2007	6.0	8.1	8.1	9.3	9.6	9.9	10.6	5.2	8.6	5.6	5.7	3.2
2008	5.2	6.1	6.5	9.3	9.7	9.7	9.9	8.7	9.0	7.2	4.9	3.8
2009	6.4	5.1	7.8	9.6	9.3	9.0	10.2	9.7	9.5	7.4	3.7	7.4
2010	5.8	9.9	9.2	10.0	10.7	9.8	10.2	10.8	9.2	6.9	4.7	3.9
2011	6.8	8.6	8.6	9.3	8.9	8.5	7.1	7.4	8.2	9.4	8.8	8.9
2012	11.0	11.2	9.5	11.1	9.2	8.5	8.3	10.0	8.2	11.6	7.8	11.6
2013	13.2	12.5	11.2	9.4	9.9	10.0	10.3	8.4	7.1	5.3	3.2	3.1
2014	5.0	5.1	8.4	5.5	5.2	5.5	5.7	9.4	5.5	5.2	5.3	5.6
2015	5.2	5.5	5.0	5.3	5.4	5.4	9.2	9.6	5.5	4.9	5.4	5.5
2016	5.1	6.7	5.7	5.2	5.1	5.4	5.3	5.0	5.1	5.7	5.2	5.2
2017	5.4	5.6	5.1	5.1	5.3	5.3	5.2	5.7	5.4	5.0	4.8	5.8
ave.	6.3	6.8	7.2	7.5	7.4	7.5	7.9	7.8	7.3	6.5	5.4	5.3

Appendix Table 10: Monthly average Wind speed in m/s for kulumsa Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	2.29	1.89	1.87	1.83	2.10	1.94	2.10	1.82	1.13	2.07	3.08	3.20
1999	2.70	2.93	1.89	2.72	1.91	1.56	1.76	1.20	0.94	1.65	3.45	3.19
2000	3.17	3.25	3.16	2.46	1.55	1.63	1.63	1.34	0.71	1.95	2.30	2.61
2001	2.38	2.44	1.19	2.46	1.17	1.39	1.48	1.42	1.07	2.13	2.78	2.57
2002	2.58	2.07	1.37	2.22	1.33	1.46	1.55	1.23	0.86	2.79	2.99	2.28
2003	1.99	2.23	2.10	1.62	2.05	1.30	1.62	1.19	0.80	2.70	2.74	2.69
2004	1.54	2.61	2.13	1.38	1.79	1.29	1.46	1.07	0.79	2.25	2.99	2.51
2005	1.85	2.32	1.53	1.62	1.21	1.27	1.42	0.97	0.87	2.34	2.64	2.57
2006	1.44	1.54	1.45	1.71	1.65	1.60	1.70	1.60	1.53	1.55	1.70	1.55
2007	1.47	1.53	1.57	1.59	1.71	1.49	1.57	1.65	1.66	1.58	1.60	1.55
2008	1.65	1.71	1.68	1.70	1.67	1.49	1.57	1.60	1.41	1.54	1.48	1.73
2009	1.70	1.77	1.61	1.54	1.67	1.76	1.50	1.59	1.54	1.65	1.45	1.66
2010	2.37	1.00	1.48	0.77	0.70	0.82	1.22	1.05	0.59	1.97	1.60	1.57
2011	0.16	3.35	1.79	1.28	1.23	0.79	1.06	0.86	0.56	3.05	2.10	2.57
2012	2.33	2.51	1.91	1.09	1.61	0.95	1.10	0.69	0.52	2.18	1.88	1.97
2013	1.95	1.93	1.32	1.00	0.70	0.81	1.05	0.70	0.52	1.30	2.04	2.16
2014	1.71	1.62	1.65	1.61	1.55	1.42	1.48	1.12	1.68	1.63	1.57	1.47
2015	1.49	1.71	1.44	1.56	1.58	1.66	1.68	1.50	1.70	1.47	1.52	1.61
2016	1.65	1.75	1.57	1.58	1.65	1.58	1.56	1.60	1.44	1.50	1.59	2.71
2017	1.62	1.46	1.67	1.51	1.62	1.76	1.74	1.63	1.58	1.55	1.62	1.67
Mean	1.90	2.08	1.72	1.66	1.52	1.40	1.51	1.29	1.09	1.94	2.15	2.19

Appendix Table 11: Monthly average Sunshine hour in hr. for kulumsa Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	5.57	5.50	5.25	5.02	5.18	5.14	4.60	5.22	5.24	4.72	5.04	5.10
1999	4.61	5.34	5.38	5.24	5.24	5.17	4.87	5.42	5.10	5.35	4.94	5.12
2000	5.19	5.57	5.41	5.36	5.66	5.22	5.06	5.24	5.76	5.08	4.94	5.13
2001	5.39	5.15	5.15	5.32	5.61	5.43	4.66	5.07	5.26	5.69	5.50	5.49
2002	4.97	5.27	5.00	5.32	5.17	5.43	4.85	5.31	5.48	4.73	5.08	5.22
2003	4.91	4.59	4.89	4.83	4.90	5.35	5.26	5.25	4.84	4.92	5.17	5.99
2004	4.92	5.27	5.16	4.81	5.17	5.21	5.08	5.24	4.98	4.93	5.24	4.53
2005	5.55	5.19	4.70	5.26	4.91	4.74	5.20	5.09	4.82	5.32	5.25	5.52
2006	8.67	8.76	6.12	6.24	7.90	7.03	5.14	4.80	4.16	6.07	8.96	7.97
2007	8.24	7.57	8.91	7.32	7.56	7.31	4.58	4.58	5.00	7.99	8.22	10.14
2008	8.61	9.29	9.74	7.14	5.82	6.90	5.25	4.49	5.67	7.19	8.24	9.13
2009	7.14	5.22	8.28	7.89	8.90	6.85	5.80	5.87	6.12	7.49	8.54	5.96
2010	8.53	5.34	6.38	6.10	5.89	6.40	4.28	4.83	2.02	8.16	7.95	8.25
2011	8.30	9.35	7.65	7.83	5.83	5.42	5.01	4.80	4.91	9.11	7.14	9.35
2012	9.43	9.62	8.37	6.64	8.55	6.79	4.77	5.16	4.46	8.11	8.41	8.72
2013	8.48	9.38	7.28	6.31	6.15	6.31	5.10	5.01	5.04	6.74	7.45	9.48
2014	8.00	7.43	5.97	7.26	5.77	7.72	4.89	5.01	4.04	7.16	6.11	8.04
2015	8.71	9.75	8.49	8.41	6.22	6.39	7.38	6.35	5.98	7.14	8.11	6.34
2016	5.21	6.07	6.71	4.54	6.01	5.96	5.09	5.22	5.56	7.56	7.44	9.01
2017	8.95	6.98	7.49	8.53	6.14	7.46	4.61	4.90	4.20	8.20	8.63	9.60
ave.	6.97	6.83	6.62	6.27	6.13	6.11	5.07	5.14	4.93	6.58	6.82	7.20

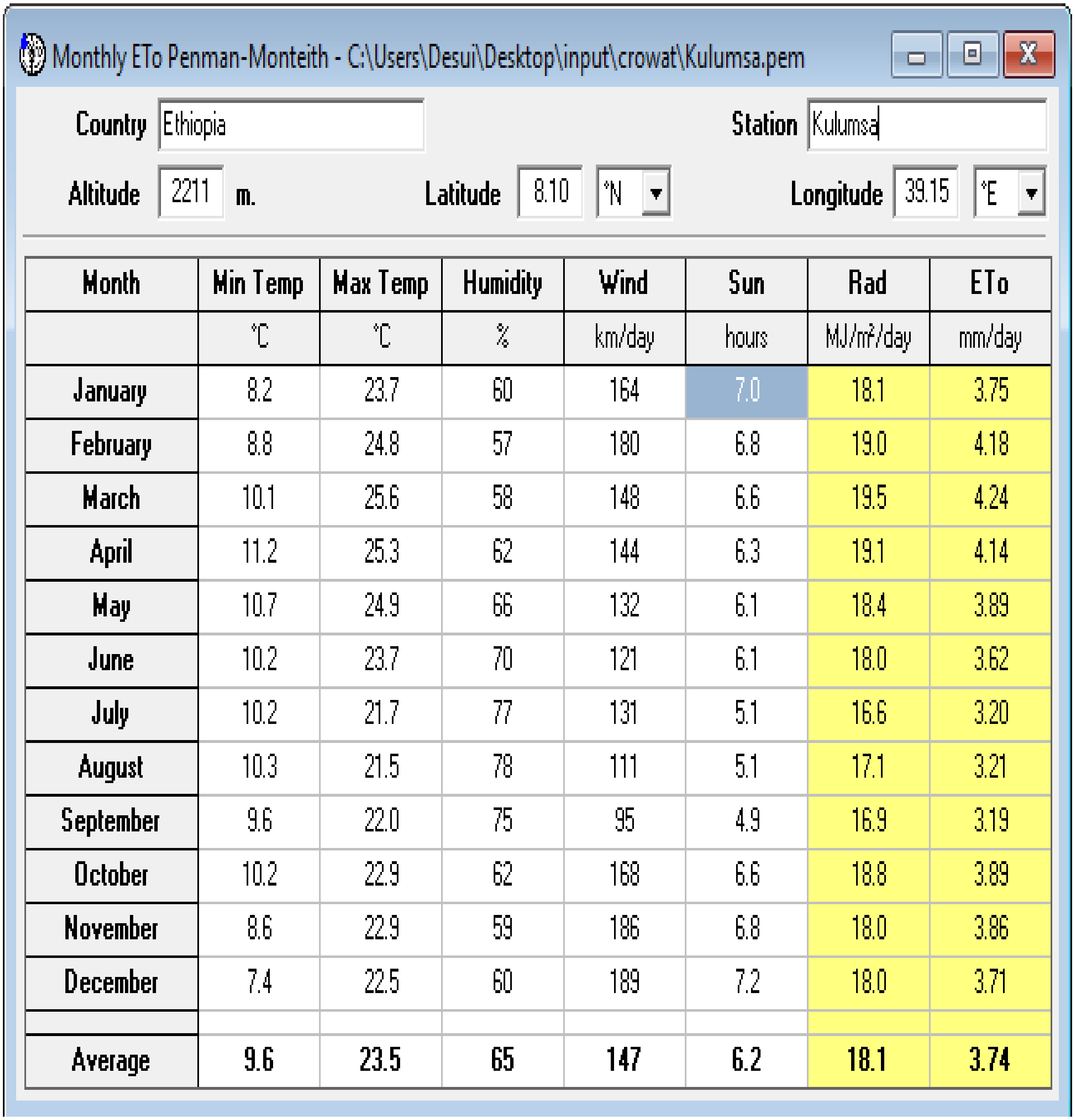
Appendix Table 12: Monthly average Relative Humidity in % for kulumsa Metrological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	76.53	68.91	70.44	66.28	67.19	68.39	79.87	85.01	82.46	68.97	54.15	49.05
1999	54.54	42.41	65.29	53.25	61.14	70.74	81.23	80.91	77.74	75.08	53.67	56.07
2000	50.42	41.70	44.30	55.37	67.86	69.63	79.72	81.83	78.43	72.05	64.48	60.83
2001	60.41	54.05	71.25	60.05	72.21	78.46	81.37	83.27	77.09	61.25	53.18	57.48
2002	71.45	51.86	64.11	57.09	61.62	69.26	71.08	79.23	74.91	51.19	45.75	68.69
2003	60.21	50.76	61.05	66.15	53.11	74.65	82.95	84.14	80.53	52.94	57.03	62.72
2004	66.60	54.28	49.06	70.00	53.03	69.54	77.83	79.83	77.62	63.67	57.63	63.13
2005	59.68	48.68	64.54	58.95	73.30	72.63	79.11	80.05	79.05	55.79	52.41	47.68
2006	57.66	55.46	59.99	69.67	63.34	71.74	82.55	82.17	80.95	67.00	58.76	68.57
2007	66.68	62.99	52.61	63.41	65.50	76.73	81.04	84.68	79.80	58.08	57.12	51.74
2008	63.59	62.21	64.62	64.69	64.47	61.93	63.64	64.56	62.25	63.99	63.90	65.24
2009	63.93	63.85	65.11	61.89	61.71	64.30	62.83	65.48	61.05	64.17	64.65	63.43
2010	57.92	66.74	66.34	73.81	76.50	76.40	80.13	82.01	81.41	57.54	56.56	53.97
2011	56.30	67.71	54.02	56.55	65.33	65.17	64.01	65.41	83.39	51.92	63.15	55.48
2012	53.81	45.88	44.59	66.41	57.37	68.42	82.12	63.99	68.43	62.35	65.57	62.38
2013	62.25	57.28	58.21	65.20	69.65	70.90	81.26	84.45	77.42	68.30	66.16	61.07
2014	55.84	61.21	64.51	62.09	68.19	62.51	77.11	82.29	80.94	71.89	62.91	59.21
2015	54.12	64.91	44.71	43.24	65.28	71.29	65.10	74.71	74.90	53.94	58.35	67.43
2016	59.23	52.26	50.41	74.87	75.25	74.87	81.14	79.86	64.54	64.72	63.38	55.44
2017	46.44	60.85	51.17	47.93	72.73	69.99	77.75	82.10	63.18	63.26	64.56	62.37
ave.	59.88	56.70	58.32	61.85	65.74	70.38	76.59	78.30	75.30	62.40	59.17	59.60

Appendix Table 13: Random consistency Index

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Appendix Table 14: Monthly reference evapotranspiration by Panman-Monteith for kulumsa Metrological station



Monthly ETo Penman-Monteith - C:\Users\Desui\Desktop\input\crowat\Kulumsa.pem

Country: Ethiopia

Station: Kulumsa

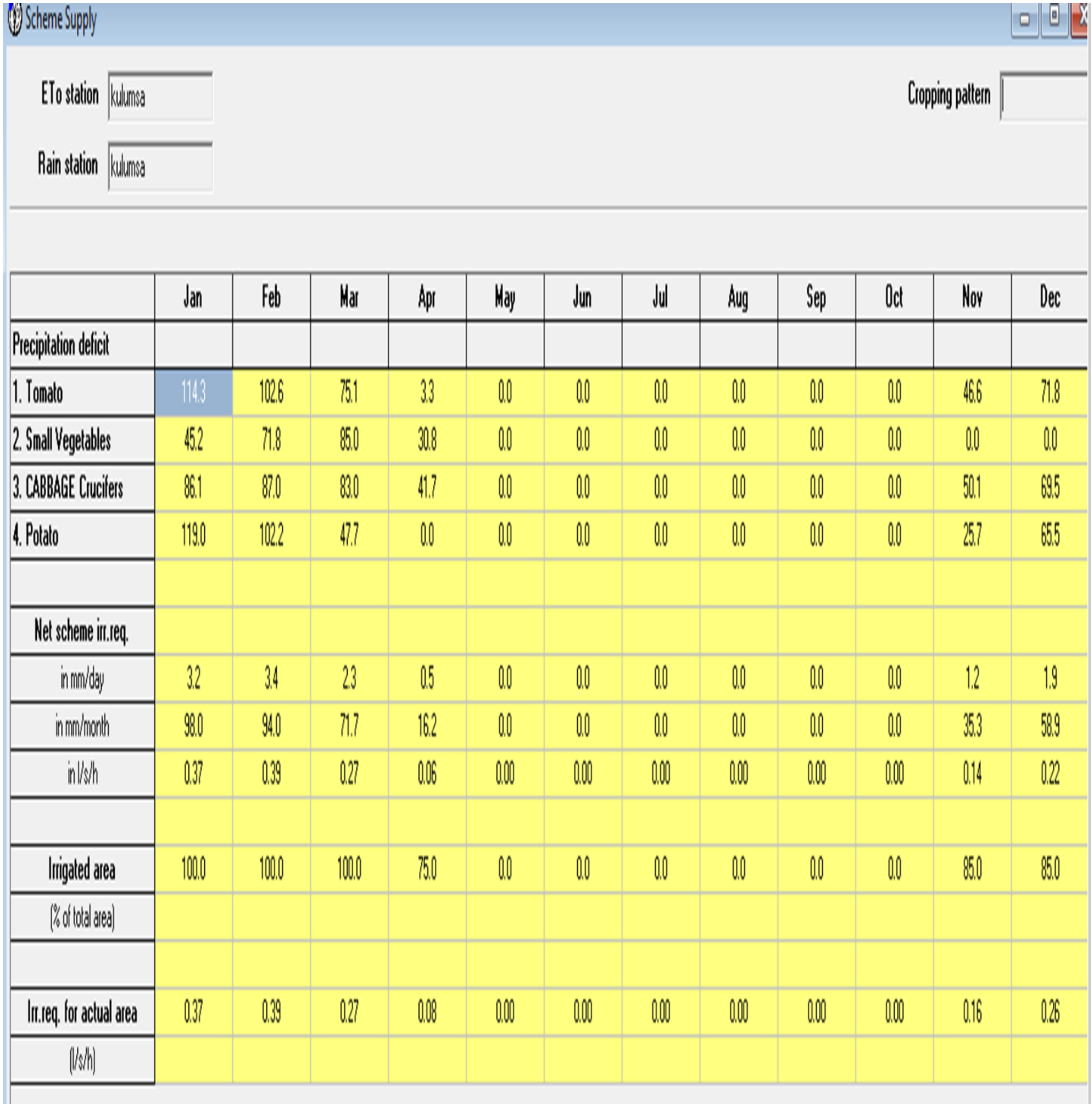
Altitude: 2211 m.

Latitude: 8.10 °N

Longitude: 39.15 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	8.2	23.7	60	164	7.0	18.1	3.75
February	8.8	24.8	57	180	6.8	19.0	4.18
March	10.1	25.6	58	148	6.6	19.5	4.24
April	11.2	25.3	62	144	6.3	19.1	4.14
May	10.7	24.9	66	132	6.1	18.4	3.89
June	10.2	23.7	70	121	6.1	18.0	3.62
July	10.2	21.7	77	131	5.1	16.6	3.20
August	10.3	21.5	78	111	5.1	17.1	3.21
September	9.6	22.0	75	95	4.9	16.9	3.19
October	10.2	22.9	62	168	6.6	18.8	3.89
November	8.6	22.9	59	186	6.8	18.0	3.86
December	7.4	22.5	60	189	7.2	18.0	3.71
Average	**9.6**	**23.5**	**65**	**147**	**6.2**	**18.1**	**3.74**

Appendix Table:15 Net irrigation Requirement For four crops commonly grown in study area.



ETo station: kulumsa

Rain station: kulumsa

Cropping pattern:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Tomato	114.3	102.6	75.1	3.3	0.0	0.0	0.0	0.0	0.0	0.0	46.6	71.8
2. Small Vegetables	45.2	71.8	85.0	30.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3. CABBAGE Crucifers	86.1	87.0	83.0	41.7	0.0	0.0	0.0	0.0	0.0	0.0	50.1	69.5
4. Potato	119.0	102.2	47.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.7	65.5
Net scheme irr.req.												
in mm/day	3.2	3.4	2.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.9
in mm/month	98.0	94.0	71.7	16.2	0.0	0.0	0.0	0.0	0.0	0.0	35.3	58.9
in l/s/h	0.37	0.39	0.27	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.22
Irrigated area	100.0	100.0	100.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	85.0	85.0
(% of total area)												
Irr.req. for actual area	0.37	0.39	0.27	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.26
(l/s/h)												

Appendix Table:16 Irrigation potential of Ethiopia by basin. (Sources: Awulachew et al. 2007; MoWE, FAO 2012; FAO 1997 and Ayalew, 2018)

Name of Basin	Type	Catchment Area (km2)	Irrigation potentials (ha)	Water resource (BCM)
Abay	River	198,890.70	815,581	54.4
Tekeze	River	83,475.94	83,368	8.2
Baro-Akobo	River	76,203.12	1,019,523	23.23
Omo-Ghibe	River	79,000	67,928	16.6
Rift Valley	Lake	52,739	139,300	5.64
Awash	River	110,439.30	198,632	4.9
Genale-Dawa	River	172,133	1,074,720	6
Wabi-Shebele	River	202,219.50	237,905	3.4
Danakil	Dry	63,852.97	158,776	0.86
Ogaden	Dry	77,121	_	0
Mereb	River	77,120	5,000	0.72
Ayisha	Dry	2,000	_	0
Total		1,118,074.53	3,800,733	123.95

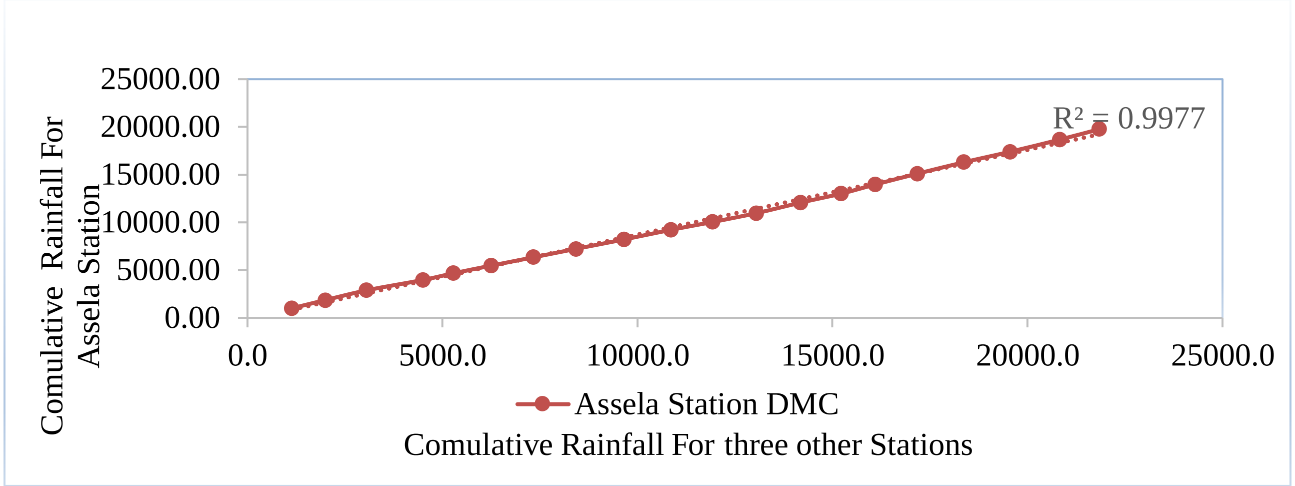
Appendix Table:17 Major lakes of Ethiopia (Source Ayalew, 2018)

Name of lake	Drainage Area km^2	Surface Area km^2	Volume (BCM)
Abaya	16,342	1,140	9.82
Abijata	10740	180	1
Ashange	129	140	0.25
Awassa	1300	129	1
Beseka	420	48.5	0.28
Chamo	18,575	317	3.24
Chaw Bahic	_	1,125	_
Hayq	83	23	1.01
Langano	2,000	230	3.8
Shala	2300	370	37
Tana	15,319	3,156	28.4
Ziway	7,380	440	1
Total			**86.8**

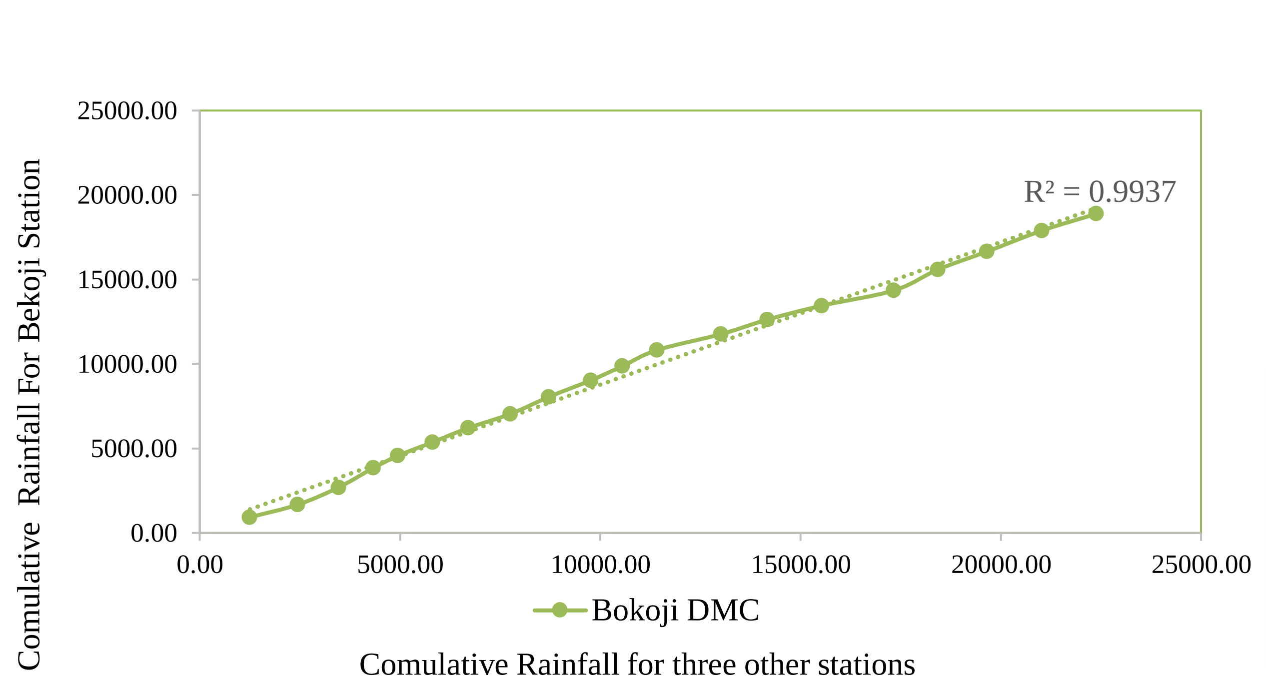
Appendix Table:1: major soil groups and soil units of the watershed (Source**:** Soils and Land Evaluation for Rift Valley Lakes Basin, (2007)

Major Soil Groupings	Identify Soil Unit	Code
Andosols	Vitric Andosols	ANz
Cambisols (CM)	Eutric Cambisols	CMe
Fluvisols (FL)	Calcaric Fluvisols	FLc
Luvisols (LV)	Haplic Luvisols	LVh
Nitisols (NT)	Rhodic Nitisols	NTr
Vertisols (VR)	Eutric Vertisols	VRe

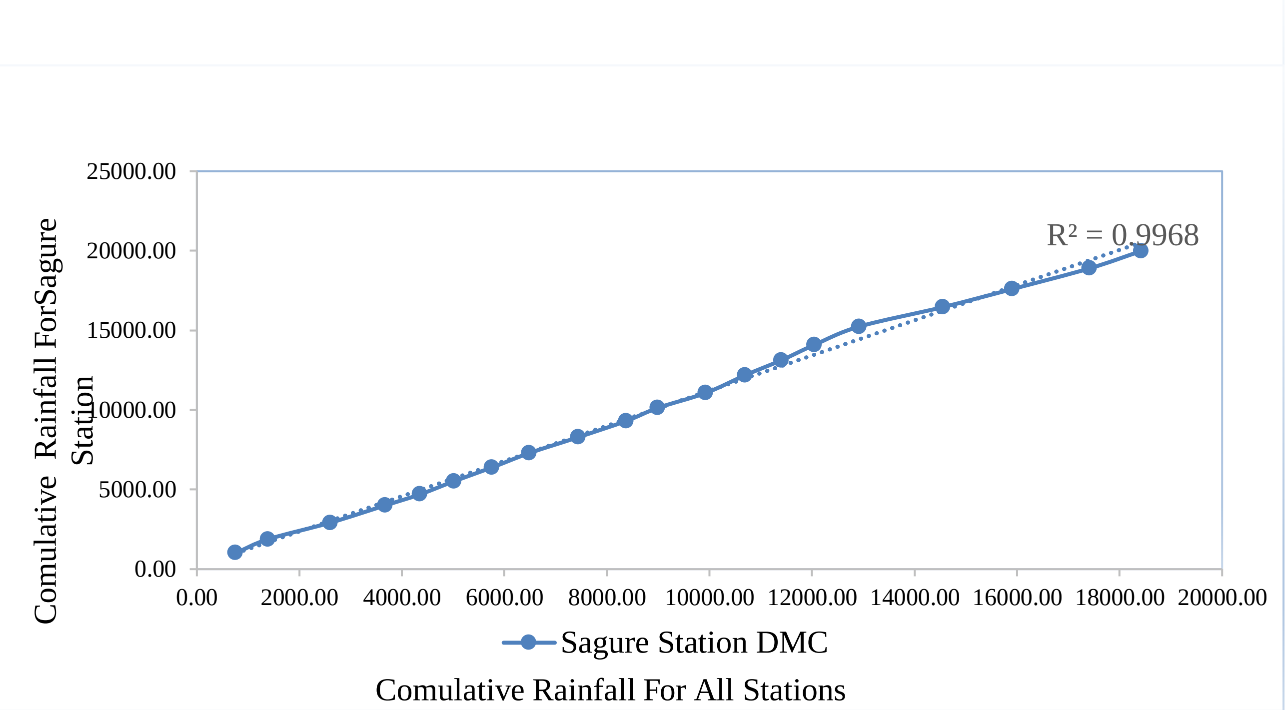
2 APPENDIX B FIGUERES



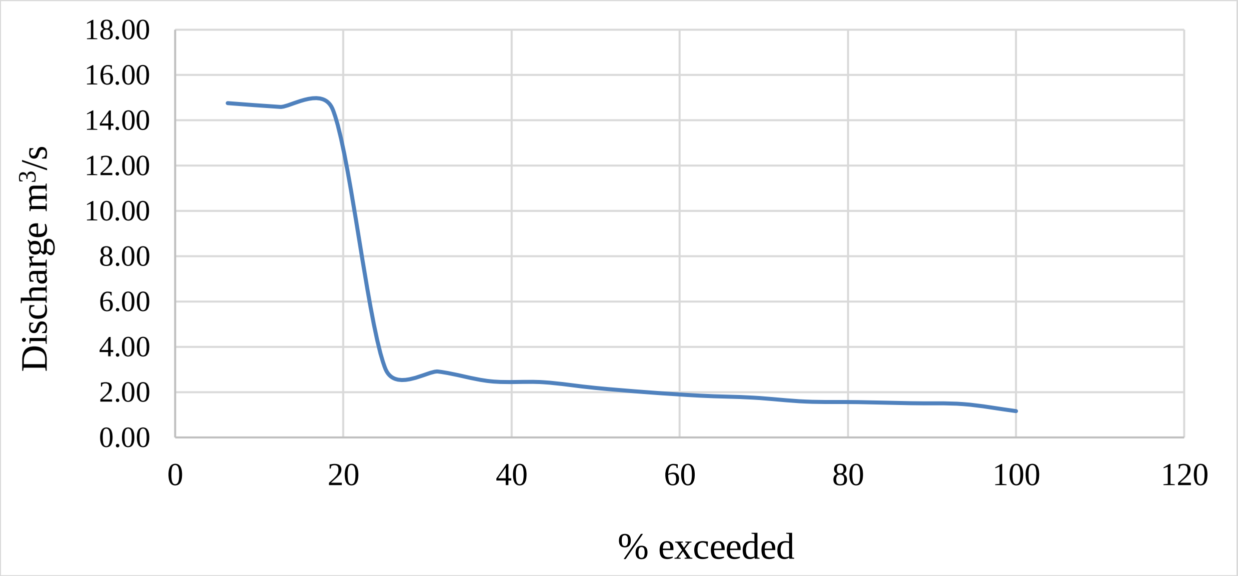
Appendix figure 1: Double mass curve for Assela Rain gage station



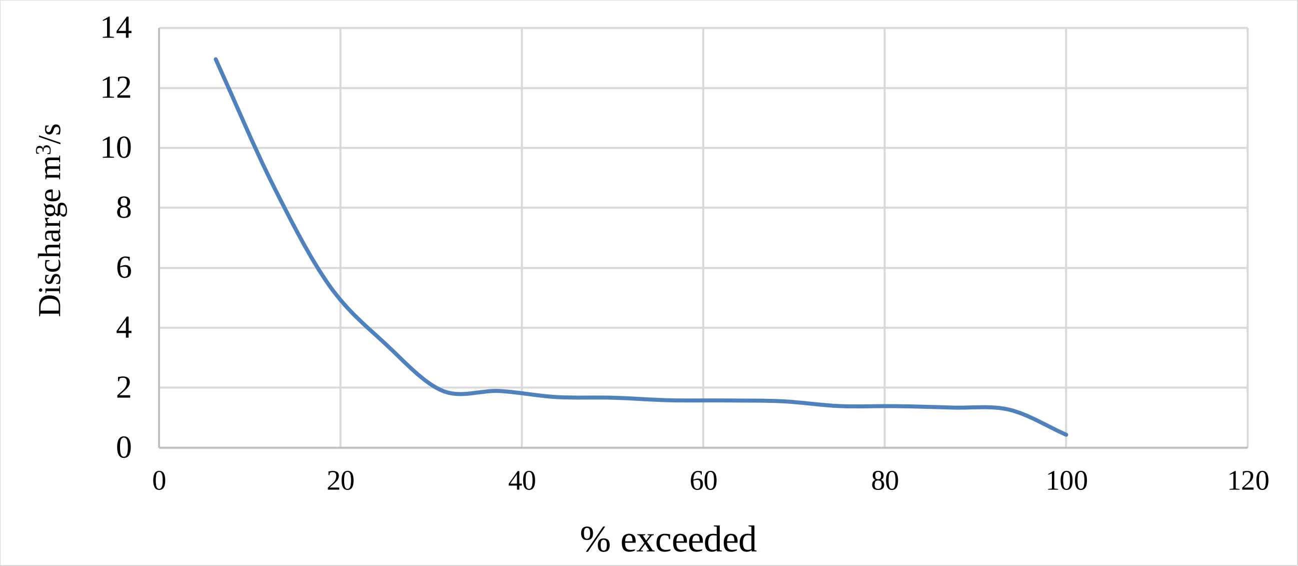
Appendix figure 2: Double mass curve for Bekoji Rain gage station



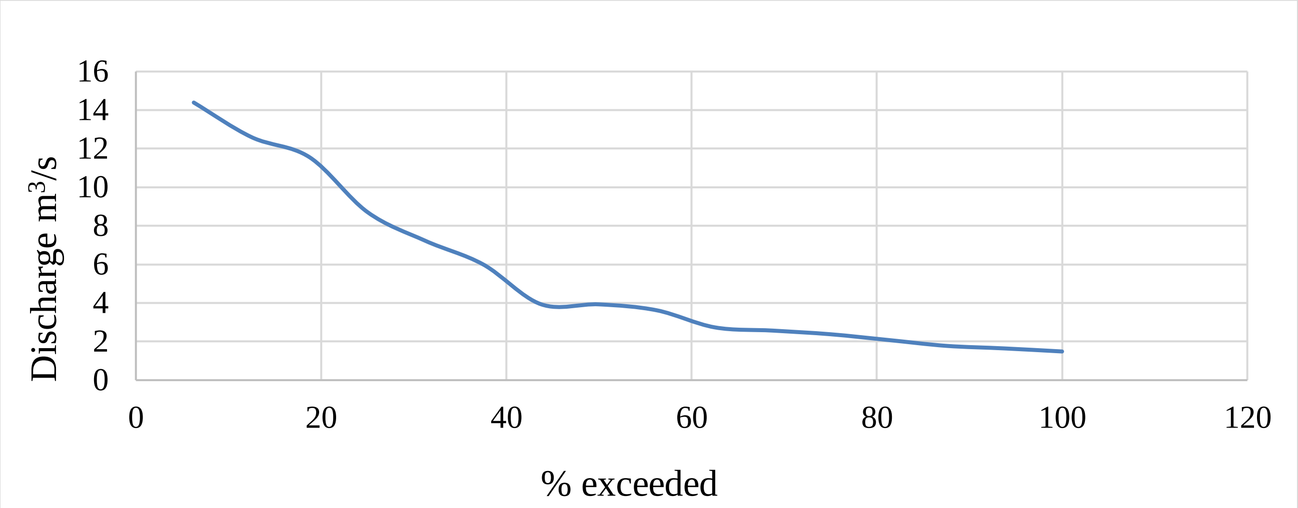
Appendix figure 3: Double mass curve for Kulumsa Rain gage station



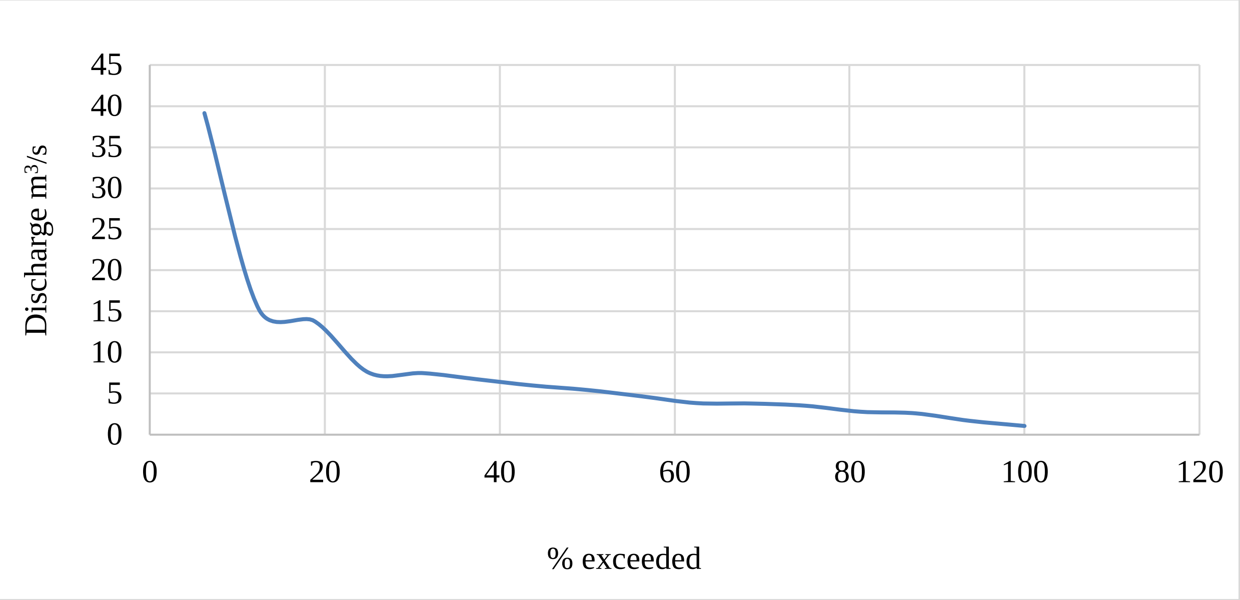
Appendix Figure 4: Flow Duration Curve for Month of January



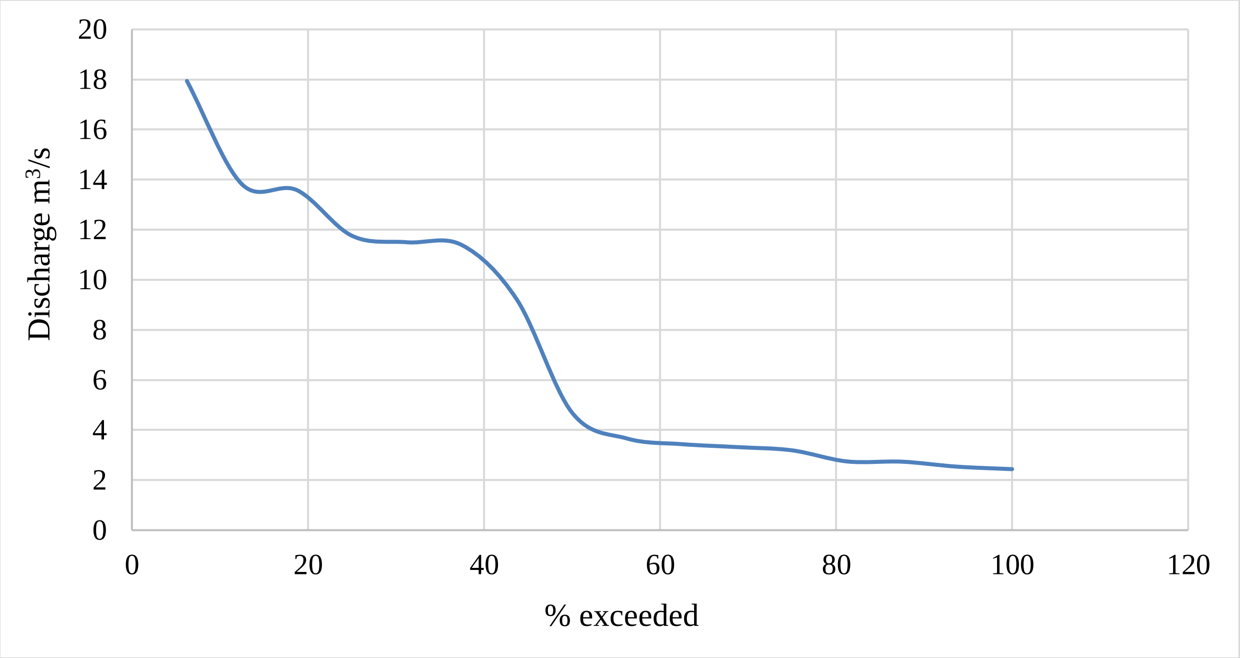
Appendix Figure 5: Flow Duration Curve for Month of February



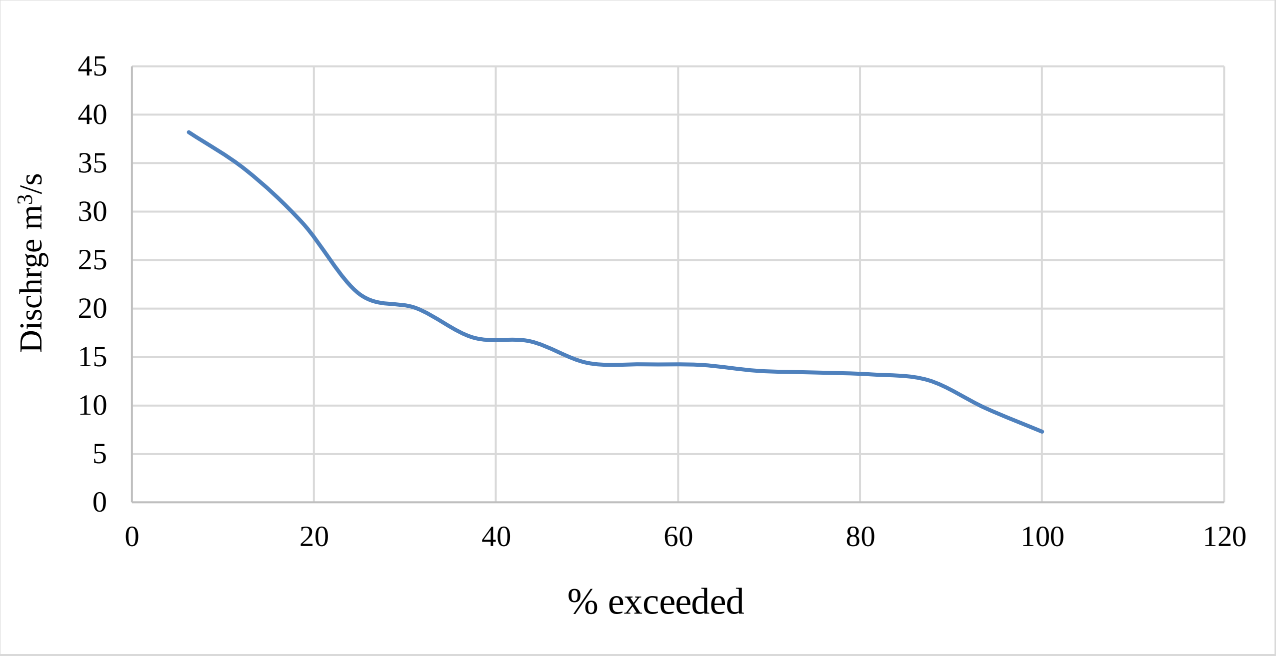
Appendix Figure 6: Flow Duration Curve for Month of April



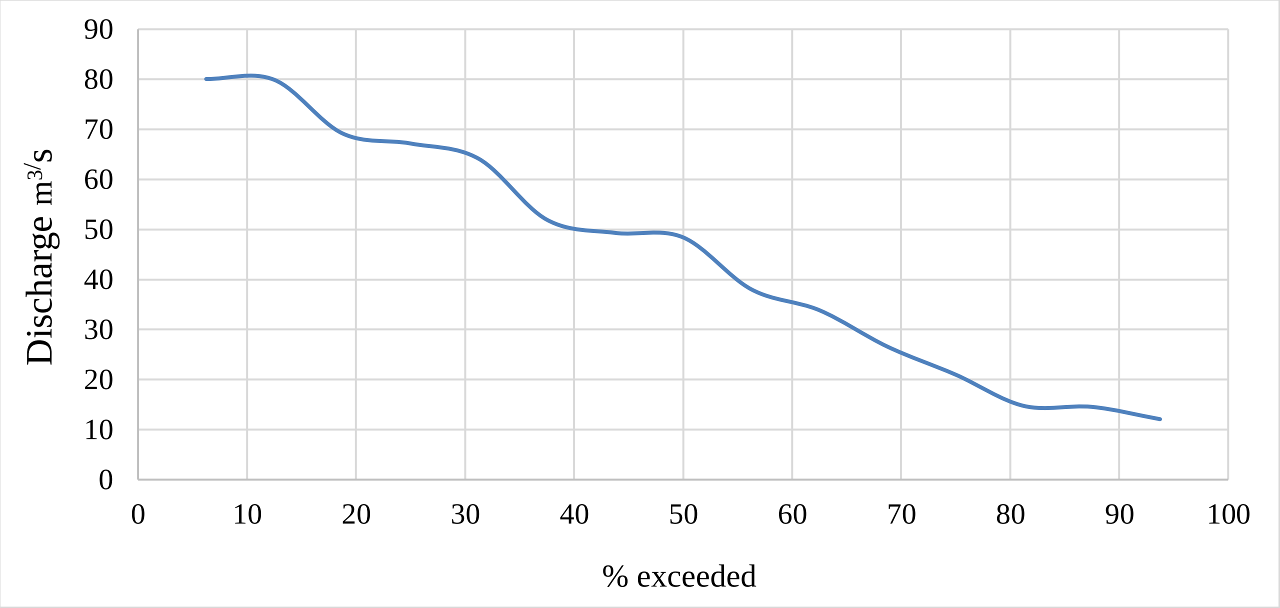
Appendix Figure 7: Flow Duration Curve for Month of May



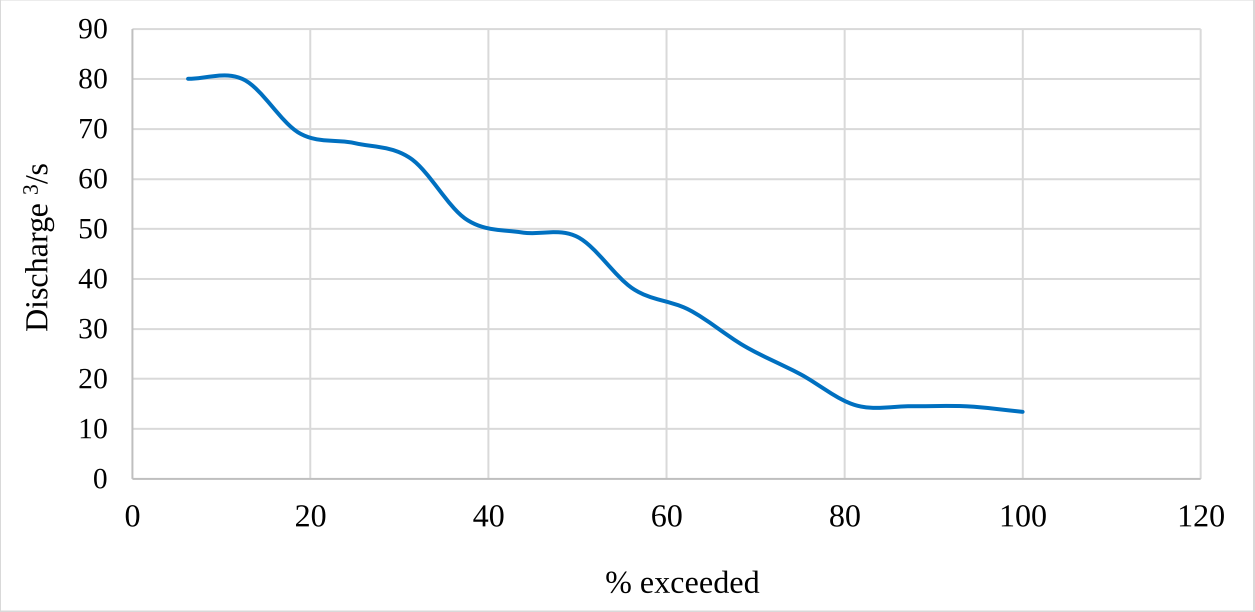
Appendix Figure 8: Flow Duration Curve for Month of June



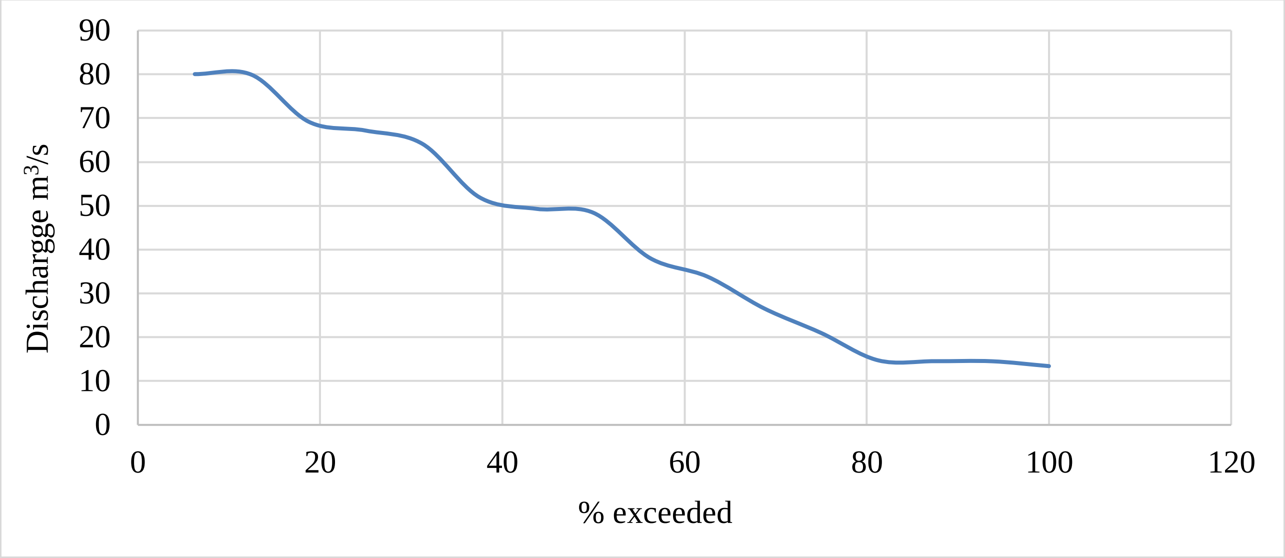
Appendix Figure 9: Flow Duration Curve for Month of July



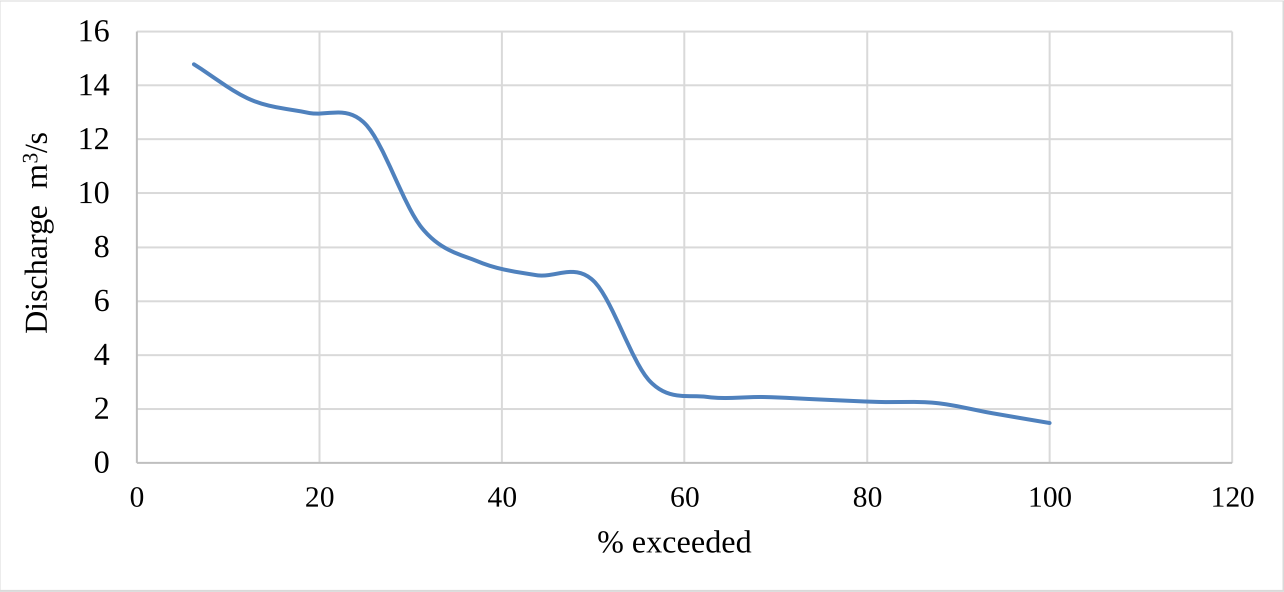
Appendix Figure 10: Flow Duration Curve for Month of August



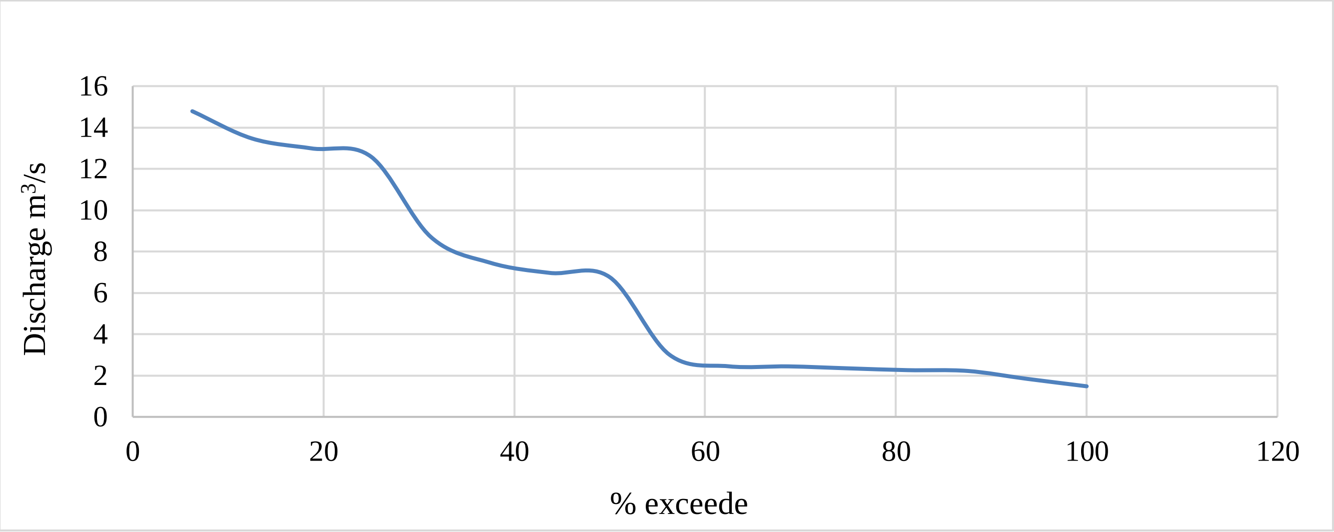
Appendix figure 11: Flow Duration Curve for Month of September



Appendix figure 12: Flow Duration Curve for Month of October



Appendix figure 13: Flow Duration Curve for Month of November



Appendix Figure 14: Flow Duration Curve for Month of December