Jimma University

School of Post Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Hydrology and Hydraulic Engineering Chair

Geographical Information System-Based Surface Irrigation Potential Assessment: A Case of Geba River Watershed, Oromiya, Ethiopia

By Ashenafi Tefera

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.

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Main Advisor: Dr.-Ing.Fekadu Fufa (Ph.D.)

Co-Advisor: Natan Molla (Msc)

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Jimma, Ethiopia

Declaration

I, the undersigned, declare that the thesis entitled "Geographical Information System-Based Surface Irrigation Potential Assessment: A Case of Geba River Watershed, Oromiya, Ethiopia" is my original work and that it has not been presented for a degree in any other university and that all sources of materials used for this thesis have been dully acknowledged.

MSc.Candidate	Signature	Date
Ashenafi Tefera	-----------------------	---------------

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This proposal 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
Co-Advisor: Natan Molla (Msc)	-------------------------	-----------------

Abstract

Proper land suitability evaluation of land resources in irrigation command area is a prerequisite for better utilization of land resources which helps to optimize and sustain the productivity of these land resources. However, in the Geba Watershed, there is no study available on the assessment of irrigation potential. Hence, this study is aimed to assess the surface irrigation potential of the Geba River Watershed in the Ilubabor Zone of Oromiya Regional State through Geographical Information System (GIS) techniques. Watershed delineation, identification of potentially irrigable land, estimation of irrigation water requirement, and surface water resources of the river were the steps followed to assess this irrigation potential. To identify potentially irrigable land, irrigation suitability factors such as soil, slope, land cover/use, distance from water supply (sources), and distance from the road were taken into account. Irrigation suitability factors are classified based on the Food and Agricultural Organization Guideline for land evaluation. The suitability of each factor was first analyzed individually and finally weighted using Analytical Hierarchy Process (AHP) method from the pair-wise comparison matrix to obtain potentially irrigable land. The irrigation suitability analysis of these factors indicate that 50.21% of slope,50.47% of LULC,65.07% of the distance from the water source, and 52.46% of the distance from the road of the study area are in the range of highly suitable to marginally suitable for surface irrigation and 77.39% of the soil in the study area is in the range of highly suitable to moderately suitable. By weighing analysis of all factors about 88.07 % of the study area was found in a range highly suitable to marginally suitable whereas about 11.93 % was restricted for surface irrigation developments. To grow on these identified irrigable areas, three crops such as potato, tomato, and cabbage are selected and their gross irrigation demand was computed from climate input data using CROPWAT 8.0 software. The low flow (90% time of exceedance flow of Geba River) was estimated by the flow duration curve. By comparing the required water and available monthly low flow of the Geba River, the river had insufficient capacity for irrigation application of the command area. Therefore, construction of storage structures or using ground water can be an option to meet irrigation potential.

Keywords: AHP, GIS, land suitability, suitability factor, surface irrigation potential

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Acronyms

AHP	Analytical Hierarchy Process
CROPWAT	Crop Water Requirement
DEM	Digital Elevation Model
DMC	Double Mass Curve
ERA	Ethiopian Road Authority
FAO	Food and Agricultural Organization
GIR	Gross Irrigation Requirement
GIS	Geographic Information System
IWR	Irrigation water requirement
LULC	Land use Land cover
MCDM	Multi-Criteria Decision Making
NIR	Net Irrigation Requirement
NMSA	National Meteorological Service Agency

1. Introduction

1.1 Background

The current world population of 7.6 billion is predicted to reach about 9.8 billion by 2050 (United Nations, 2017)**.** The increasing number of populations will result in considerable additional demand for food**.** A recent FAO analysis of 93 developing countries expects agricultural production to increase over the period 1998–2030 by 49% in rainfed systems and by 81% in irrigated systems (Tukura and Feyissa, 2020)**.** Therefore, higher agricultural production is expected from irrigation systems than in rainfed systems.

The population of Ethiopia has been increasing and it is above one hundred million (Hirko, 2017)**.** Most of the population in Ethiopia lives in highland areas, with 85% being rural and dependent on agriculture with a low level of productivity (Haile, 2015)**.**

The economy of Ethiopia is mainly dependent on agriculture (Shitu and Berhanu, 2020). However, this agriculture is primarily based on rainfall. It is estimated that in Ethiopia about 90% of food production comes from rainfed smallholder agriculture with low productivity, thus making rainfall the single most important determinant of food security and economy of the country (Singh, 2019). However, this region's rainfall is characterized as unreliable due to a high degree of both inter- and intra-annual variability, which further decreases the productivity of rainfall-dependent agriculture (Singh, 2019). In addition, poor land management coupled with increasing climate extremes is affecting the livelihoods of these communities(Shitu and Berhanu, 2020).

Ethiopia has a significant irrigation potential from both available land and water resources that could be easily developed for irrigation. The country has been gifted with ample water resources with 12 river basins with an annual runoff volume of 124.5 billion m3 of water and an estimated 30 - 40 billion m3 of groundwater potential (JOWSET, 2020). The irrigable land potential of the country 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 can be irrigated with Surface Water Potential and Rain Water Harvesting.

Proper use of land depends on the suitability or capability of land and water resources for the development of irrigation facilities could lead to a substantial increase in food production in many parts of the country (Girma, *et.al;*, 2020)**.**In developing supplementary irrigation, evaluating and assessing the potential and suitability of the land area will provide a comprehensive and integrated economic viability and sustainability of water resource development (Kebede and Ademe, 2016).

The Geba watershed was found in the Ilubabor Zone of Oromiya National Regional State which has abundant water and land resources, but its agricultural system does not yet fully productive and mainly depends on rainfed agriculture. To introduce improved irrigation technology and expand irrigation investment, irrigation land suitability assessment is a very important tool in terms of agriculture development planning and choosing suitable irrigation methods (Yeshita, 2019). However, there was no study conducted in the Geba watershed based on weighting the land resources for irrigation potential, this study has added some assets to explore the irrigation resource (potential) in the study area. And also, potentially irrigable areas in the study area have not been identified and do not match with the water requirements of some crops grown in the study area. Therefore, the objective of this study was to assess the irrigation potential of the Geba river watershed for irrigation using GIS techniques.

1.2 Statement of the problem

Proper land suitability evaluation of land resources in irrigation command area is a prerequisite for better utilization of land resources which helps to optimize and sustain the productivity of these land resources. Several researchers have carried out on irrigation land suitability evaluation using a geographic information system (GIS) in different parts of the world, including Ethiopia (e.g.Ganole, 2010; Worqlul et al.,2017; Singh, *et al*,2019; Girma R, *et al*,2020). For example, Singh *et al.*, (2019), stated that the pattern of land suitability is one of the indicators of irrigation development as well as the sustainability of land production, resource utilization, and management, which provides a basis for the selection of appropriate irrigation techniques. However, the majority of the current land-use practices of Ethiopia are not based on suitability analysis.

Land needs careful and appropriate use that is vital to achieve optimum productivity and to ensure environmental sustainability for the future generation. This requires an effective and operative management of land information on which such decisions should be based because the land is one of the non-renewable natural resources. Furthermore, the information about the suitability of the land, water resources availability and water requirements of irrigable areas should be combined in the irrigation planning process.

The efforts to establish small and large-scale irrigation schemes in the Geba Watershed are constrained by several uncertainties. Firstly, the potential of the water resources is not known. Secondly, potentially irrigable areas have not been identified and matched with the water requirements of some crops commonly grown in the Geba Watershed.

Therefore, to overcome these uncertainties, this study was carried out by using GIS as a tool for assessing irrigation potential in Geba Watershed by considering the Slope, soil, LULC, river, and road proximity. Furthermore, the study attempted to estimate the water resource potential of the river catchments in the Geba Watershed and the irrigation water requirements of the identified irrigable areas for cultivating some selected crops in the area.

1.3 Objectives

1.3.1. General Objective

The main purpose of the study is to assess surface irrigation potentials of Geba River Watershed using GIS techniques.

1.3.2. Specific Objectives

The specific objectives of the research are: -

- ❖ To identify suitable land for surface irrigation by producing land suitability map
- ❖ To quantify the surface water availability of the watershed during the dry season
- ❖ To estimate the total irrigation water requirement for potato, tomato, and cabbage in the watershed.

1.4 Research Questions

The research answers the following questions: -

1) How much area of Geba river watershed was suitable for surface irrigation?
2) How much quantity of surface water was available during the dry season?
3) How much is the estimated irrigation water requirement of potato,tomato and cabbage in the watershed?

1.5 Scope

The study is a watershed level study with an areal extent of 2813.37Km^2 and focuses on the identification of potentially irrigable sites, estimation of the availability of surface water sources and total irrigation water requirement, and producing a suitability map of the Geba river watershed for surface irrigation method. GIS is used to assess surface irrigation potential using irrigation suitability factors such as slope, soil, land use/cover, distance from the water supply, and distance from the road. In addition, Cropwat8.0 was used to estimate irrigation water demand, and Geba 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.

1.6 Significance of the study

This study is a GIS-based assessment of surface irrigation land suitability and development of a map for the Geba River watershed and it will provide helpful information to various stake holders as follows; the government institution of the area, contractors, and consultants will benefit from the study as a source of information for irrigation assessment and utilization. The study will provide a map that will help the concerned body to come up with appropriate measures to address problems resulting from the unavailability of surface water irrigation in the area. Other researchers will use the findings as a reference for further research on the suitability of land for irrigation.

1.7 Limitations

Shortage of data in the study area was the main problem faced. The recorded data by the different organizations were not recorded correctly. Some of the meteorological data for the study area in the station were missing. Lack of detailed soil characteristics of the watershed and availability of flow data for the study area in the station with high missing that can affect the final output of the study.

2. Literature Review

2.1. Definition of Irrigation Potential

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. (FAO,1997). However, to assess the information on land and water resources at the river basin level, knowledge of physical irrigation potential is necessary. The area which can potentially be irrigated depends on the physical resources 'soil' and 'water', combined with the irrigation water requirements as determined by the cropping patterns and climate (FAO,1997). Therefore, the physical irrigation potential represents a combination of information on gross irrigation water requirements, areas of soils suitable for irrigation, and available water resources by basin. However, environmental and socioeconomic constraints also have to be taken into consideration to guarantee sustainable use of the available physical resources (FAO,1997).

2.2. Irrigation Potential in Ethiopia

Ethiopia has a significant irrigation potential from both available land and water resources that could be easily developed for irrigation. The country has been gifted with ample water resources with 12 river basins with an annual runoff volume of 124.5 billion m3 of water and an estimated 30-40 billion m3 of groundwater potential (JOWSET, 2020). The estimates of the irrigation potential of Ethiopia vary from one source to the other, due to the lack of standard or agreed criteria for estimating irrigation potential in the country (Ganole,2010). According to Worqlul *et al* (2017) irrigable land potential of Ethiopia is estimated to be 6 million hectares of which 8 % can be irrigated using ground water. The rest of irrigable land can be irrigated with Surface Water Potential and Rain Water Harvesting.

2.3. Previous Study on Evaluating Impact of Land-Use/Land-Cover Change on Surface Runoff using Arc SWAT Model in Sore and Geba Watershed, Ethiopia (Mekuriyaw,2019)

Sore and Geba watershed are sub-watersheds of the Baro river basin. The change of LULC has made a substantial consequence on the hydrology including surface runoff, stream flow, evapotranspiration, sediment loading, and water yield of the study watershed. Vegetation cover helps to reduce soil erosion by interrupting and dissipating the erosive power of rainfall, runoff, and wind. It has also a role in reducing the volume of runoff by increasing the infiltration by following the root system and increases soil organic content which increases the aggregate stability of the soil. Within the study period, there has been a decline of natural forests and expansion of agricultural lands. As can be quantified in this study the expansion of agricultural lands generates the highest surface runoff. In general, during the study period, significant influence of LULC change was reflected in changes to the hydrologic system of the region with an important management implication for this region as well as other similar regions in Ethiopia.

2.4. Land Evaluation and Suitability Classification

Land evaluation is the process by which the suitability of land for specific uses such as irrigated agriculture is assessed (FAO,1985). The fitness of a given type of land for a defined use is land suitability. The land may be considered in its present condition or after improvement. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976, 1979, 1985, 1993, 2007a).

The suitability classification has its framework and structure. The framework has the same structure, i.e. recognizes the same categories, in all of the kinds of interpretative classification. Each category retains its basic meaning within the context of the different classification and as applied to different kinds of land use. Generally, land suitability classification reflects degrees of suitability (Table 2.1) stated by FAO (1976, 1979, 1985, 1993, 1995, 2007a).

Table 2. 1 Categories of the suitability classification (FAO, 1976, 1979, 1985, 1993, 1995, 2007a).

Categories	**Explanation**
Land suitability orders	Reflecting kinds of suitability
Land suitability classes	Reflecting degrees of suitability within Orders
Land suitability subclasses	Reflecting kinds of limitation or main kinds of improvement measures required, within Classes
Land suitability unit	Reflecting minor differences in required management

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 with methods of irrigation considered (FAO, 2007). Other factors that determine land suitability analysis as stated by FAO (2007a) are Social condition, infrastructure status, and stakeholder participation. According to FAO (2007), there are two land suitability orders represented by the symbols S (suitable) and N (unsuitable). There are five classes: 1, 2, and 3 for suitable and; 1 and 2 for unsuitable order that expresses the degree of suitability or unsuitability (Table 2.2).

Table 2. 2 Structure of land suitability orders and classes (FAO, 2007)

Order	Class	Description
Suitable (S)	S1 (Highly suitable)	Land having no, or insignificant limitations to the given type of use
	S2 (Moderately suitable)	Land having minor limitations to the given type of use
	S3 (Marginally suitable)	Land having moderate limitations to the given type of use
Unsuitable (N)	N1 (Currently not suitable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	N2 (Permanently not suitable)	Land with so severe limitations which are very difficult to be overcome

2.5 Irrigation Land Suitability Evaluation Factors

The main parameters that determine the irrigation potential of a given land are the physical and chemical factors of the land. The attributes are physical soil factors as slope, soil depth, soil texture, soil drainage, soil fertility and soil salinity, water resource factors as water availability, water quality, and distance to the water source (FAO, 1979).

Social condition, infrastructure status, and stakeholder participation are also the major factors that determine land suitability analysis (FAO, 2007a).

All the above physical and chemical soil properties, water resource status, infrastructure, and social factors include in the study which helps to evaluate the irrigation and suitability at the watershed level.

2.5.1. Slope

The slope is the main evaluation factor for surface irrigation suitability analysis since it affects water flow, the fertility of soil profile, depth of irrigation, and drainage of the river basin. According to FAO guidelines (FAO, 1999), the slope map of the river basin was reclassified into four suitability classes namely: (i) highly suitable (S1), (ii) moderately suitable (S2), (iii) marginally suitable (S3) and (iv) not suitable (N).

2.5.2 Soil

Soil is a major factor in determining the suitability of an area for agriculture and sustained irrigation (Husein *et al.*, 2019)**.** The assessment of soils for irrigation involves using properties that are permanent that cannot be changed. Such properties include drainage, texture, depth, salinity, and alkalinity (Ganole, 2010)**.** Even though salinity and alkalinity hazards are possibly improved by soil management practices, they could be considered as limiting factors in evaluating the soils for irrigation (FAO, 1997).

2.5.3. Land Use Land Cover

Land use and land cover are often used interchangeably. Land use refers to the actual economic activity for which the land is used i.e., food production commercial forestry, etc. Land cover refers to the cover of the earth’s surface i.e., vegetation (by type), bare soil, urban development, etc. without reference to how that cover is used (GLCN, 2006). The land use could be commercial forestry, watershed protection/conservation, national park, wild life, recreation, etc. similarly, grass land (land cover) could be used (land use) for wild life grazing and the land use may be tourism. Land areas may often have multiple uses (Jaruntorn et al., 2004).

2.5.4. Distance from the water source

Water is the most important resource for any country and of the entire society as a whole, since no life is possible without water. 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 year when it is available (FAO, 1985).

The amount of water available for irrigation should be quantified and the exact locations to which water can be economically delivered should be determined; since it is useful in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also required that the water source is near the center of the irrigated area to minimize the size of the delivery channels and pipelines. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length) and thereby develop the irrigation system economically (Seleshi Bekele & Ayana, 2007).

2.5.5. Distance from road

Social condition, infrastructure status, and stakeholder participation are the major factors that determine land suitability analysis (FAO, 2007a). Distance from the road also has been considered as one of the evaluation parameters in land suitability for irrigation purpose since the road is one of the infrastructures which affects market participation due to travel time and cost.

2.6. Overview of GIS Technology

A Geographic Information System (GIS) is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data (FAO,2015).
GIS is a computer-based system that offers a convenient and powerful platform for performing suitability evaluation (Meron, 2007). GIS techniques and procedures have an important role in analyzing decision problems (Malczewski, 2005). Geographically referenced data are data that describe both the locations and characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface (FAO, 2015). Therefore, the important advantage of using GIS technology is to perform a spatial multi-criteria decision study. Through this application of GIS, various criteria can be developed based on neighborhood analysis operations (Pereira, 1993). A GIS also provides a means for visualizing resource characteristics, thereby enhancing understanding in support of decision making.

2.6.1. Application of GIS

1. Mapping: The main application in GIS is mapping where things are and editing tasks as well as for map-based query and analysis (Campbell, 1984). A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. The map represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend.

2. Watershed Delineation: Watershed is the catchment area that drains into a common outlet. Simply, the 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). Delineation of a watershed means determining the boundary of the watershed. GIS uses DEM data as input to delineate watersheds with the integration of Arc GIS spatial analysis (Winchell et al., 2008).

3.Weighted Overlay Analysis: Weighted overlay is a method for applying a regular measurement scale of principles to diverse and dissimilar inputs to produce an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding an optimal site for irrigation requires the weighting of factors such as land cover, slope, and soil (Yang, 2003). To prioritize the influence of these factor values, weighted overlay analysis uses an evaluation scale from 1 to 9 by 1. For example, a value of 1 represents the least suitable factor in evaluation while a value of 9 represents the most suitable factor in evaluation. Weighted overlay only accepts integer rasters as input, such as a raster of land cover/use, soil types, and slope to find suitable land for irrigation (Janssen, 1990).

2.6.2. GIS as a Tool for Irrigation Potential Assessment

In the past, several studies have been made to assess the irrigation potential and water resources by using Geographic Information System tools.

FAO (1987) conducted a study to assess land and water resources potential for irrigation in Africa based on river basins of countries. It was one of the first GIS-based studies of its kind at a continental level. It proposed a natural resource-based approach to assess irrigation potential. Its main limitations were in the sensitivity of criteria for defining land suitability for irrigation and in water allocation scenarios needed for computation of irrigation potential.

FAO (1997) has studied the irrigation potential of Africa taking into consideration the above limitations. It focused mainly on quantitative assessment based on physical criteria (land and water), but depend on information collected from the countries.

Melaku (2003) carried out a study on the assessment of irrigation potential at the Raxo dam area (Portugal) for strategic planning by using RS and GIS. This study considered only the amount of available water in the dam and the topographic factor slope in identifying potential irrigable sites on the downstream side of the dam.

Negash (2004) conducted a study on irrigation suitability analysis in Ethiopia a case of Abaya-Chamo Lake Basin. It was GIS-based and had taken into consideration soil, slope, and land use, and water resource availability in perennial rivers in the basin to identify potentially irrigable land.

Meron (2007) carried out a study on surface irrigation suitability analysis of southern Abay Basin by GIS technique. This study considered soil, slope, and land cover /use factors to find suitable land for irrigation with respect to the location of available water resource and to determine the combined influence of these factors for irrigation suitability analysis, weighted overlay analysis was used in Arc GIS.

2.6.3. AHP Application Concept for Land Suitability Analysis

The AHP is a method widely used in MCDM to obtain the required weightings for different criteria (Mendoza, 2006). It has been successfully employed in GIS-based MCDM since the early 1990s (Marinoni, 2004). This approach enables us to compare different variants and ranks the factors, criteria, and parameters according to their importance.

The AHP method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix in which all relevant criteria identified are compared against each other based on preference factors. The weights can then be aggregated. GIS-based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria. It has been applied to a variety of decision-making problems (Feizizadeh and Blaschke,2001).

2.6.4. Limitations of GIS Technology

Application of the GIS in suitability analysis has been used in a wide range of crops and landforms but still in many parts of the world limitations exists as follows (FAO, 1995): a) The inadequate analysis of real-life problems as they occur in complex land management and sustainability issues at the household level, and as they involve the integration of biophysical, socio-economic and political considerations in a truly holistic manner;b) The limitation in data availability and data quality at all scales, especially those that require substantial ground truth;c) The lack of common data exchange formats and protocol: d) The inadequate communication means between computer systems, data suppliers, and users due, for instance, to poor local telephone networks.

2.7. Irrigation Water Requirement

Irrigation water should perform the necessary function without any adverse effects on the fertility of the soil or the proper growth of plants. Suitability of water for irrigation is described in which relate to the general irrigation problems of salinity, sodicity, acidity, and specific ion toxicity of other elements (FAO, 1985, Meron, 2007). In quantifying how much water is required for irrigation, it is necessary to distinguish between crop water requirement, net irrigation water requirement, gross irrigation water requirement, and their components as listed below with respect to the irrigable command area (FAO, 1985).

1. Reference crop Evapotranspiration (ETo)

The evapotranspiration from a reference surface not short of water is called the reference crop evapotranspiration and is denoted by ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith method is recommended as the sole method for determining ETo. The method has been selected because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Moreover, procedures have been developed for estimating missing climatic parameters (FAO, 2006). The FAO Penman-Monteith method has been developed by unambiguously defining the reference surface as a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m, and an albedo of 0.23' (FAO, 1998). The reference surface closely resembles an extensive surface of green grass that is of uniform height, actively growing, completely shading the ground, and adequately watered. The Penman-Monteith Equation is given as Equation 2.1, (FAO, 1998):

$$ETo=\frac{0.408\,\Delta(Rn-G)+\frac{\gamma\,900}{T+273}U2(es-ea)}{\Delta+\gamma\,(1+0.34\,U2)} \quad \text{Eq. (2.1)}$$

Where: ETo = Reference evapotranspiration (mm/day), Rn = Net radiation at the crop surface (MJ/m2 per day), G = Soil heat flux density (MJ/m2 per day), T = Mean daily air temperature at 2 m height (°C), u2 = Wind speed at 2 m height (m/sec), es = Saturation vapour pressure (kPa) ea = Actual vapour pressure (kPa), es - ea = Saturation vapour pressure deficit (kPa)

Δ = Slope of saturation vapour pressure curve at temperature T (kPa/°C) and γ = Psychrometric constant (kPa/°C).

2.Crop water requirement (CWR) and crop evapotranspiration (ETc)

According to FAO (1984), crop water requirement is the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non-restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment.

The values of ETc and CWR (Crop Water Requirements) are identical, whereby ETc refers to the amount of water lost through evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss (FAO, 2002). According to FAO, (2002), ETc can be calculated from climatic data by directly integrating the effect of crop characteristics into ETo. Using recognized methods, an estimation of ETO is done. Experimentally determined ratios of ETc/ ETo, called crop coefficients (Kc), are used to relate ETc to ETo.

$ETc = ETo \times KC$……………………………………………………………………….Eq. (2.2)

Where: ETc = Crop evapotranspiration (mm/day), ETo = Reference crop evapotranspiration (mm/day) and Kc = Crop coefficient (fraction).

3. Effective rainfall

Effective rainfall is part of the rainfall that can be effectively used by the crop, depending on its root zone depth and the soil storage capacity. It contributes to crop water requirement, net irrigation water requirement, or both (FAO, 2002).

4.Net irrigation water requirement (NIWR)

Irrigation water requirements (IWR) refer to the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirements. If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the irrigation system (FAO, 2002).

5.Gross irrigation water requirement (GIWR) GIWR is defined as the net irrigation water requirement, plus conveyance losses between the source of the water and the field, plus any additional water for leaching over and above percolation (FAO, 2002).

2.8. Overview of CROPWAT Model

FAO (1985) defined CROPWAT as a decision support system established by the Land and Water Development Division for planning and management of irrigation practice in water resource development. According to Meron (2007), CROPWAT is a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes. The calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop, and soil data. (FAO,1985). Once all the data is entered, CROPWAT8.0 windows automatically calculate the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade, or monthly.

3. Materials and Methods

3.1. Description of the Study Area

3.1.1 Location

The study area is the Geba River watershed, which is located in South West part of Oromiya National Regional State, Ethiopia.

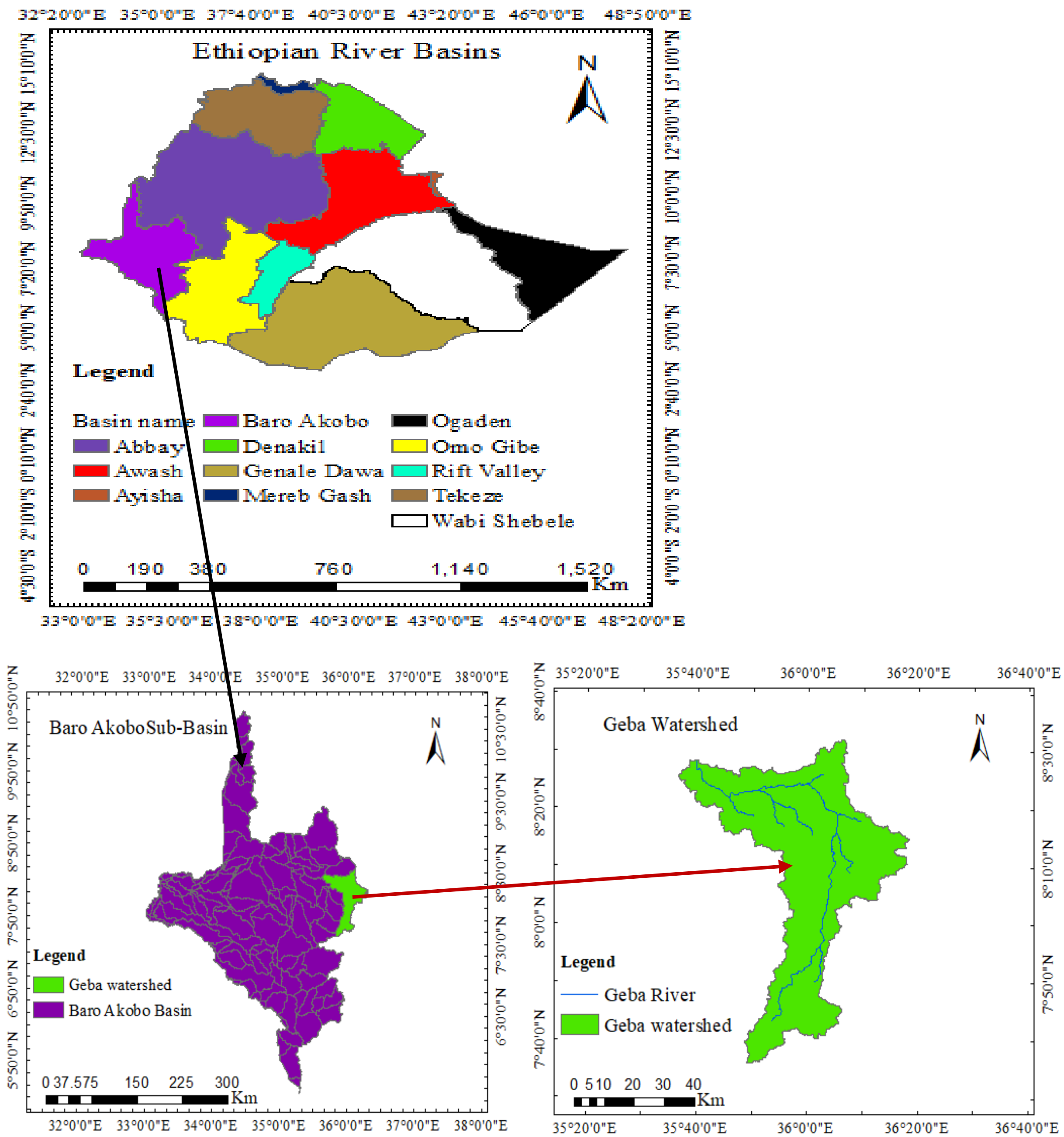

Figure 3.2 Study area map

The major part of the watershed is found in Ilubabor Zone and some part of the watershed is found in Jimma Zone. The geographical location of the study area extends from 35°35'0" to 36°20'0"E longitude and 7°35'0" to 8°35'0" N Latitude. It covers an area of about 2,813.37Km^2 in the Baro Akobo sub-basin.

3.1.2 Topography

Topography is the arrangement of the natural and artificial physical features of an area. Topography is defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution (JOWSET, 2020)**.** The elevation of the study area is varied from 1164 to 2993 m above mean sea level.

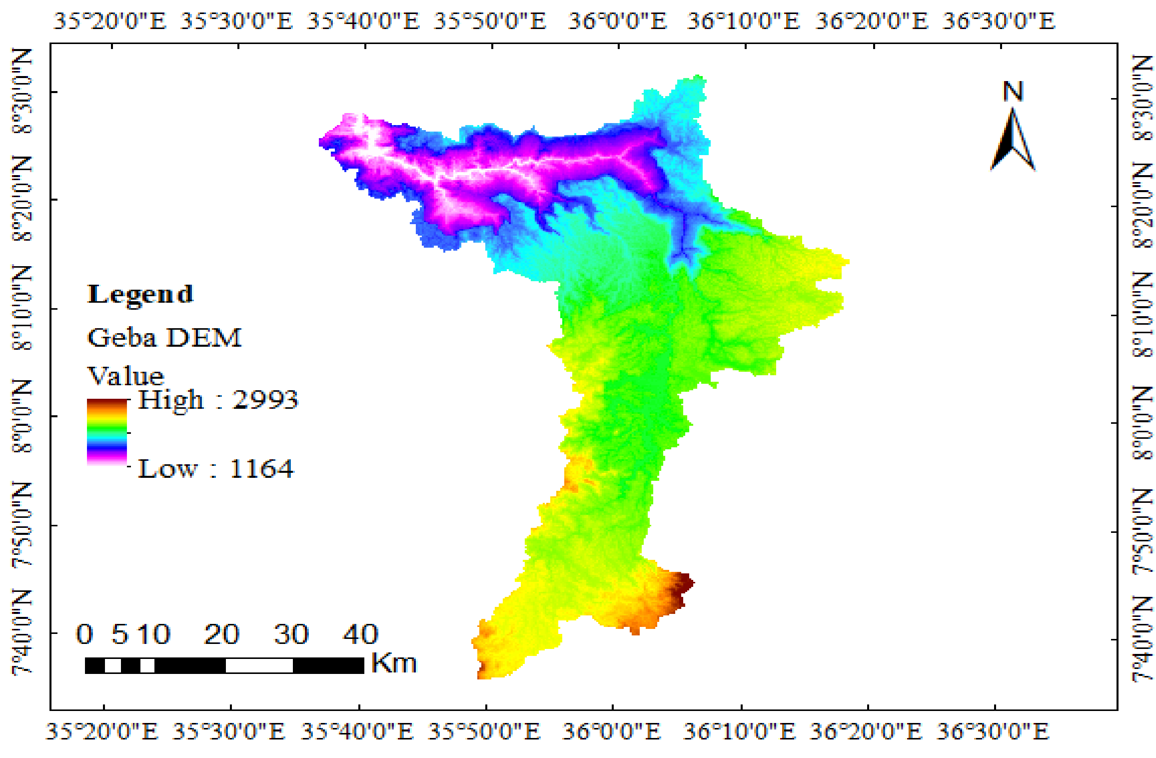

Figure 3. 3 Digital Elevation Model

3.1.3 Climate

The climate of the Geba Watershed is relatively warm and humid. The maximum temperature of the study area varies from 22 -27.3 °C and the minimum 11.9–13.7 °C. The average annual rainfall over the study area was estimated as 1843 mm with maximum rainfall is fed during May–September. (Asnake, *et al.*,2020).

3.1.4. Soil

The major soil types in the study area are Haplic Nitosols, Humic Alisols, Humic Nitosols, and Lithic Leptosols. From these Humic Nitosols covers the largest area and Haplic Nitosols covers the smallest area.

3.1.5 Land Use/ Land Cover

The major land cover/use of the study area was composed of forest, agricultural land, grass land, shrub land, and built-up areas. From these, the forest and agricultural land covers the large area. Each of the land cover types is tremendously influenced by properties of land forms, soils, and climate as elsewhere in Ethiopia.

3.2. Materials and Softwares

The softwares that were used for this study include ArcGIS10.8, CROPWAT8.0, XLSTAT2018, and Microsoft excel.

ArcGIS10.8 which was used for processing and analyzing the data base and developing and executing map from the database.

CROPWAT 8.0 for estimating ETo, crop, and irrigation water requirement

XLSTAT2018 for filling of missing metrological and stream flow data.

Microsoft Excel was used for the preparation of meteorological data for CROPWAT 8.0 software to estimate irrigation water requirement and used to prepare tables and graphs in the report. In addition to AHP was also prepared by Microsoft Excel.

3.3. Methods

3.3.1 Data Collection

Before simulation of any model, it is important to collect the relevant and appropriate data to achieve the objective of the research. So, to assess the surface irrigation potential of the study area the Secondary datas has been collected from different organizations.

The required secondary data for this study includes Digital Elevation Model (DEM), land use/land cover data, soil data, road data, Meteorological data and stream flow data.

1.Digital Elevation Model (DEM)

The DEM was used to delineate the Geba watershed and to develop slope map for reclassification as one of irrigation suitability factors.

The DEM of 12.5m by 12.5m resolution was downloaded from the Alaska satellite facility @ the website: https://vertex.daac.asf.alaska.edu/.

2.Land Use/Land Cover data

The LULC (2013) data for this study was obtained from the Ethiopian Mapping Agency. This data was one of the inputs for assessing land suitability in the study area.

3.Soil data

Soil is one of the important factors in land suitability assessment for surface irrigation and is also used as input data in CROPWAT 8.0 to calculate crop water requirement. This soil data were obtained from the Ethiopian Ministry of Water, Irrigation, and Energy.

4. Meteorological data

Meteorological data such as rainfall, temperature, wind speed, sunshine, and relative humidity were collected from the National meteorological service agency (NMSA). These data have been used to quantify the crop water requirement of some selected crops using Cropwat 8.0 software.

5. Stream flow data

Discharges of the Geba station were obtained from the Hydrology Department of the Ministry of Water irrigation and energy which is recorded for 14 years of data from (2000-2013). The stream flow data were used to assess the river flow potential of the gauged sites for irrigation purposes.

6.Road Network data

Vector data showing the asphalt and gravel road network for the entire country was collected from the Ethiopian Road Authority (ERA). This data was used as a factor with others to assess suitable land for the study area.

3.3.2. Data pre- processing and Quality checking

The different data inputs which were collected from different data sources may contain errors due to failures of the measuring device or the recorder. So, before using the data for a specific purpose, the data were to be checked and errors had to be removed. The analysis was extended to hydrological and meteorological data to prepare input data for irrigation water requirement estimation using the CROPWAT model.

3.3.3 Filling of Missing Meteorological and Flow Data

The continuity of the record may be broken with missing data due to many reasons such as the absence of a recorder, carelessness of the observer, break or failure of instruments. Therefore, it is often necessary to estimate these missing data. There are different methods used for filling the missed data records of a given gauging station. For this study, any missing data were filled by the method of linear regression by multiple imputation using XLSTAT2018 software with Microsoft Excel from its nearest neighboring stations. XLSTAT is used for filling in missing rainfall and stream data (Taube, 2019). XLSTAT is the richest tool for data analysis and the statistical treatment with MS Excel. It can execute preparing, describing, visualizing, analyzing, and modeling data, correlation tests, parametric and non-parametric tests, testing for outliers, homogeneity, and trends. For quantitative data, XLSTAT allows to removal of observations with missing values, use a mean imputation method, use a nearest neighbor approach and algorithm (Lloyd, 2019).

3.3.4 Metrological Data Analysis

Five meteorological stations such as Hurumu, Chora, Bedele, Metu, and Gatira were available (Figure 3.3). From those meteorological stations Hurumu station is selected in quantifying irrigation water requirement; because this station was found in the watershed and have relatively short period missing data with full metrological data.

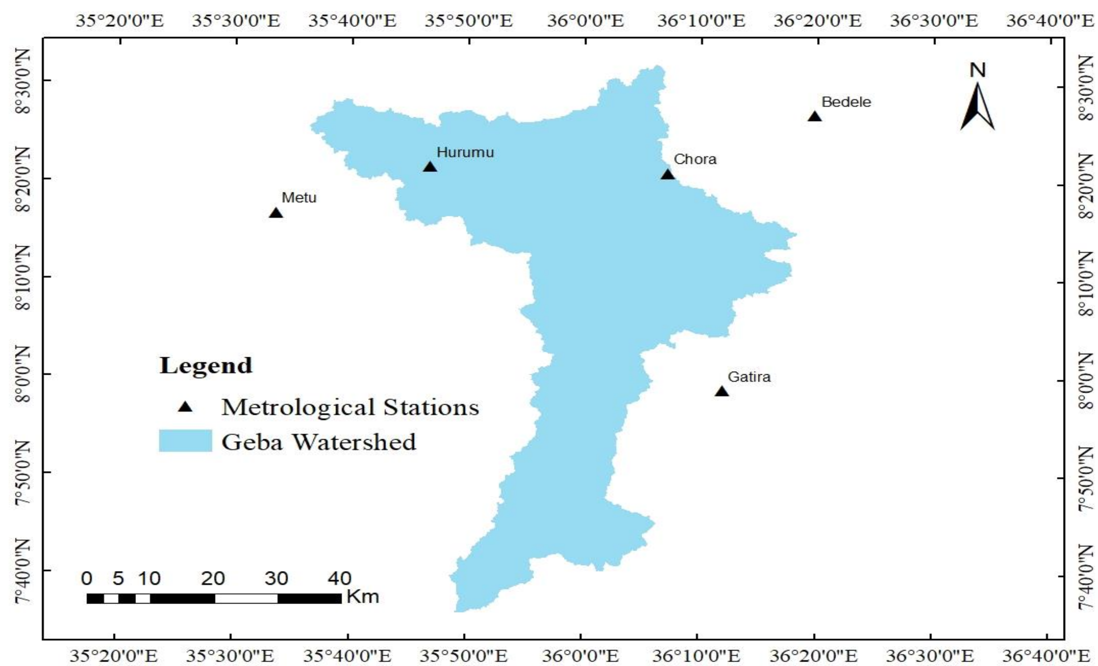

Figure 3. 3 Metrological stations in and surrounding Geba Watershed

1.Rainfall

The main rainy season in and nearby the study area is from May to September. The highest rainfall was observed in July. The short rainy season was from November to March. Rainfall data were recorded from five stations include Bedele, Chora, Metu, Hurumu, and Gatira Stations. Annual Average rainfall for Bedele, Chora, Metu, Hurumu, and Gatira stations were 1178,1038,904,1087 and 647mm respectively. The average monthly rainfalls of different stations in and around the study area were given graphically in Figure 3.4.

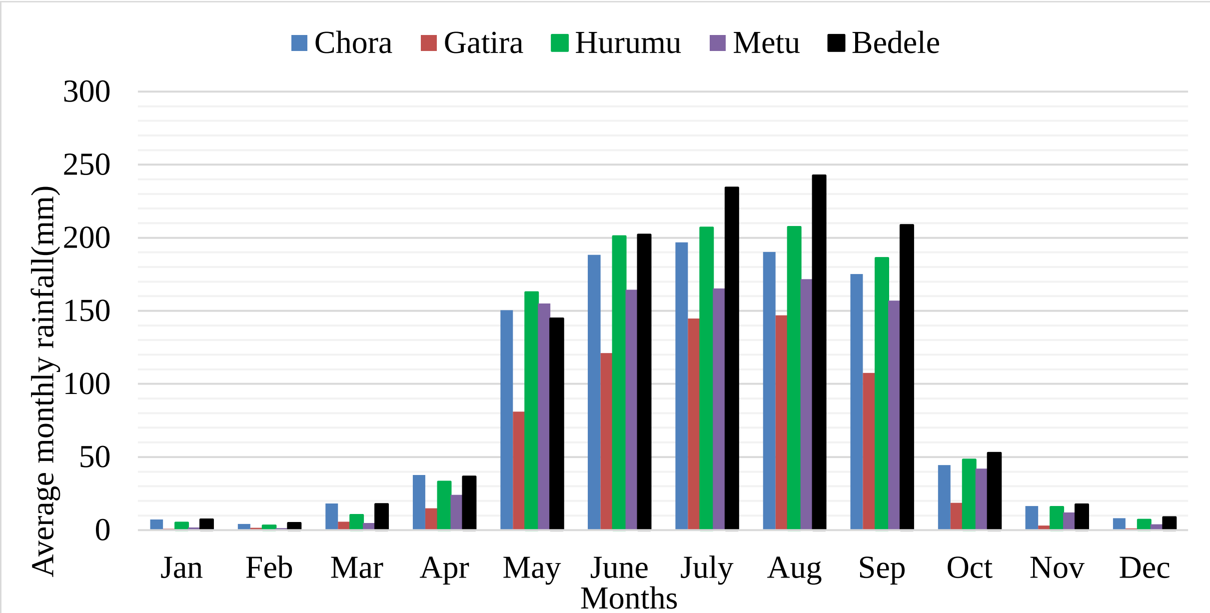

Figure 3. 4 Average monthly rainfall of different stations in and around Geba River Watershed

2. Temperature

Temperature data was also taken from five stations, Bedele, Chora Metu, Hurumu, and Gatira. Based on the recorded data the mean monthly minimum and maximum temperature of the study area were 10.72 and 25.47^{o}C at Hurumu station; and 10.88 and 25.21℃ at Chora station. Generally, the months of February, March, and April had the highest temperature while June, July, August, and September had the lowest temperature.

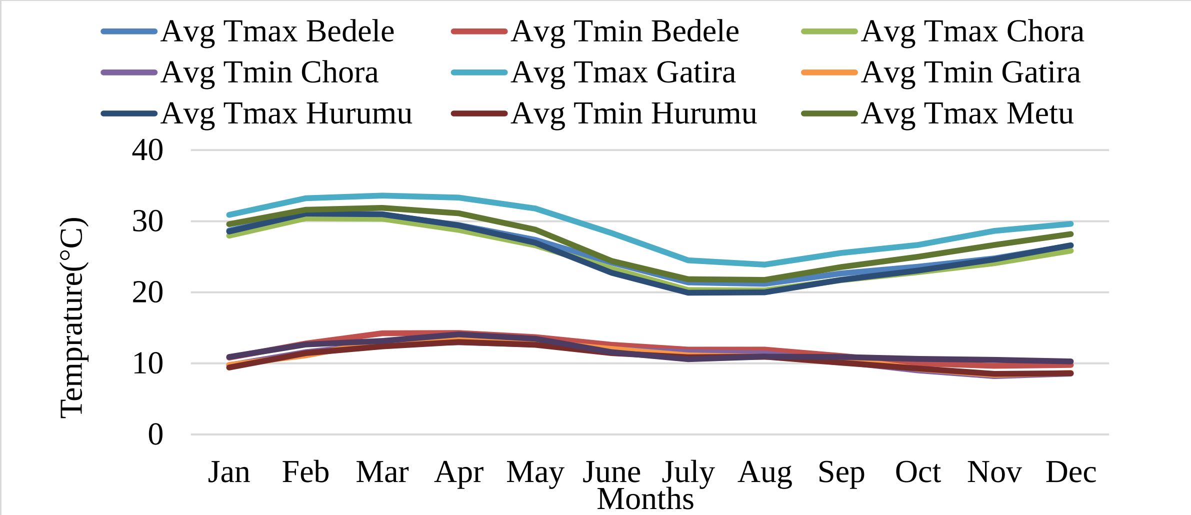

Figure 3. 5 Average monthly maximum and minimum temperature

3. Relative Humidity (%)

Relative humidity data was one of the data that was used as input data for CROPWAT8.0 to calculate ETo. The annual average relative humidity of twenty years (1996-2015) at Hurumu station was 73.9 %, and the highest of 93.5 % is experienced in August. The lowest humidity of 44.5 % is in February.

4. Wind Speed (Km/day)

Wind characteristics such as wind velocity, frequency, and direction of winds are important regarding selection of irrigation methods and the rate of transpiration of crops. The annual average wind speed of Hurumu Station is 80.4km/day

5. Sunshine hours

The sunshine hour of Hurumu station was varied from 3.7 to 8.8 hours. Low sunshine hours were during rainy seasons.

Table 3.1: Monthly average minimum and maximum temperatures, wind speed, relative humidity of Hurumu Station

Month	Tmin(°C)	Tmax(°C)	Relative Humidity (%)	Wind(Km/day)	Sunhrs
Jan	9.4	28.5	57.8	75.5	8.5
Feb	11.5	31.1	44.5	84.2	8.1
Mar	12.4	31.0	52.7	80.5	6.0
Apr	13.0	29.4	61.8	92.7	7.9
May	12.6	27.0	77.9	92.5	7.4
June	11.4	22.7	89.5	83.8	5.9
July	10.9	19.9	93.2	94.8	3.7
Aug	11.0	20.0	93.5	79.7	4.8
Sep	10.1	21.8	91.1	76.6	6.5
Oct	9.3	23.0	83.2	76.9	7.5
Nov	8.5	24.6	74.8	62.8	8.8
Dec	8.6	26.6	66.5	65.2	7.7

3.3.5 Checking the Consistency of Rainfall Data

Inconsistency would arise in the hydrological data if the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record. This inconsistency can be differentiated from the time the significant change took place. Some of the common causes for the inconsistency of the records are shifting of rain gauge station to a new location, Change in the ecosystem due to disaster, such as forest fires, land slide, and Occurrence of observational error from a certain date.

To prepare the rainfall data for further application, their consistency was checked using double mass curve analysis. A plot of accumulated rainfall data at the site of interest against the accumulated average at the surrounding stations is generally used to check the consistency of rainfall data (Nemec, 1973). The plot line should be straight and the R-squared value is found between, 0.6 - 1 (Datoo, 2019).

The mean annual cumulative rainfall of eighteen years of each station was drawn on the y-axis and the mean annual cumulative rainfall of all base stations was drawn on the x-axis to check the consistency of each of the rainfall stations using a double mass curve. The rainfall data is consistent with R^2 = 0.9996 for Bedele and Metu, R^2 = 0.9999 for Hurumu and Chora, and R^2 = 0.9997 for Gatira stations (Figure 3.8).

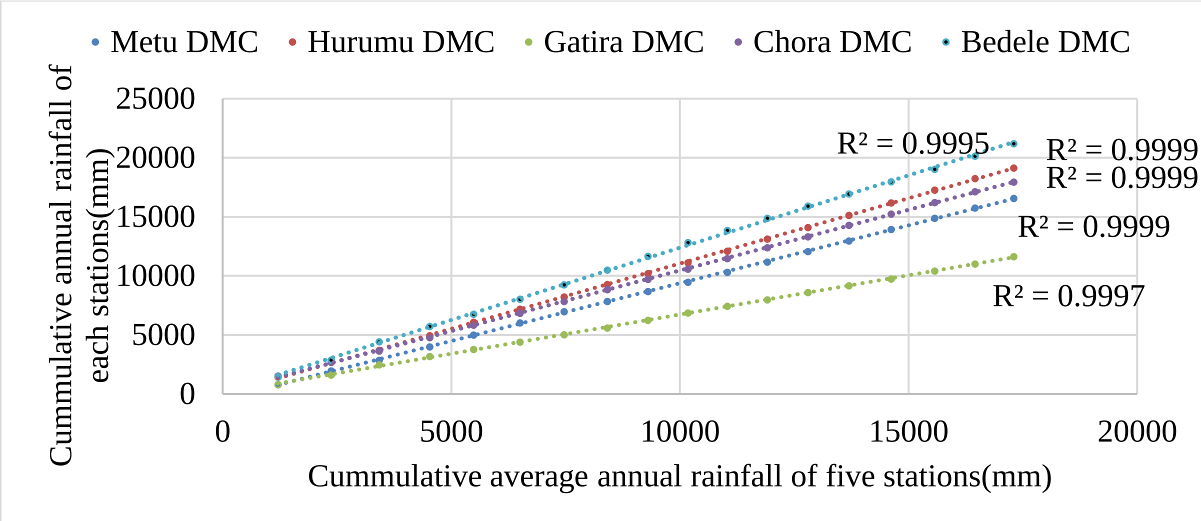

Figure 3. 6 DMC of five rainfall stations

3.3.6 Watershed Delineation

The first step in creating ArcGIS model input is the delineation of the watershed from DEM. The DEM of 12.5m by 12.5m resolution was downloaded from the Alaska satellite facility @ the website: https://vertex.daac.asf.alaska.edu/. Geba Watershed was delineated by using Arc Catalog tools in ArcGIS 10.8 of Spatial Analyst Tool with this DEM. The following steps were used in watershed delineation: Filling, flow direction, flow accumulation, roaster calculation, stream link, stream order, stream to feature, outlet selection, and watershed delineation.

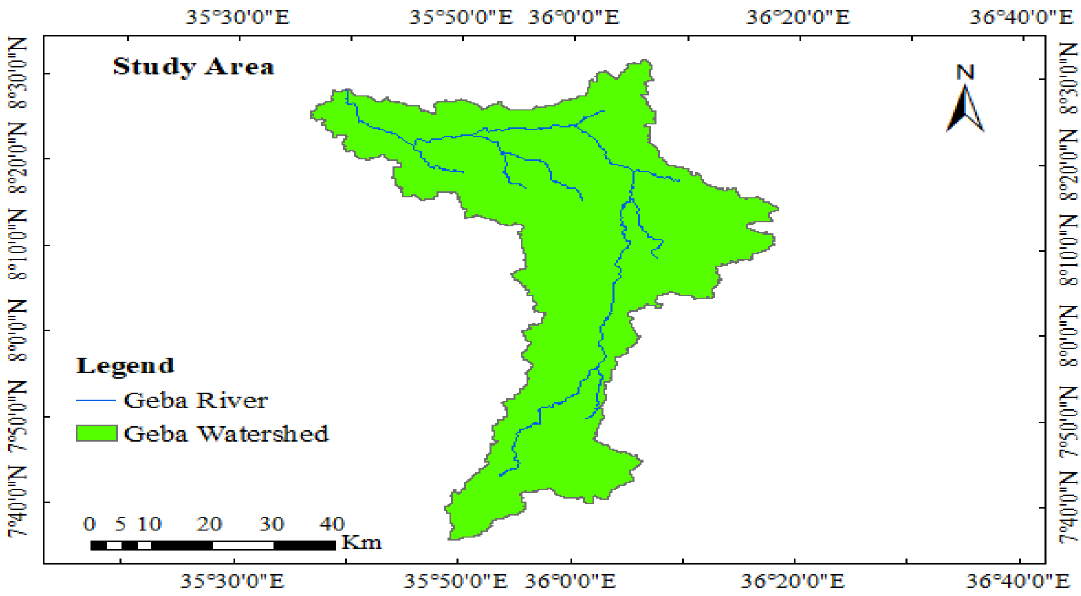

Figure 3.7 Geba River Watershed

3.3.7 Identification of Potential Irrigable land

For this study identification of suitable land for surface, irrigation was carried out by considering the slope, soil (depth, drainage, and texture), LULC, distance from water source, and distance from the road. The individual suitability of each factor was first analyzed and finally weighted to get potentially irrigable land.

3.3.7.1. Slope Suitability Analysis

The slope of the study area was derived from DEM of 12.5m by 12.5m spatial resolution using the "Spatial Analysis Slope" tool in Arc GIS 10.8 and classified based on the FAO classification system using the "Reclassification" tool into suitability classes. The four suitability ranges S1, S2, S3, and N were classified for surface irrigation as shown in table 3.2.

Table 3.2 Slope suitability classification for surface irrigation (FAO, 1990)

Slope (%)	Factor rating	Description
0 – 2	S1	Highly suitable
2 – 5	S2	Moderately suitable
5 – 8	S3	Marginally suitable
> 8	N	Marginally not suitable

3.3.7.2. Soil Suitability Analysis

The analysis of soil suitability for this study was conducted in the following ways firstly each soil physical parameter (soil texture, soil drainage, and soil depth) were prepared as feature layers in GIS software. Second, the feature layers of the parameters were converted into a raster layer using the conversion tool to raster and finally soil suitability map of each soil physical parameter was classified based on the FAO soil suitability classification for surface irrigation (Table 3.3).

The following soil suitability ratings were used based on FAO guidelines for land evaluation (FAO, 1991) and FAO land and water bulletin (FAO, 1997).

Table 3. 3 Soil suitability factors (FAO, 1991)

Factors	Factor rating			
	S1	S2	S3	N
Soil texture	L-SiCL,C	SL	-	-
Soil depth	>100	80 - 100	50 - 80	< 50
Drainage class	Well	Imperfect	Poor	Very poor

1.Soil Texture

Based on the particle size soils are divided into three major types of soil textures. These include clay, silt, and sand soils. According to FAO (1999) Guidelines for soil evaluation, the soil texture of the study area was evaluated and classified into Clay, Sandy loam, and Loam, and their distribution in the study area was mapped in Figure 3.8.

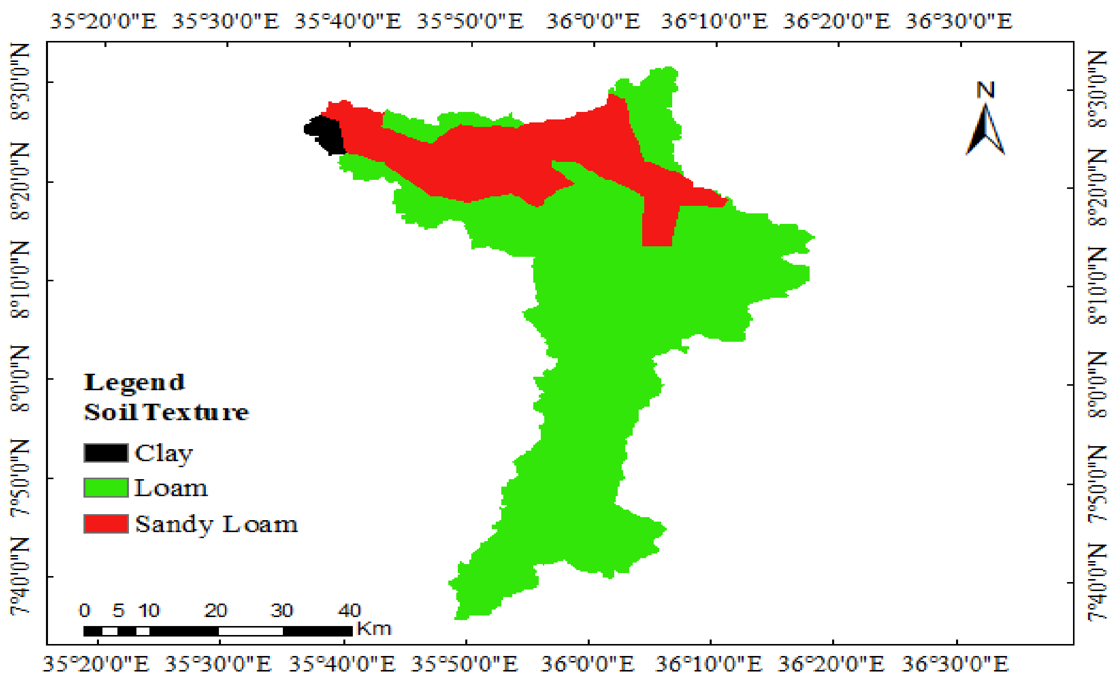

Figure 3. 8 Soil texture map of Geba Watershed

2. Soil Depth

The soil depth is the thickness of soil materials, which give structural support, nutrients, and water for crops. The depth of soil that can be effectively exploited by plant roots is an important criterion in the selection of land for irrigation. (JOWSET,2020). The soil depth of the study area was found to be from shallow to very deep. It was ranging from 10 cm to 200 cm (Figure 3.9).

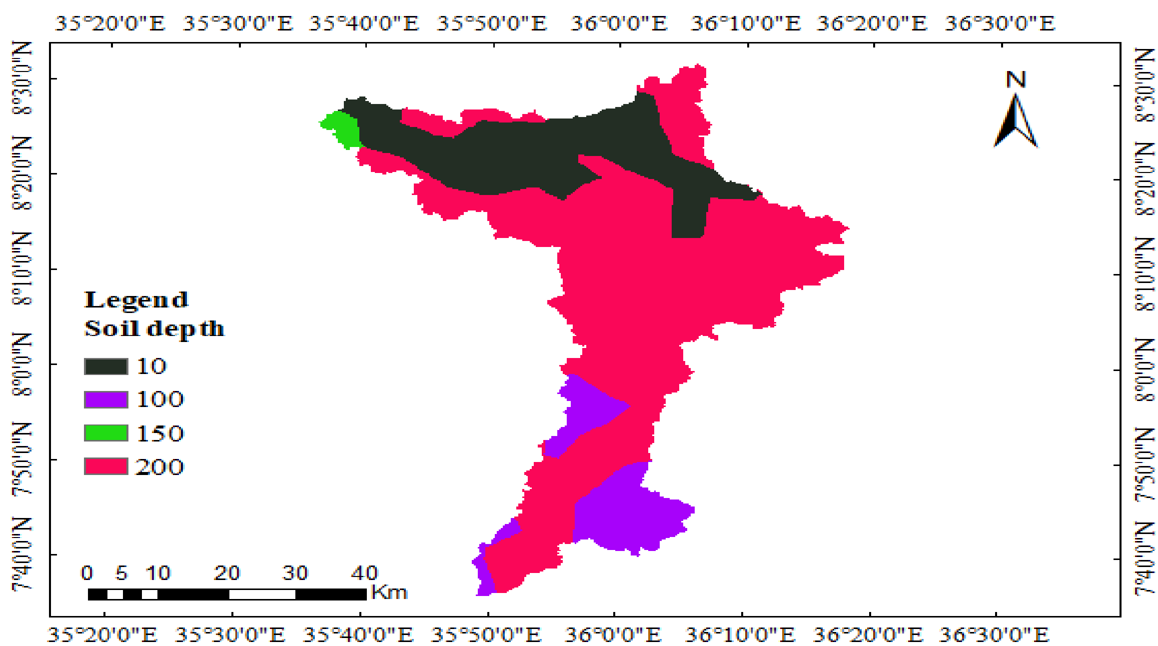

Figure 3. 9 Soil depth map of Geba Watershed

3. Soil Drainage

Soil drainage is a natural process by which water moves across, though, and out of the soil as a result of the force of gravity. Many agricultural soils need good drainage to improve or sustain production or to manage water supplies. According to (FAO, 1997) the Guideline for soil drainage was divided into four classes. These classifications were: well-drained, moderately drained, poorly drained, and imperfectly drained. The soil drainage of the study area was classified in to well-drained and imperfectly drained (Figure 3.10).

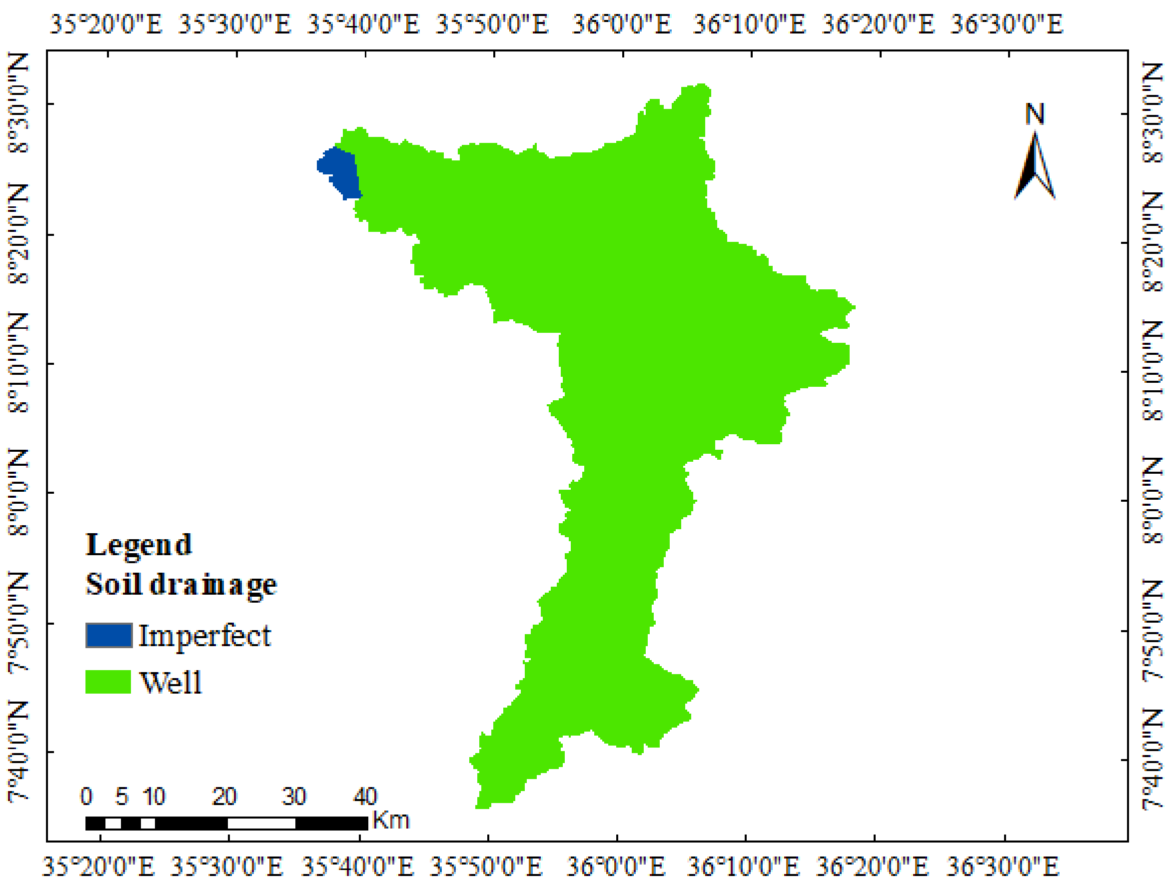

Figure 3. 10 Soil drainage map of Geba Watershed

4. Soil Type

The major soil type in the Geba watershed was Haplic Nitosols, Humic Alisols, Humic Nitosols, and Lithic Leptosols. The major soil type and their distribution were presented in Figure 3.8.

Alisols are mainly derived from basalts, granites, and granodiorites and possess favorable drainage, structure, and workability (Meron,2007). They are particularly common in the hilly area of the southern fringe of the study area and it covers a small proportion of the area.

Nitisols are derived from basalts/tuffs and granites/associated felsic materials. The soils are reddish-brown, clay-to-clay loam in texture, well-drained, and very deep. They also have good permeability, a favorable structure, and a high-water holding capacity. They cover the largest area of the Geba watershed. Leptosols are soils with an incomplete solemn and without clearly expressed morphological features.

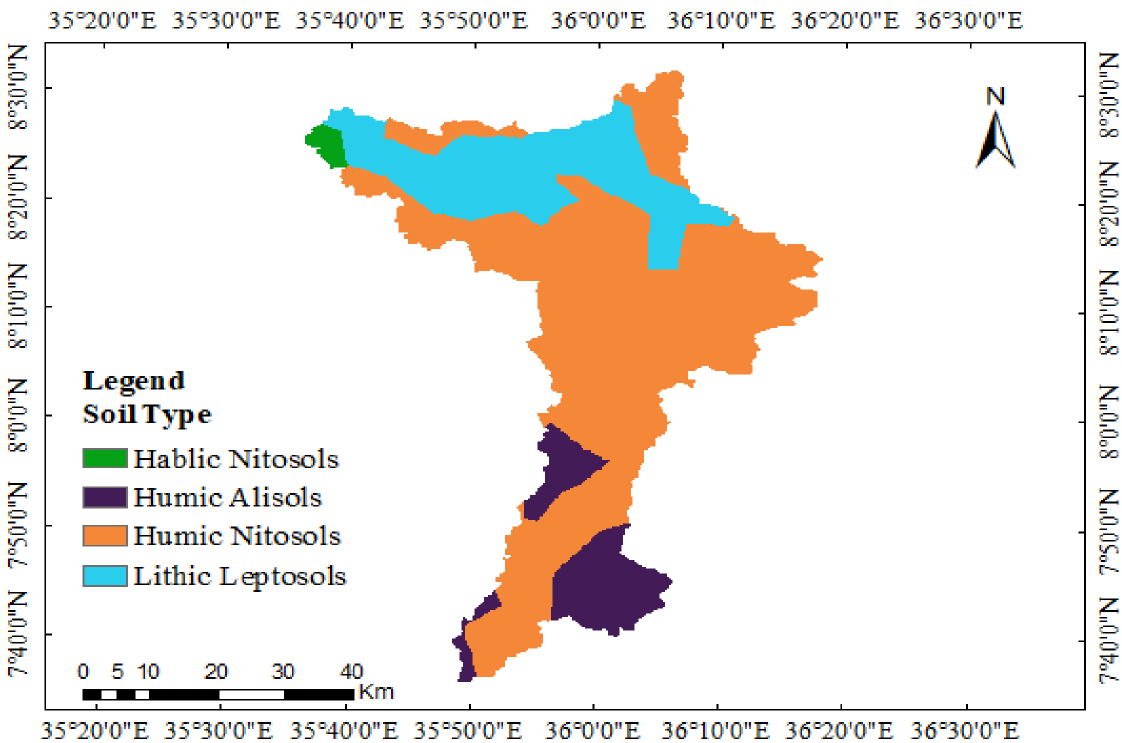

Figure 3.11 Soil type map of Geba Watershed

3.3.7.3. Land use/land cover analysis

Land use/land cover is also the factor, which is used to evaluate the land for irrigation. LULC map of the study area was derived from land use land cover map obtained from the Ethiopian mapping agency which was used to develop the LULC map of the Geba watershed. LULC influences the cost of irrigation practice to prepare the land for agriculture. The types of LULC of the Geba watershed were ranked based on their importance for surface irrigation potential, costs to remove or change for cultivation, and environmental impacts under the watershed.

Table 3. 4 Land cover/use evaluation criteria description (FAO, 1996)

Category	Name	Description of LULC types
S1	Highly Suitable	Cultivated……dominantly, moderately
S2	Moderately Suitable	Shrub land, grassland, woodland
S3	Marginally Suitable	Open forest
N	Not suitable	Dense forest, built-up areas, waterbodies

The major LULC of the study area was composed of forest, agricultural land, grass land, shrub land, and built-up areas. The details of LULC of the study area are showed (Figure 3.12).

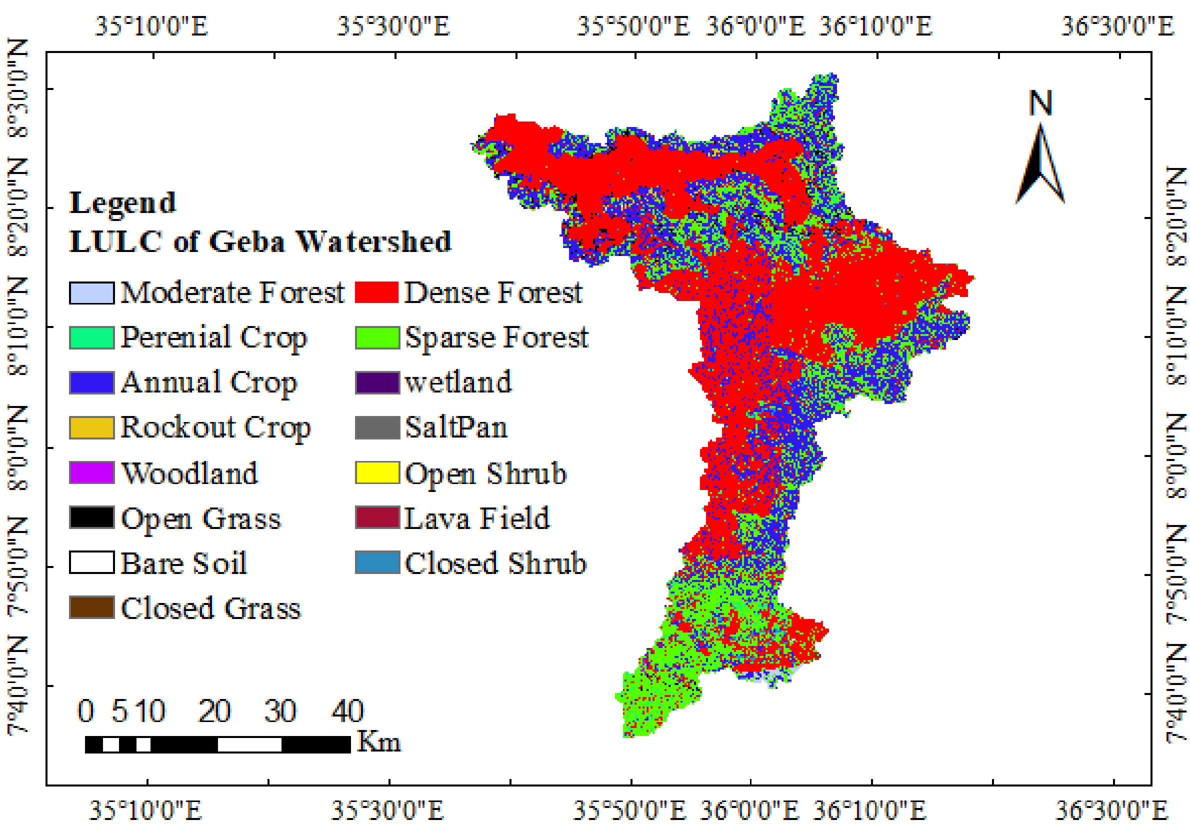

Figure 3. 12 Land cover/use map of Geba Watershed

3.3.7.4 Distance from Water Source suitability

Determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source is near the center of the irrigated area to minimize the size of the delivery channels and pipelines. To identify irrigable land close to the water source (rivers), straight-line

(Euclidean) distance from rivers of Geba watershed is calculated using DEM of 12.5m by 12.5m cell size and reclassified. The distance from water supply was classified based on literature (Table 3.5). The farthest distances were assigned as not suitable and closer distances were classified as highly suitable. Then, the reclassified distance was used for weighted overlay analysis together with other factors.

Table 3. 5 Distance from water supply suitability for irrigation (Seleshi,2016)

Distance from water (km)	Suitability class	Description
0-1.5	S1	Highly suitable
1.5-3	S2	Moderately suitable
3-5	S3	Marginally suitable
>5	N	Not suitable

3.3.7.5. Distance from road suitability

Distance from the road is another factor that is used to evaluate land suitability for irrigation because it represents market access. Vector data showing the asphalt and gravel road network of Ethiopia was collected from the Ethiopian Road Authority (ERA) and the study area was clipped from it. Then, the vector data of road were changed to raster data using conversion tool of ArcGIS 10.8, and straight-line (Euclidean) distance from road was calculated using raster data of road and reclassified. The distance from the road was classified based on literature (Table 3.6). Then, reclassified distance from road was used for weighted overlay analysis together with other factors.

Table 3. 6 Distance from road suitability for irrigation (Seleshi,2016)

Distance from the road(km)	Suitability class	Description
0 – 3	S1	Highly suitable
3 – 6	S2	Moderately suitable
6 – 10	S3	Marginally suitable
> 10	N	Marginally not suitable

3.3.8. Developing the Pairwise Comparison

To determine the relative importance/weight of criteria and sub-criteria, the AHP method of MCE was used. In order to compute the weights for the criteria and sub-criteria, a pair wise comparison matrix (PWCM) was constructed, each factor was compared with the other factors, relative to its importance, on a scale from 1/9 to 9 introduced by (Saaty, 2008). The intensity of importance and their explanation is given in appendix table 15.

If factor X is exactly as important as Y, this pair receives an index of 1. If X is much more important than Y, the index is 9. All gradations are possible in between. For a "less important" relationship, the fractions 1/1 to 1/9 are available: if X is much less important than Y, the rating is 1/9. The values are entered row by row into a cross-matrix. The diagonal of the matrix contains only values of 1. If X to Y was rated with the relative importance of n, Y to X has to be rated with 1/n. Then to calculate the weight, a normalized comparison matrix was created: each value in the matrix was divided by the sum of its column. To get the weights of the individual criteria, the mean of each row of this second matrix was determined. These weights are already normalized; their sum is equal to 1.

In the application of the AHP method, the weights derived from a pairwise comparison matrix must be consistent. It should be noted that for preventing bias thought criteria weighting the Consistency Ratio was used (CR). Consistency for a comparison matrix was measured by calculating the consistency index (CI) (Eqn. 3.1).

$$CR = \frac{CI}{RI} \qquad \text{Eq. (3.1)}$$

Where, CI= Consistency Index and RI= Random Consistency Index, Moreover, CI was computed using Eq. (3.2)

$$CI = \frac{\lambda\, max - n}{n-1} \qquad \text{Eq. (3.2)}$$

Where: λ_{max}= maximum Eigen value and n = numbers of criteria or sub-criteria in each pair-wise comparison matrix. The bigger the matrix is the higher the inconsistency level. (Mendoza *et al.*,2008). The average random consistency index is given in Appendix Table 14.

3.3.9. Weighing of Irrigation Suitability Factors to find Potential Irrigable land

Identification of suitable land for surface irrigation was carried out by considering the slope, soil (depth, texture, and drainage), land cover /use, distance from water and road as irrigation suitability factors. The individual suitability of each factor was first analyzed and finally weighted to get potentially suitable land for surface irrigation. Once their individual suitability was assessed, the irrigation suitability factors were used as the input for irrigation suitability model to find the most suitable land for surface irrigation.

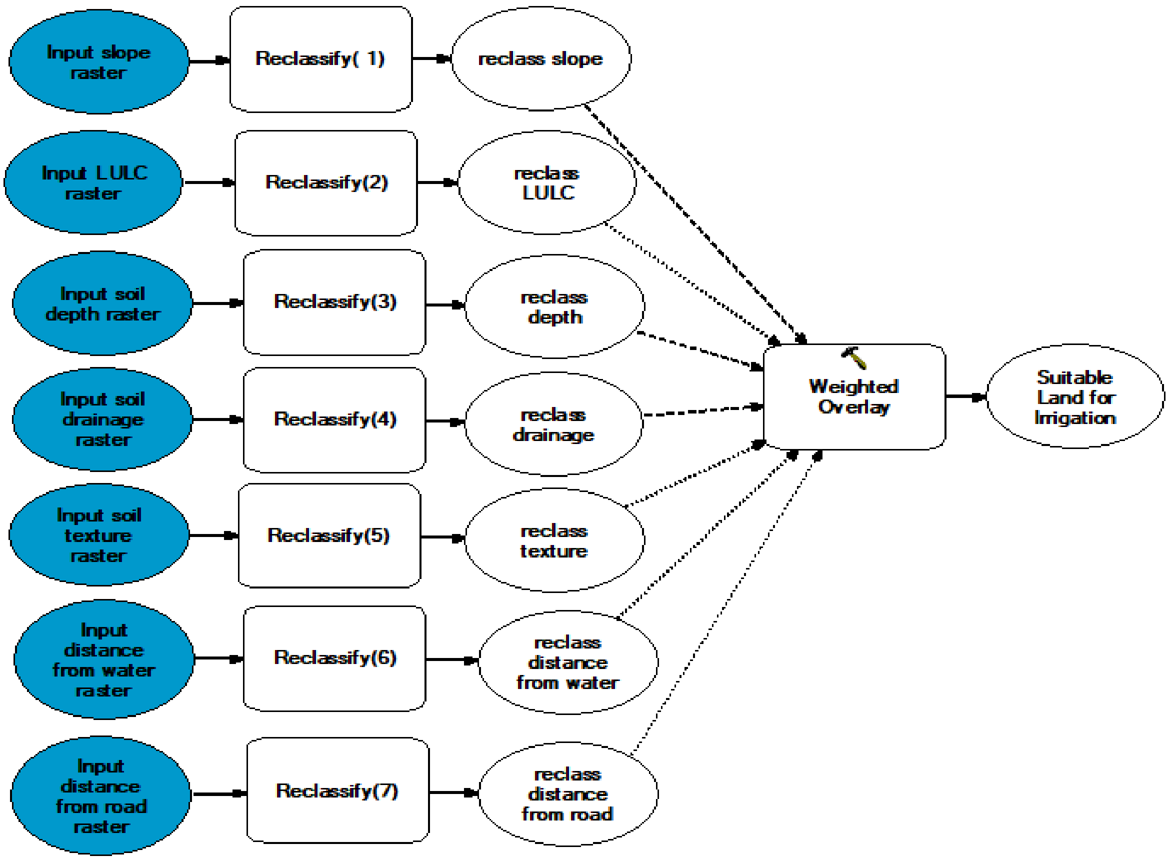

Figure 3. 4 Surface irrigation suitability analysis model

3.3.10 Assessment of surface water availability and irrigation water requirement

3.3.10.1 Surface water availability

Available surface water of the watershed was assessed using stream flow discharges obtained from the Ministry of Water, Irrigation and Energy department of hydrology. The stream flow data of gauged river Geba in the watershed were used to estimate surface water resources at the site by making a Flow Duration curve.

Flow Duration curve provides the percentage of time (duration) of a daily or monthly stream flow is exceeded for a certain year period (Vogel and Fennessey, 1994). For this particular study, the Flow duration curve was developed using fourteen years (2000-2013) Geba river discharge.

3.3.10.2 Irrigation water requirement

Irrigation water requirement for major crops grown in the study area was computed using the CROPWAT 8.0 software. Crop types that are commonly grown in the study area are Tomato, cabbage, and potato. 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 of the study area were used as data input in CROPWAT 8.0 software. In addition to climate data inputs, the software was used crop pattern and soil data to compute crop water requirements (CWR).

I. Reference Evapotranspiration (ETo): The data used for calculation of ETo are geographical coordinates of the Hurumu station (i.e., latitude, longitude, and elevation above mean sea level), temperature maximum and minimum (C), relative humidity maximum and minimum (%), wind speed (km/day) and sunshine hours. ETo is calculated by using the Penman-Monteith method with the help of CROPWAT 8.0 as shown in Appendix Table 8.

II.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 the CROPWAT model (Smith, 2000).

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

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

$$ETc = Kc \times ETo \quad \text{Eq. (3.3)}$$

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

V. 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 by the following expression in CROPWAT 8.0 software.

$$ETc = ETo - Peff \quad \text{Eq. (3.4)}$$

Where: Peff = effective rainfall (mm); ETc = crop evapo-transpiration for a given crop (mm/day)

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

NIWR= $\frac{\sum_{i=1}^{n} IWRi*Ai}{A}$ ……………………………………………………………..Eq. (3.5)

Where: NIWR = Net irrigation water requirement (mm); Ai= the area cultivated with the crop i (ha); A = the area of the scheme (ha)

VII. Gross irrigation water requirement (GIWR): Gross irrigation water requirement refers to the amount of water diverted from the source for irrigation purposes. According to FAO (2001), GIWR of crops at the identified potential irrigable sites was estimated by considering an efficiency of 50% for surface irrigation as follows.

GIWR= $\frac{NIWR}{Ep}$ ……………………………………………………………….……………Eq. (3.6)

Where: Ep = project efficiency (%); GIWR = Gross irrigation requirements (mm); NIWR = Net irrigation water requirement (mm)

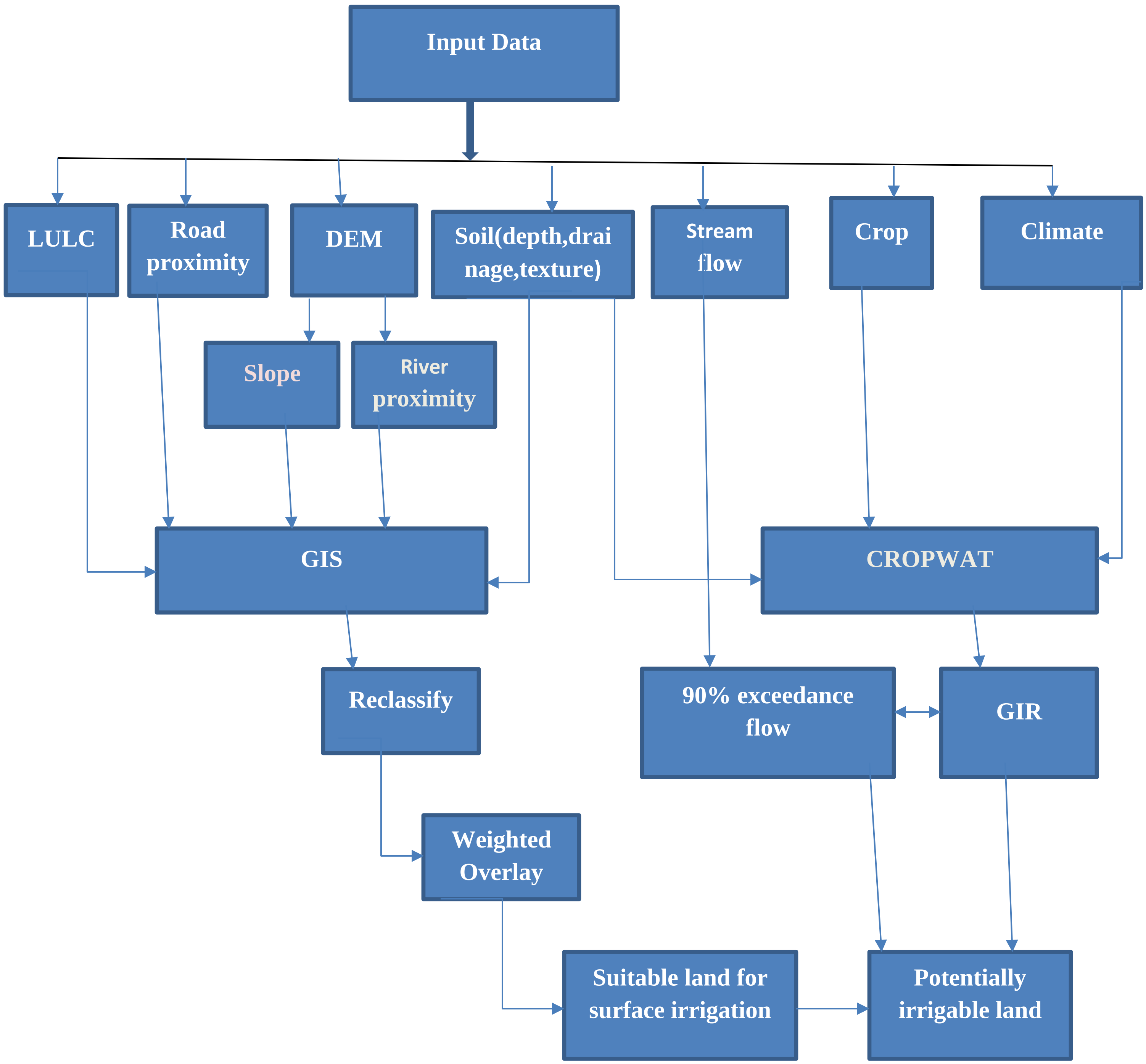

Figure 3. 5 General flow chart of the study method

4. Results and Discussions

4.1 Land Suitability for Surface Irrigation

4.1.1 Slope Suitability

The slope was considered as the main evaluation factor for surface irrigation suitability analysis. Since the slope affects water flow, fertility of soil profile, depth of irrigation, and drainage of the watershed. The slope of the study area was classified into four suitability classes (S1, S2, S3, and N) based on the FAO (1999) suitability classes (Table 4.1) and the slope suitability map was developed (Figure 4.1).

Table 4. 1 Slope suitability range of the study area for surface irrigation

Slope (%)	Area coverage		Suitability class	Description
	ha	%		
0 – 2	28154.66	10.07	S1	Highly suitable
2 – 5	54902.38	19.63	S2	Moderately suitable
5 – 8	57377.69	20.51	S3	Marginally suitable
> 8	139268.49	49.79	N	Not suitable

The slope suitability of the study area for the development of surface irrigation system shown in (figure 4.1) and area coverage of suitability classes are presented in (table 4.1), indicated that 10.07% (28154.66ha) is highly suitable, 19.63% (54902.38ha) is moderately suitable, 20.51 % (57377.69 ha) is marginally suitable and 49.79% (139268.49 ha) is marginally not suitable for surface irrigation systems. Hence, the majority of the study area is marginally suitability to marginally not suitable for surface irrigation in terms of slope suitability. In the current condition, the majority of the study area (49.79%; steep slope) is not recommended for the implementation of surface irrigation based on slope regarding its work efficiency and cost for land leveling, canal construction, and value for the pumping system.

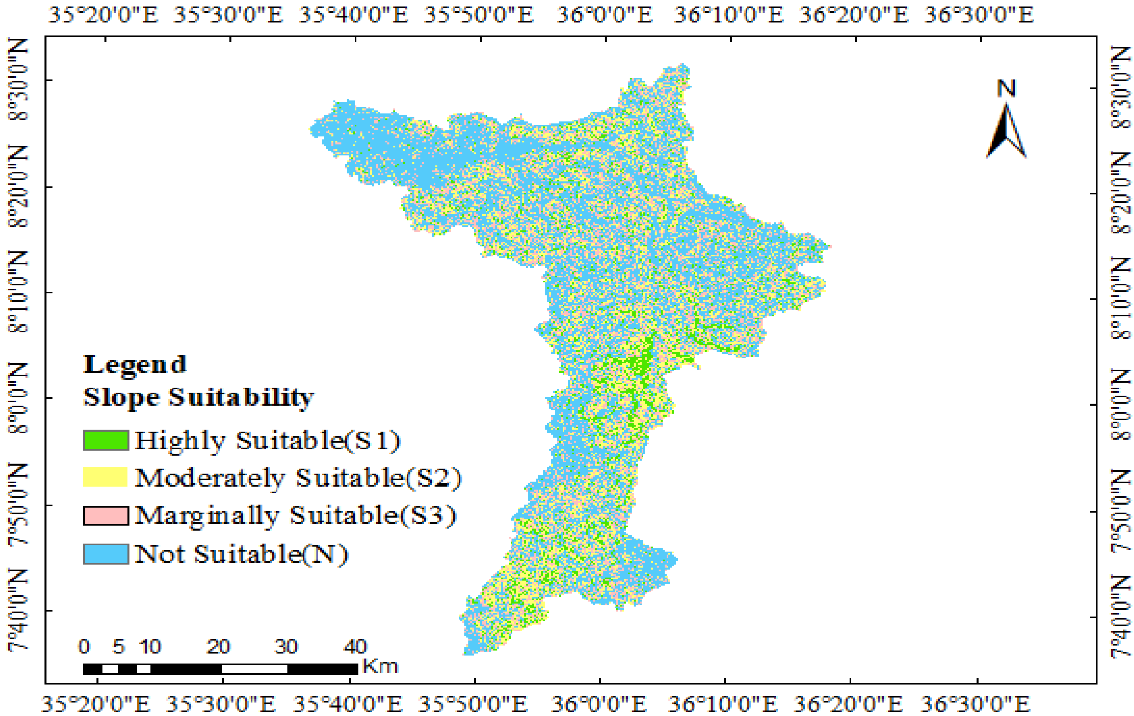

Figure 4. 1 Slope suitability map of Geba Watershed

4.1.2 Soil Suitability

The three major soil physical properties to evaluate soil suitability in the watershed are soil depth, soil drainage, and soil texture properties; each data was taken accordingly from FAO standards and general Blue Nile soil master plans to describe in detail as follows.

4.1.2.1 Soil depth suitability

Soil depth is among the important physical soil parameters used to evaluate soil suitability for surface irrigation development. The soil depth properties of the study area were classified according to FAO soil evaluation techniques.

Table 4. 2 Soil depth and their suitability class

Soil depth (cm)	Area coverage		Soil depth suitability	Description
	Ha	%		
150, 200	187504.2	66.65	S1	Highly suitable
100	30214.8	10.74	S2	Moderately suitable
10	63617.94	22.61	N	Marginally not suitable

The soil depth suitability of the study area for the development of surface irrigation system shown in (figure 4.2) and area coverage of suitability classes are presented in (table 4.2). indicated that 66.65%(187504.2ha) is deeper depth and highly suitable, 10.74% (30214.8ha) is moderate depth (100cm) and moderately suitable, 22.61% (63617.94ha) is very shallow depth(10cm) and not suitable for surface irrigation systems. Generally deeper soil can provide more water and nutrients to plant than shallow soils.

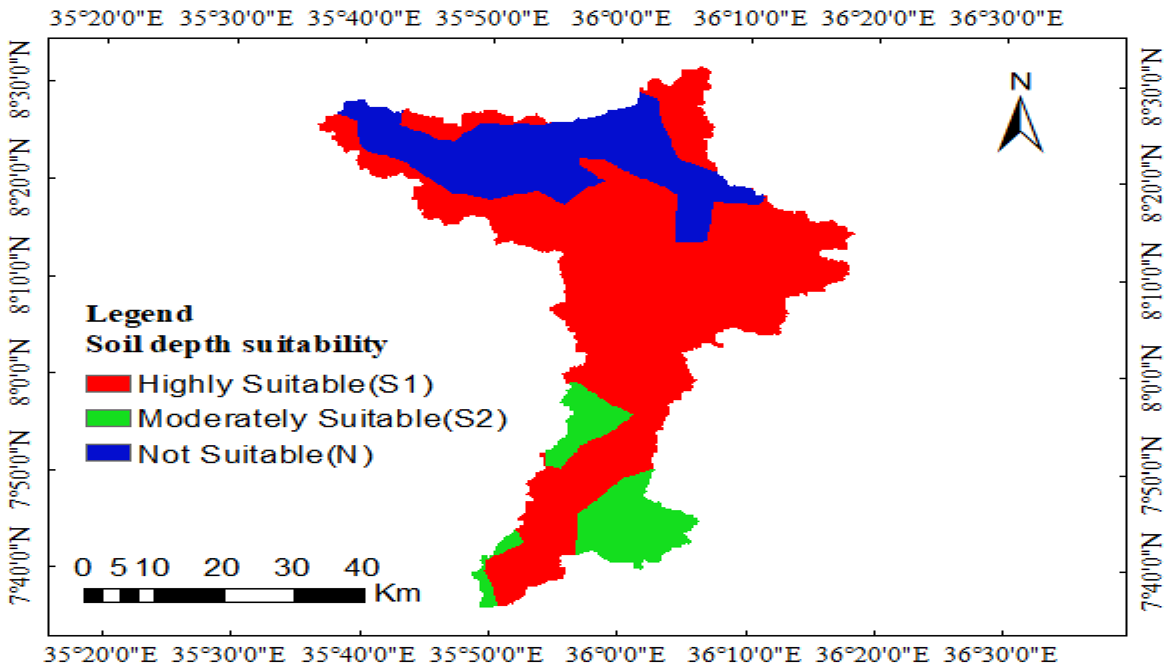

Figure 4. 2 Soil depth suitability map of Geba Watershed

4.1.2.2 Soil Drainage suitability

Soil drainage is one of the important parameters for the evaluation of the area for surface irrigation.In the study area, based on the FAO, 1984 guidelines, two soil drainage classes (well drained and imperfectly drained classes) were identified.

Table 4. 3 Soil drainage suitability and their coverage area

Soil drainage class	Area coverage		Soil drainage suitability	Description
	Ha	%		
Imperfect drain	2736.06	0.97	S2	Moderately suitable
Well drain	278581.26	99.03	S1	Highly suitable

The well-drained soils are categorized under a high suitability rating class and the imperfectly drained soils are categorized as moderately suitable for surface irrigation development (FAO, 1984). The majority of the study area (99.03%) or 278581.26 ha was covered by well-drained soil and only 0.97% (2736.06 ha) of the soils in the study area were categorized under imperfectly drained class (Table 4.3). Generally, the study area was suitable for surface irrigation development in terms of soil drainage.

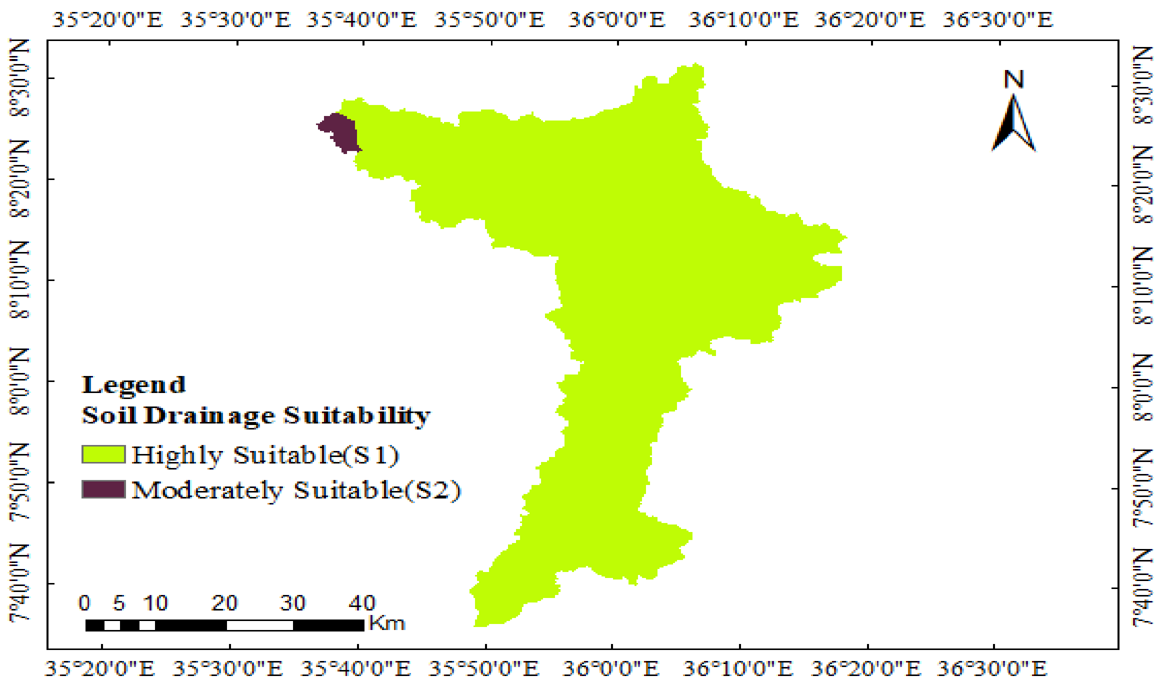

Figure 4. 3 Soil drainage suitability map of Geba Watershed

4.1.2.3 Soil Texture Suitability

Soil texture is another important property as it determines pore spaces of that soil which influence the soil permeability and infiltration rate. Soil texture suitability for irrigation was evaluated according to the FAO guide line for land evaluation. Soil texture class in the study area was found in (Table 4.4) and their distributions in the study area were mapped in Figure 4.4.

Table 4. 4 Soil texture and their suitability class

Soil texture	Area coverage		Suitability class	Description
	Ha	%		
Clay	2736.06	0.97	S1	Highly suitable
Loam	214984.92	76.42	S1	Highly Suitable
Sandy Loam	63596.34	22.61	S2	Moderately Suitable

The soil texture suitability of the study area for the development of surface irrigation system shown in (figure 4.4) and area coverage of suitability classes are presented in (table 4.4). The majority of the study area (77.42%) was dominated by loam soil and a small portion (0.97%) by clay classified as highly suitable. The rest portion of the study area (22.61%) was covered by sandy loam soil classified as moderately suitable for surface irrigation. Hence, all of the study areas was suitable for surface irrigation development in terms of a soil texture parameter.

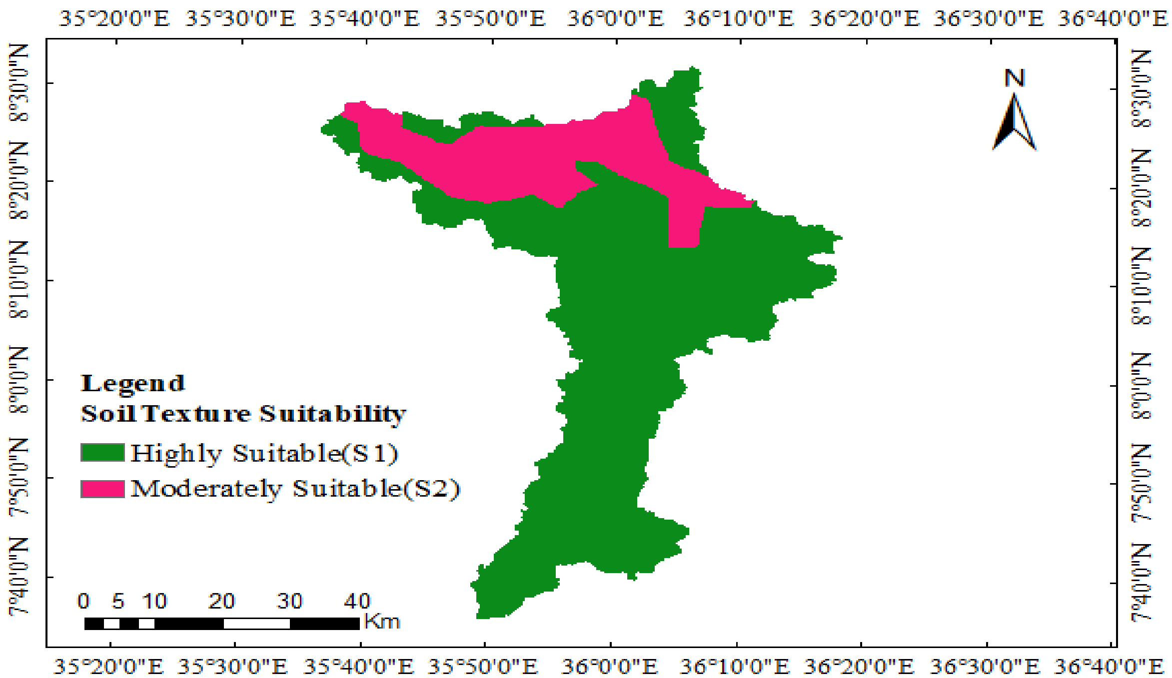

Figure 4. 4 Soil texture suitability map of Geba Watershed

4.1.2.3 Soil type suitability

The major soil type identified in the study area were Haplic Nitosols, Humic Nitosols, Humic Alisols, and Lithic Leptosols.

Haplic Nitosols soil group covers the smallest area 2736.06ha (0.97%) and is characterized as imperfectly drained and moderately deep soil. This soil is moderately suitable(S2) for irrigation. Humic Nitosols soil group covers the largest area 184771.21ha (65.68%) and is characterized as well-drained and deep soil. Therefore, this soil is classified as highly suitable(S1) for irrigation. Humic Alisols soil group covers 30213.71 ha (10%) and it is characterized as well-drained and moderately deep soil. This soil is also classified as highly suitable(S1) for irrigation. Lithic Leptosols soil group covers 63596.34 ha (22.61%) and it is characterized as well-drained and very shallow depth property. This soil is limited by shallow soil depth (10 cm) which is unfavorable for crop growth and surface irrigation method. Generally, in the study area, there is no land with soil types that can be categorized as S3 (marginally suitable) for surface irrigation. The soil drainage, soil depth, soil texture, and soil type suitability of the watershed are described in Table 4.5 within their area suitability from the total area of the watershed.

Table 4. 5 Soil type characteristic suitability

Soil type	Texture	Drainage	Depth	Texture suit	Drain suit	Depth suit	Soil type suit	Area coverage	
								ha	%
Haplic Nitosols	Clay	Imperfect	150	S1	S2	S1	S2	2736.06	0.97
Humic Nitosols	Loam	Well	200	S1	S1	S1	S1	184771.21	65.68
Humic Alisols	Loam	Well	100	S1	S1	S2	S1	30213.71	10.74
Lithic Leptosols	Sandy Loam	Well	10	S2	S1	N	N	63596.34	22.61

The map showing the soil suitability of the study area is shown in Figure 4.5; indicates that the majority of the soils in the study area are highly to moderately suitable for surface irrigation.

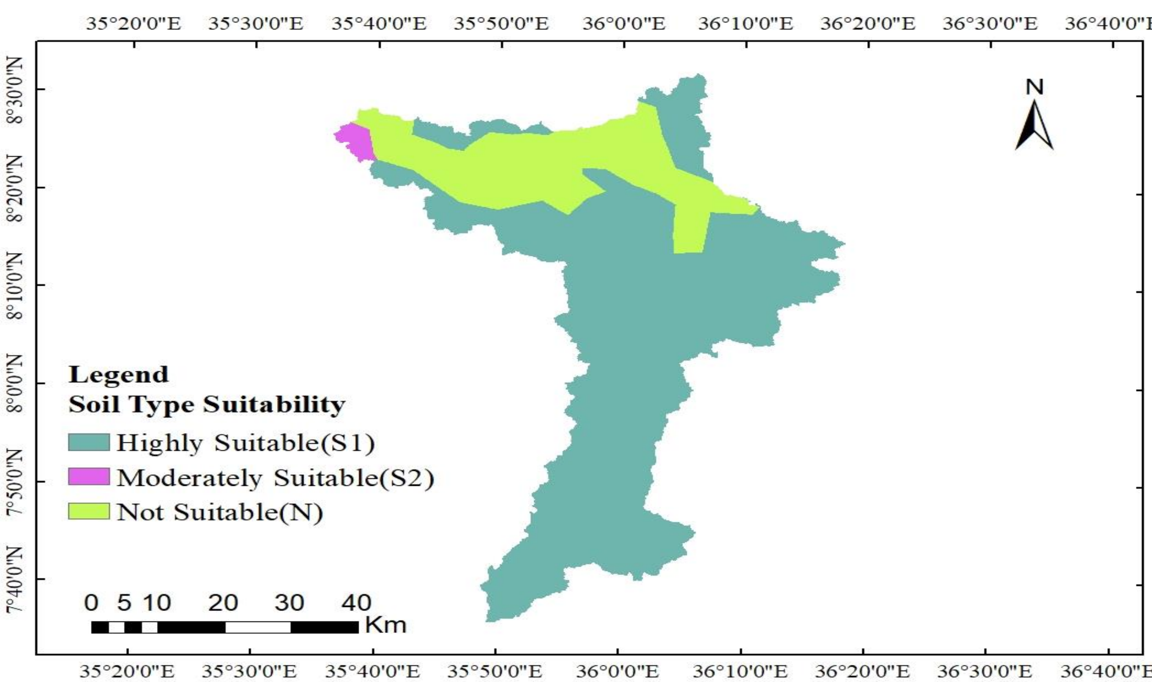

Figure 4. 5 Soil suitability map of Geba Watershed.

4.1.3 Land Use/Cover Suitability

The types of land use/ land cover of the study area were ranked based on their importance for surface irrigation potential, costs to remove or change for cultivation, and environmental impacts under the watershed. After rank was given for the land use types, reclassified map of the study area was developed (Figure:4.6). The land-use type was reclassified into four suitability classes, highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and marginally not suitable (N) Table 4.6.

Table 4. 6 Land cover/Use suitability reclassification

Land use/cover	Area coverage		Suitability class	Description
	Ha	%		
Agricultural land	77039	27.45	S1	Highly suitable
Grass and shrubland	6433.65	2.29	S2	Moderately suitable
Open forest and woodland	58329.63	20.73	S3	Marginally suitable
Dense forest and built-up areas	139535	49.59	N	Marginally not suitable

Land use/cover types of Agricultural land(Annual and perennial crop) were classified as highly suitable for irrigation with the assumption that these land cover classes could be irrigated without or with a limited cost for land clearing and farm preparation. It covered 27.45% (77039ha) of the study area. According to the agricultural practice, commonly grown grass and shrubland was classified as the second suitable area next to agricultural land which covered 2.29% (6433.65ha) of the study area. On the land use/cover suitability classification open forest and woodland were classified as lands marginally suitable for irrigation which covers 20.73% (58329.63ha) of the study area. This is due to their work efficiency, the cost for land clearing, and land preparation for irrigation, whereas dense forest and built-up areas were classified as lands not suitable or restricted for irrigation. Those land cover classes were 49.59% (139535 ha) of the total land cover of the study area they are restricted to use for irrigation.

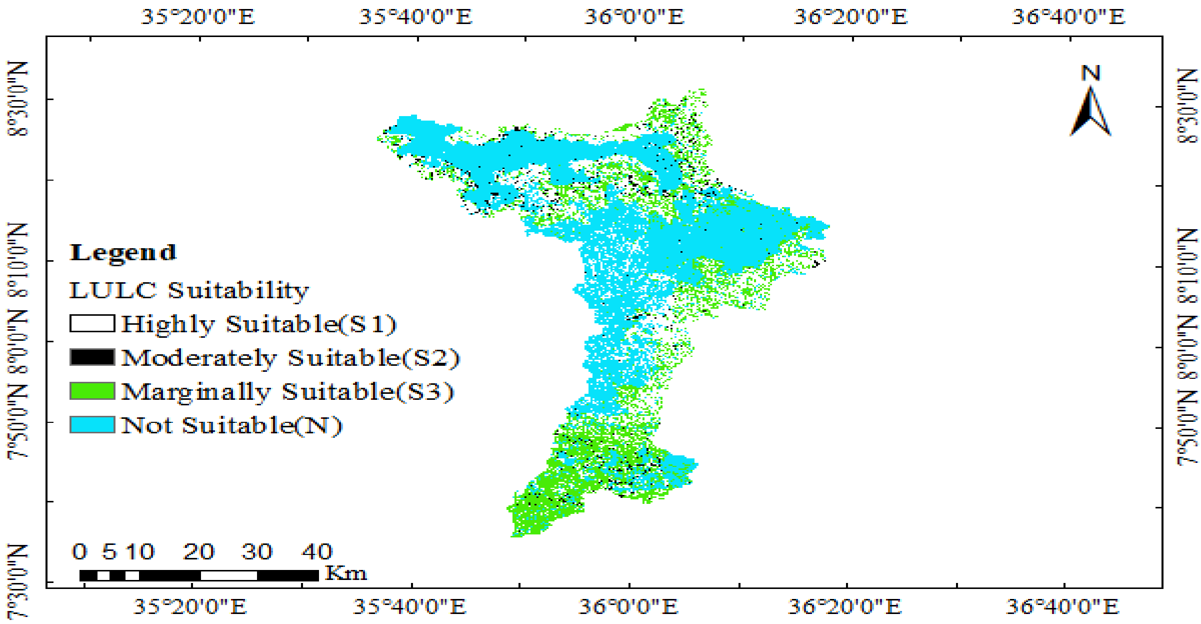

Figure 4. 6 Reclassified LULC suitability map of the study area

4.1.4 Distance from Water Source Suitability

Distance from source has been considered as one of the evaluation parameters in land suitability for irrigation purposes. By considering delineated watershed, command areas that were closest to the water supply (Geba River) were classified as high suitable land for irrigation. Those areas far away from the water source were classified as not suitable especially for small-scale and traditional irrigation.

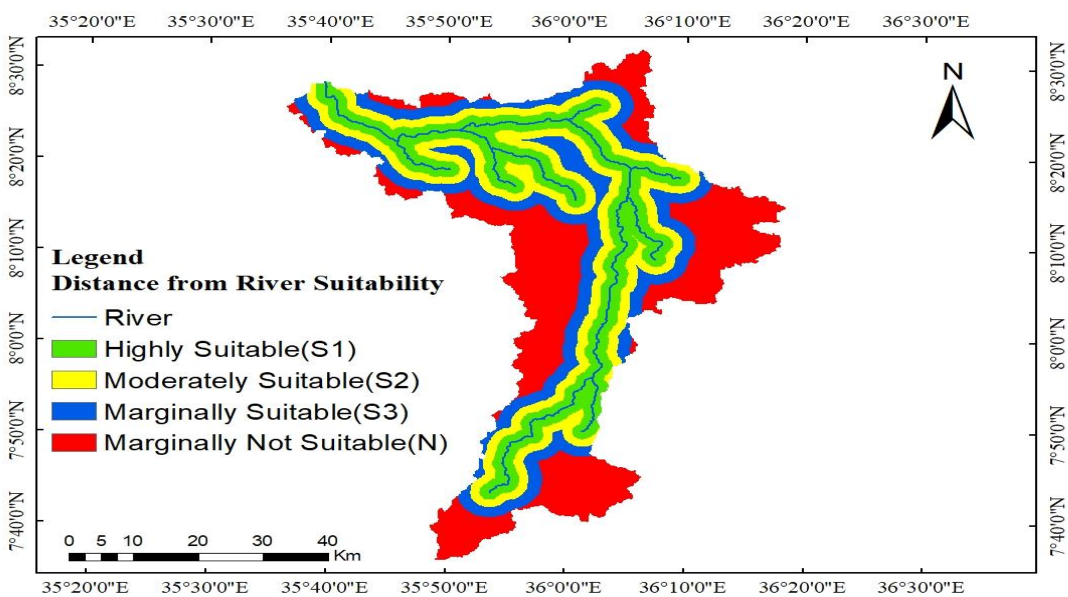

Figure 4. 7 Distance from river suitability map

The suitability of distance from the water of the study area for the development of surface irrigation system shown in (Figure 4.7) and area coverage of suitability classes are presented in (Table 4.7), indicated that 24.65% (69359.44ha) is highly suitable, 20.59% (57932.32ha) is moderately suitable, 19.83% (55788.92ha) is marginally suitable and 34.93% (98256.10ha) is not recommended (N) for the implementation of surface irrigation practice in the present situation in terms of nearness to a water supply. Generally, the majority of the study area is highly suitable to marginally suitable for surface irrigation in terms of distance from a water supply.

Table 4. 7 Distance from water supply suitability for irrigation

Distance from water (km)	Area coverage		Suitability class	Description
	ha	%		
0 – 1.5	69359.44	24.65	S1	Highly suitable
1.5 – 3	57932.32	20.59	S2	Moderately suitable
3 – 5	55788.92	19.83	S3	Marginally suitable
> 5	98256.10	34.93	N	Marginally not suitable

4.1.5 Distance from Road Suitability

Distance from the road also has been considered as one of the evaluation parameters in land suitability for irrigation purpose since the road is one of the infrastructures which affects market participation due to travel time and cost. As the command area is near to the road it lowers the cost and travel time and vice versa.

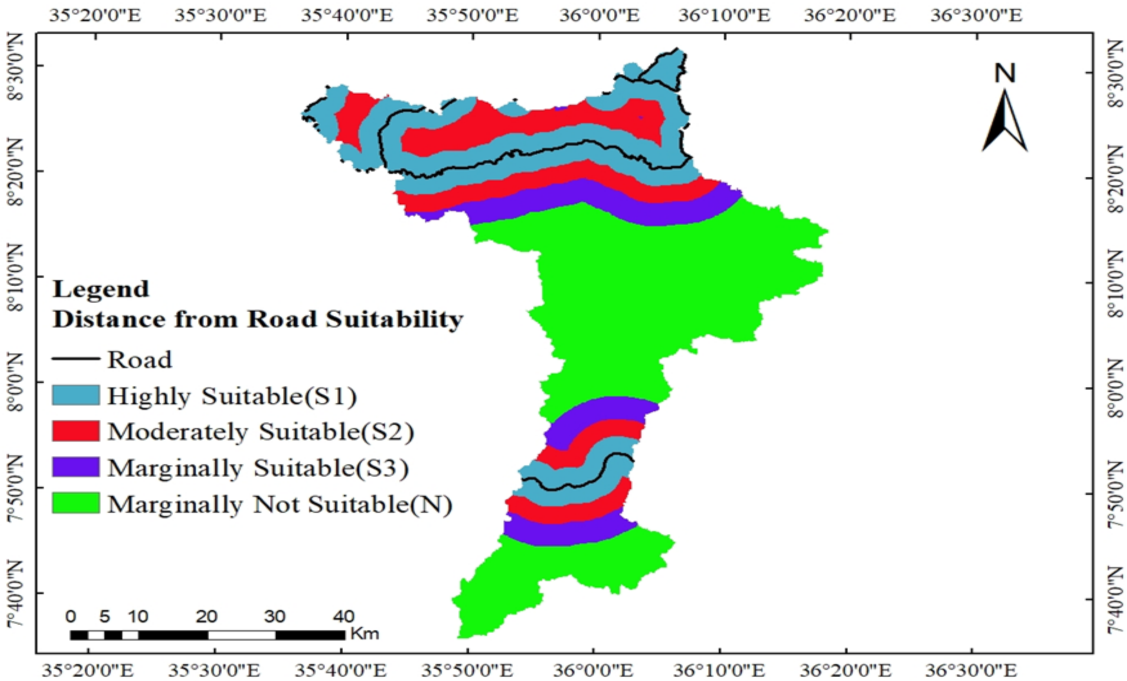

Figure 4. 8 Distance from road suitability map

The suitability of distance from the road of the study area for the development of surface irrigation system was mapped (Figure 4.8) and area coverage of suitability classes indicated that 24.25% (68212.94ha) is highly suitable, 16.73% (47065.34ha) is moderately suitable, 11.48% (32293.29ha) is marginally suitable and 47.54% (133765.18ha) is not suitable for surface irrigation systems in terms of distance from road(Table 4.8),

Table 4. 8 Distance from road suitability for irrigation

Distance from the road(km)	Coverage Area		Suitability class	Description
	Ha	%		
0 – 3	68212.94	24.25	S1	Highly suitable
3 – 6	47065.34	16.73	S2	Moderately suitable
6 – 10	32293.29	11.48	S3	Marginally suitable
> 10	133765.18	47.54	N	Marginally not suitable

4.5. Overall suitability of Land

Land suitability for surface irrigation development was identified by assessing slope, land use/cover, soil suitability, distance from water sources, and road. This identification was done by using Arc GIS 10.8 model weighted overlay analysis in the spatial analysis tool. According to Saaty, 2008) the analytic hierarchy process derived scales of values for pair-wise comparisons, developed pair-wise comparison matrix to calculated relative weights. The scoring process was based on the relative importance of a criterion. The factor “slope” is the most important since all its values are greater than 1 in its row followed by “river proximity” that only has one value less than 1 (Table 4.9). Based on pair-wise calculated value of criteria weight slope is the most important factor followed by the river proximity. The least important factor in considering irrigation suitability is “LULC” with all its row values less than 1.

Table 4. 9 Pair-wise computation matrix result from scouring for irrigation suitability criteria

Factors	Slope	River proximity	Road proximity	Soil depth	Soil drainage	Soil texture	LULC
Slope	1	2	3	4	4	5	6
River proximity	0.50	1	2	2	3	4	5
Road proximity	0.33	0.50	1	2	2	3	4
Soil depth	0.25	0.33	0.50	1	1	2	3
Soil drainage	0.25	0.33	0.50	1	1	2	3
Soil texture	0.20	0.25	0.33	0.50	0.50	1	2
LULC	0.17	0.20	0.25	0.33	0.33	0.50	1
SUM	2.70	4.62	7.58	10.83	11.83	17.50	24

Then the table was formulated for normalization based on Table 4.9, by dividing each value of a cell of the column to the total column. The average of each row in this table was the weights of each factor. The weight of the factors was calculated by multiplying the average of each row by 100.

Table 4. 10 Normalized matrix

Factors	Slope	River Proximity	Road Proximity	Soil depth	Soil drainage	Soil texture	LULC	Weight
Slope	0.370	0.433	0.396	0.338	0.338	0.286	0.250	0.344
River Proximity	0.185	0.217	0.264	0.169	0.254	0.229	0.208	0.218
Road Proximity	0.123	0.108	0.132	0.169	0.169	0.171	0.167	0.149
Soil depth	0.093	0.072	0.066	0.085	0.085	0.114	0.125	0.091
Soil drainage	0.093	0.072	0.066	0.085	0.085	0.114	0.125	0.091
Soil	0.074	0.054	0.044	0.042	0.042	0.057	0.083	0.057

texture								
LULC	0.062	0.043	0.033	0.028	0.028	0.029	0.042	0.038

Then, the Consistency for a comparison matrix was measured by calculating the consistency index (CI). The steps followed for the calculation of the consistency ratio as:

❖ Computation of lambda (λ)

The values of the factors in the matrix which is not normalized (Table 4.9) are multiplied with their respective weight (table 4.10) and summation is done. Finally, the result of each row is divided by the weight in the row. This was done for all rows.

Example:

Row1:1*0.344+2*0.218+3*0.149+4*0.091+4*0.091+5*0.057+6*0.038=2.468/0.344=7.17
using similar procedures the value become 7.16, 7.13, 7.04,7.04,6.98 and 7.01 for row 2, row 3, row 4, row 5, row 6 and row 7 respectively. Then the mean of the lambda (λ) was 7.075.

❖ Computation of Consistency Index (CI)

The Consistency index is the ratio of (λ – n) to (n – 1) which is 0.0124, where n=7

❖ Computation of Consistency Ratio (CR)

Consistency ratio (CR) is the ratio of consistency index (CI) to random index (RI). For n = 7, RI is = 1.32 from appendix table 14. Then the value of consistency ratio (CR) is 0.0095, which was acceptable for weighting the factors to evaluate the land capability of the Geba watershed for developing an irrigation suitability map. This was less than 0.1, the maximum allowable as recommended in (Mendoza *et al.*, 2008) for a consistent pair-wise comparison of 10 %.

Therefore, the calculated weight was accepted and multiplied by 100 to be used as an input in the ArcGIS overlay tool of percentage influence.

The result was given with values in four classes. The land suitability map was divided into four suitability classes (Figure 4.9). These were highly suitable, moderately suitable, marginally suitable, and not suitable. From the total land of the Study area 6048.75ha (2.15%) was highly suitable, 86454.95ha (30.73%) moderately suitable, 155270.06(55.19%) marginally suitable, and 33563.54 ha (11.93%) not suitable for surface irrigation.

Table 4. 11 Result of land suitability class and area coverage of the study area

Area coverage		Suitability class	Description
ha	%		
6048.75	2.15	S1	Highly suitable
86454.95	30.73	S2	Moderately suitable
155270.06	55.19	S3	Marginally suitable
33563.54	11.93	N	Not suitable

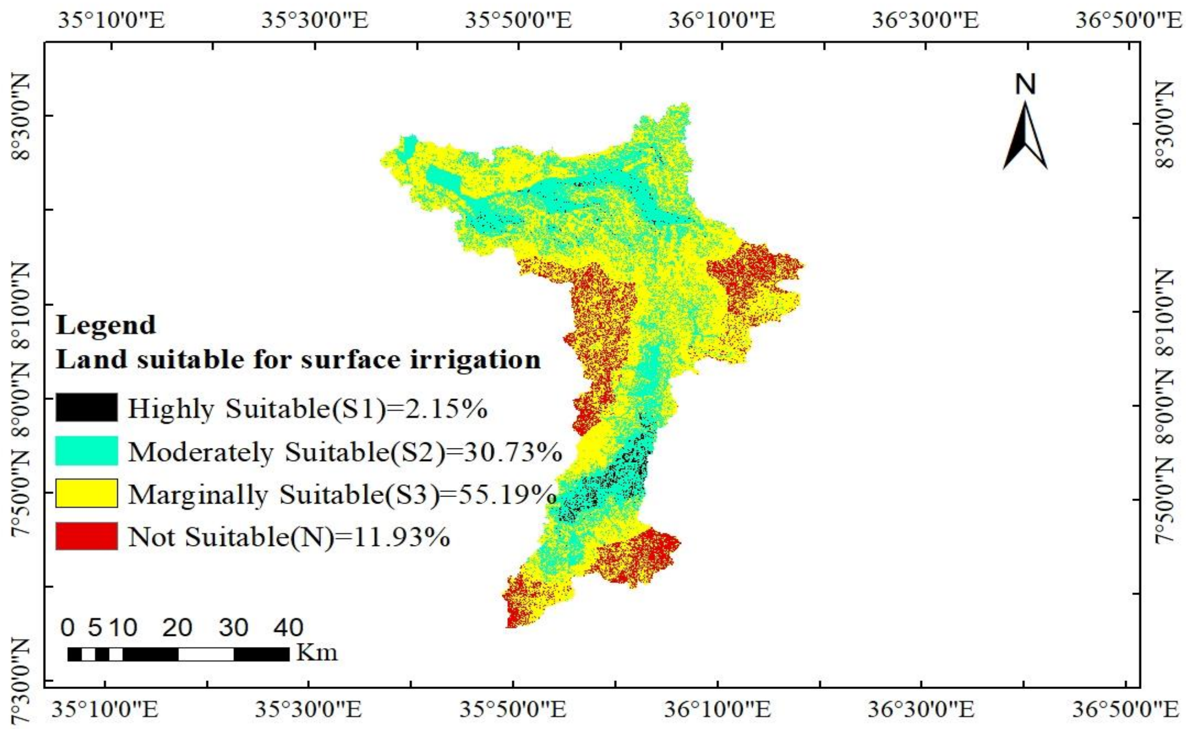

Figure 4. 9 Land suitability map of Geba Watershed for surface irrigation

4.6. Crop and Irrigation Water Requirements

To determine irrigation water demand, crops such as cabbage, tomato, and potato were identified in the study area. Irrigation water demand for each selected crop was determined by using Hurumu Meteorological Station. Since Hurumu station has full meteorological data which is an input for CROPWAT8 software in appendix table 6. The crop requirement of each crop was calculated as shown in Appendix 10,11 and 12.

The monthly total net irrigation water requirement was computed by summing net irrigation water requirement of each crop as shown in Table 12. Then, the gross irrigation water requirement (GIWR) was calculated by considering 50% efficiency for surface irrigation (Table 4.12).

4.7. Irrigation Potential of Geba River Watershed

According to FAO (1997), surface irrigation potential for surface irrigation was obtained by comparing irrigation water requirements in identified irrigable land and the available streamflow of the watershed. In the whole growing season from November to April irrigation water demand was greater than the available streamflow.

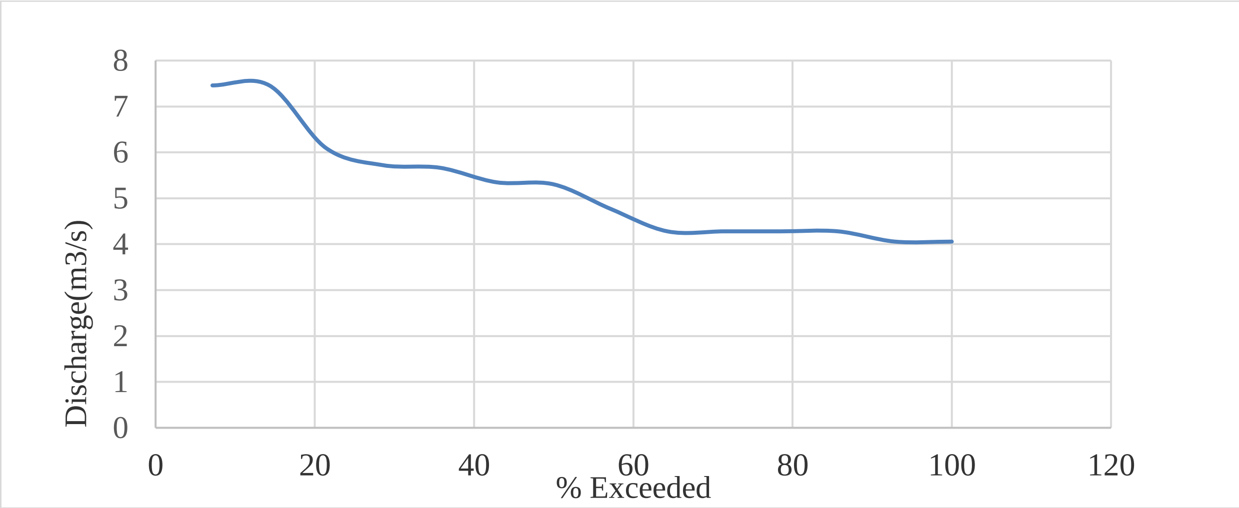

Figure 4.10 Flow duration curve for February

Potential irrigable Land was computed by dividing 90% dependable monthly flow of Geba River for total gross irrigation requirement in each month of all crops (Table 4.12).

Table 4. 12 Comparison of gross irrigation requirement and 90% exceedance of Geba River flow

Month	NIWR(m3/s/h)	GIR (m3/s /h)	90% dependable Geba River flow (m3/s)	Irrigation potential (ha)
Jan	0.00045	0.0009	6.11	6788.9
Feb	0.00055	0.0011	4.15	3772.7
Mar	0.00041	0.00082	3.29	4012.2
Apr	0.00013	0.00026	3.38	13000
May	0	0	5.49	-
June	0	0	26.05	-
July	0	0	72.95	-
Aug	0	0	118.37	-
Sep	0	0	162.37	-
Oct	0	0	71.38	-
Nov	0.00011	0.00022	15.1	68636.4
Dec	0.00025	0.0005	10	20000

The result indicates that the maximum Gross water irrigation requirement was found in February, which was 0.0011m3/s/h and the minimum available flow in February was found to be 4.15m3/s. Therefore, the command area that can be irrigated using the available flows in the study area was 3772.7ha.

5. Conclusions and Recommendations

5.1 Conclusions

The assessment of surface irrigation potential was conducted for Geba River Watershed which is located in Ilubabor Zone of Oromiya Regional State, Ethiopia. The total coverage area of the Geba Watershed obtained through watershed delineation is 2,813.37km^2. It had been carried out to evaluate and estimate suitable irrigable land and irrigation potential of Geba River in the study area and develop a final suitability map. The main irrigation suitability factors undertaken during the study were slope, soil, land use land cover, distance from water source, and road.

Irrigation suitability was evaluated based on FAO Guideline such as highly suitable (S1), moderately suitable (S2), marginal suitable (S3), and not suitable (N). Resulted from the irrigation suitability analysis; 50.21% of slope,50.47% of LULC,65.07% of the distance from the water source, and 52.46% of the distance from the road of the study area was identified in the range of highly suitable to marginally suitable for surface irrigation and 77.39% of the soil in the study area was identified in the range of highly suitable to moderately suitable. While,49.79% of slope,22.61% of soil,49.53% of LULC,34.93% of the distance from the water source, and 47.54% of the distance from the road of the study area was classified as not suitable for surface irrigation. The overall suitability of the area for surface irrigation was made using the weighted overlay of the parameters with the help of AHP (soil, slope, LULC, distance from water source and road) developed on Arc GIS 10.8. About 88.07 % of the total lands in the watershed were in the range of highly suitable to marginally suitable for surface irrigation development, whereas 11.93% were grouped in unsuitable class.

Irrigation water demand of cabbage, potato, and tomato crops were computed from climatic data input using FAO Penman-Monteith in CROPWAT 8.0 software. The irrigation demand of the irrigable land was evaluated and compared with 90% exceedance flow and showed that the existing water resource potential could irrigate 3772.7ha of the land in the study area. The main limitation for surface irrigation in the study area was the available water not the land for irrigation. In general, the majority of the study area was ranged as highly to marginal suitable for surface irrigation potential in terms of land suitability factors.

5.2 Recommendations

The identified surface irrigation potential of the Geba River in the study area can assist in policy decisions during the development of irrigation projects in the Ilubabor Zone. Therefore, the considered recommendations to develop sustainable irrigation investment are: -

- The surface irrigation potential was carried out in this research by considering the only distance from water sources, distance from the road, soil, slope, and land cover/use factors. But the effects of other factors such as water quality, environmental, economic, and social terms should be assessed to get sound and reliable results.
- In this research, estimation of potential surface water irrigation requirement of identified command areas was carried out by selecting three types of crops. But the future research should select several crops that can be grown in the area to calculate gross irrigation requirements of identified potential irrigable land among river catchments.
- Since irrigation water demand is greater than the available streamflow, the construction of storage structure or utilization of groundwater is recommended to increase the irrigable land if possible.

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Appendices

1.Appendix tables

Appendix Table1: Hurumu Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1996	2.3	0.4	5.0	21.1	158.3	178.4	191.9	182.0	140.4	11.5	9.9	1.2	902.2
1997	0.9	0.9	10.9	33.1	175.7	159.3	165.6	204.2	152.4	41.7	9.0	7.8	961.3
1998	17.9	3.2	28.8	52.6	182.4	170.8	180.8	197.3	186.8	33.1	20.7	6.2	1080.6
1999	3.7	0.0	25.9	77.2	145.5	174.8	181.4	199.2	142.6	73.7	23.3	13.5	1060.7
2000	2.7	0.9	19.8	16.9	132.9	192.7	197.1	197.5	194.1	70.2	4.2	0.1	1029.2
2001	8.2	2.4	1.5	54.7	169.5	166.6	183.3	157.3	154.1	87.9	3.2	6.5	995.3
2002	0.0	0.0	1.4	64.3	179.8	181.5	181.6	156.7	171.5	63.5	9.0	1.6	1011.0
2003	0.0	1.9	12.0	25.7	128.0	190.1	196.6	207.0	155.5	50.2	8.8	7.8	983.4
2004	15.9	0.0	7.4	5.2	101.7	174.4	184.1	190.4	161.9	65.0	1.9	8.6	916.6
2005	0.0	8.5	7.2	17.2	96.1	187.3	209.6	173.1	172.9	33.7	17.6	10.0	933.1
2006	3.5	1.6	2.7	30.2	126.0	186.8	202.5	217.6	196.9	46.8	18.7	5.8	1039.0
2007	4.0	0.1	15.1	34.8	151.8	186.8	213.1	213.2	167.4	42.7	10.8	0.2	1039.9
2008	0.1	1.7	9.8	7.4	173.3	223.1	234.4	199.9	181.1	61.3	9.6	16.2	1118.0
2009	5.4	12.6	6.4	38.4	161.8	209.7	195.8	227.9	234.8	20.8	9.2	0.0	1122.8
2010	5.9	0.3	1.9	78.9	210.4	236.5	223.3	214.4	204.8	41.1	25.4	3.3	1246.2
2011	12.5	11.8	15.1	40.0	124.1	172.6	186.5	190.9	158.6	68.0	5.4	23.8	1009.4
2012	6.7	12.9	6.9	30.4	250.4	180.5	245.4	198.0	233.8	32.1	21.7	15.3	1234.2
2013	8.0	1.4	14.6	14.6	234.2	284.6	281.9	306.3	231.4	31.0	47.8	3.5	1459.4
2014	2.4	0.2	7.9	16.5	155.8	291.1	255.0	260.4	253.5	20.4	22.4	7.6	1293.2
2015	2.9	1.7	6.3	4.3	195.6	274.4	229.0	255.0	227.4	68.6	38.1	4.0	1307.3
Average	5.2	3.1	10.3	33.2	162.7	201.1	206.9	207.4	186.1	48.2	15.8	7.2	1087.1

Appendix Table 2: Chora Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1996	0.2	0.4	8.9	20.5	140.3	172.1	169.6	173.3	134.2	6.7	3.2	0.1	829.5
1997	1.2	0.7	18.0	37.7	150.9	144.0	151.4	202.5	145.5	34.5	6.7	9.0	902.1
1998	17.4	3.3	33.4	37.6	165.2	161.6	167.5	179.5	166.9	25.5	19.6	7.1	984.6
1999	2.9	0.0	35.1	66.4	124.0	152.9	158.8	191.1	141.2	61.0	15.2	7.0	955.6
2000	1.6	0.3	24.1	14.5	117.5	172.5	192.6	186.6	176.9	66.7	4.9	0.0	958.3
2001	10.3	1.3	2.6	51.8	151.4	165.9	156.3	135.0	145.1	91.0	1.3	3.1	915.0
2002	0.0	0.0	0.4	62.9	183.6	169.6	165.1	142.1	141.3	54.9	10.0	2.9	932.7
2003	0.0	0.2	19.2	15.2	117.7	178.1	192.4	192.9	136.1	38.7	4.0	5.7	900.1
2004	16.4	0.2	9.9	9.7	87.2	141.7	184.3	186.9	161.8	56.0	2.3	7.4	863.9
2005	0.0	7.8	13.8	21.8	79.2	176.0	206.4	149.8	160.7	23.5	11.4	12.0	862.4
2006	5.6	2.8	4.9	30.3	111.5	185.9	200.3	208.7	188.1	52.5	10.8	5.2	1006.7
2007	4.4	0.0	16.9	48.2	128.4	173.7	209.1	192.3	167.7	37.4	10.4	0.0	988.5
2008	0.4	2.1	15.3	6.2	138.8	203.1	221.1	185.6	178.7	53.6	6.4	14.0	1025.2
2009	4.8	12.3	5.7	38.0	146.6	192.2	192.1	213.6	221.1	18.9	5.0	0.0	1050.2
2010	3.3	0.1	0.2	69.7	175.0	232.1	216.1	194.7	184.3	33.9	22.5	1.6	1133.5
2011	18.8	6.3	11.8	34.2	100.3	161.7	176.4	172.4	151.8	73.6	4.8	25.9	937.9
2012	7.5	30.7	9.9	37.0	237.1	160.7	231.5	198.5	210.2	21.2	23.1	20.6	1188.1
2013	29.2	5.0	45.7	71.0	234.2	289.1	261.0	246.1	232.1	35.0	62.0	5.0	1515.3
2014	5.1	0.3	55.5	52.2	180.2	296.4	254.1	230.5	222.7	29.6	40.9	23.3	1390.7
2015	15.9	11.9	33.8	28.3	240.7	237.7	229.2	224.0	237.4	75.7	66.5	14.5	1415.5
Average	7.2	4.3	18.3	37.7	150.5	188.4	196.8	190.3	175.2	44.5	16.5	8.2	1037.8

Appendix Table 3: Metu Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1996	0.6	1.3	1.1	13.7	153.4	156.2	169.0	164.1	125.0	12.5	9.3	1.4	807.6
1997	0.0	0.2	2.9	21.5	169.1	143.4	150.8	172.7	135.9	43.3	6.9	3.4	850.1
1998	6.1	1.0	18.4	38.7	175.9	156.5	158.9	180.6	179.2	26.4	12.0	2.7	956.3
1999	0.9	0.0	8.6	74.7	158.9	160.1	165.6	168.6	133.4	78.0	26.6	6.6	982.1
2000	1.9	1.3	11.9	11.9	130.5	171.2	167.9	173.5	162.3	58.8	4.7	0.0	896.0
2001	3.5	1.2	0.1	51.2	161.3	141.1	168.7	140.9	136.2	67.2	4.0	2.7	878.1
2002	0.0	0.0	0.1	41.9	154.2	154.6	152.1	141.8	153.0	62.7	6.9	0.0	867.4
2003	0.0	0.6	7.7	16.9	119.7	156.6	158.7	179.2	145.4	43.9	6.1	5.0	839.7
2004	4.1	0.0	4.5	2.6	101.8	162.6	142.3	165.1	141.5	63.8	3.5	7.5	799.1
2005	0.0	3.8	1.4	11.2	96.8	159.7	184.2	168.1	153.5	29.6	19.6	6.6	834.4
2006	0.9	0.8	1.7	20.1	118.9	155.4	170.5	192.5	169.4	31.1	16.3	2.0	879.7
2007	2.5	0.2	12.1	20.0	156.6	173.6	178.2	198.4	143.5	35.6	8.6	0.2	929.5
2008	0.0	0.4	2.1	6.6	181.7	207.6	208.7	185.5	162.5	56.0	11.1	13.5	1035.9
2009	2.3	3.0	3.3	21.8	158.9	203.3	160.5	194.1	215.9	19.2	10.1	0.0	992.3
2010	6.1	0.2	1.9	77.5	211.9	216.0	194.0	198.5	182.5	40.7	24.3	1.7	1155.4
2011	3.6	5.2	7.3	33.0	127.1	147.2	160.7	172.8	154.8	63.8	2.3	19.0	896.8
2012	3.2	5.9	4.0	18.0	244.1	168.5	221.7	183.6	233.3	41.6	18.6	8.7	1151.3
2013	1.1	0.0	7.3	1.0	203.8	141.5	134.5	158.6	125.1	16.1	12.0	0.2	801.4
2014	0.0	0.0	0.2	1.3	121.7	167.7	136.1	165.4	164.7	17.5	12.8	0.4	787.7
2015	0.1	0.0	0.1	0.3	155.6	144.1	125.7	128.9	124.2	33.6	25.0	0.0	737.6
Average	1.9	1.3	4.8	24.2	155.1	164.4	165.4	171.6	157.1	42.1	12.0	4.1	903.9

Appendix Table 4: Bedelle Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1996	18.3	5.2	40.0	38.1	170.9	159.7	179.1	212.4	196.9	27.3	16.8	7.2	1071.9
1997	2.2	0.0	25.8	77.5	131.9	175.8	189.0	223.2	171.9	76.5	18.0	9.4	1101.2
1998	0.7	0.9	25.9	18.1	127.4	179.7	191.6	209.4	227.6	75.4	7.6	0.0	1064.3
1999	13.7	2.0	2.4	42.2	152.2	184.9	162.6	173.4	166.3	113.5	2.0	2.5	1018.0
2000	0.0	0.0	0.4	83.8	170.9	172.2	186.0	170.3	174.5	70.9	11.1	2.6	1042.5
2001	0.2	1.4	21.7	21.1	121.3	194.2	227.4	218.9	166.6	42.6	11.7	4.7	1031.8
2002	12.0	0.2	10.6	16.4	84.0	172.4	232.4	245.2	188.4	57.6	3.4	9.1	1031.5
2003	0.5	10.9	21.0	21.8	73.7	188.1	247.0	195.7	212.6	28.5	12.1	16.2	1028.2
2004	3.3	6.3	10.4	36.6	102.5	206.0	236.7	271.4	217.2	57.9	7.5	5.1	1160.9
2005	4.5	1.2	19.3	46.6	112.9	190.7	263.6	256.4	193.4	50.7	14.0	0.1	1153.6
2006	0.3	2.1	13.0	13.4	148.8	233.7	281.0	247.1	217.9	55.8	7.5	16.2	1236.7
2007	4.5	10.2	6.8	35.1	143.7	204.9	248.6	300.2	250.1	20.7	6.1	0.0	1230.8
2008	3.3	0.1	0.1	72.8	162.6	240.1	267.3	243.1	213.4	34.7	23.4	1.9	1262.9
2009	17.4	7.8	10.8	33.7	97.2	181.3	206.0	228.5	162.9	73.6	5.1	27.4	1051.5
2010	11.3	30.8	7.6	38.2	246.4	166.6	242.1	247.8	222.2	23.8	23.0	27.7	1287.3
2011	25.6	1.2	42.1	37.1	217.8	272.1	284.2	344.4	253.1	20.1	59.5	4.0	1561.2
2012	3.4	0.3	40.3	15.4	149.8	279.5	302.1	270.7	276.0	21.0	34.8	18.1	1411.4
2013	8.6	7.6	21.5	12.3	190.5	235.1	269.8	307.7	247.3	98.3	51.3	7.2	1457.2
Average	7.2	4.9	17.8	36.7	144.7	202.1	234.2	242.5	208.8	52.7	17.5	8.8	1177.9

Appendix Table 5: Gatira Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1996	2.8	0.9	8.6	9.9	96.7	118.2	121.2	140.2	113.3	16.3	1.7	0.7	630.5
1997	0.0	0.0	6.2	26.1	73.7	105.2	105.3	170.2	82.6	15.5	5.3	1.0	591.2
1998	0.5	0.6	7.7	5.0	68.1	119.5	150.2	155.9	116.6	51.4	0.4	0.0	676.0
1999	0.5	0.2	2.9	14.9	91.0	115.9	91.8	103.9	87.0	70.8	0.6	0.0	579.5
2000	0.0	0.0	0.1	37.5	105.1	95.2	107.1	104.9	102.6	14.1	3.0	0.4	570.0
2001	0.0	0.9	11.8	5.1	66.0	124.2	153.4	166.8	78.0	14.8	0.6	0.3	621.9
2002	1.9	0.2	5.7	13.4	57.5	88.4	116.8	155.9	78.3	12.1	0.3	4.6	535.1
2003	0.0	7.8	5.7	25.3	51.7	111.1	151.4	119.0	81.5	7.0	2.4	2.3	565.0
2004	0.7	0.3	5.4	12.6	71.5	120.4	129.0	162.8	102.2	19.9	5.0	0.9	630.6
2005	2.0	0.0	5.4	23.4	74.9	108.7	165.1	133.1	118.8	12.1	1.9	0.0	645.3
2006	0.6	0.1	11.1	4.2	72.4	118.8	127.6	121.8	109.2	10.0	2.2	1.7	579.7
2007	1.3	5.4	0.9	6.7	74.6	127.1	131.0	118.0	144.1	6.4	0.1	0.0	615.7
2008	0.6	0.0	0.5	17.6	86.5	154.2	146.5	119.9	85.0	10.0	13.1	0.0	634.1
2009	3.4	0.1	4.6	19.4	64.0	98.8	116.9	127.4	88.6	46.7	0.7	4.0	574.6
2010	1.2	9.9	10.6	19.7	133.9	89.6	145.6	172.5	130.0	5.9	1.1	2.6	722.6
2011	0.1	0.0	8.3	11.1	107.9	159.3	218.2	186.9	146.2	0.4	10.9	0.0	849.3
2012	0.0	0.0	6.5	8.0	83.2	164.4	220.5	208.2	128.2	1.1	0.2	0.2	820.6
2013	0.7	0.2	0.5	9.2	79.2	160.3	207.5	176.0	141.5	19.7	5.3	0.4	800.6
Average	0.9	1.5	5.7	14.9	81.0	121.1	144.7	146.9	107.4	18.6	3.0	1.1	646.8

Appendix Table 7: Mean monthly discharge flow data from Geba River

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
2000	10.4	6.1	4.6	7.7	20.1	40.6	100.7	135.0	204.9	204.9	28.4	17.0
2001	9.5	7.5	4.8	9.2	28.9	91.2	117.3	98.8	160.0	160.0	65.1	15.6
2002	10.5	5.7	4.3	7.6	5.5	27.3	99.5	169.5	207.6	207.6	16.9	10.6
2003	6.1	4.1	6.7	6.6	4.8	20.5	99.9	107.3	153.7	153.7	14.2	8.5
2004	5.4	5.3	3.7	3.8	6.3	34.4	104.4	181.4	232.0	232.0	18.9	12.8
2005	7.6	4.8	5.1	3.8	10.3	25.5	70.2	216.9	221.1	221.1	30.8	12.6
2006	6.9	4.3	3.3	3.6	13.4	34.9	143.9	279.3	253.2	253.2	57.2	24.7
2007	6.9	4.3	3.3	3.2	5.5	27.3	99.5	169.5	190.2	190.2	14.9	12.5
2008	6.9	4.3	3.3	3.6	13.4	34.9	137.5	180.7	165.9	165.9	15.4	9.6
2009	6.1	4.1	2.9	3.6	13.4	26.9	88.7	151.4	204.3	204.3	22.4	12.6
2010	6.9	4.3	3.3	3.1	7.4	31.3	57.9	216.9	221.1	221.1	30.8	12.6
2011	6.9	5.3	3.7	3.8	6.3	34.4	84.7	210.2	201.9	201.9	39.3	14.7
2012	9.5	7.5	4.7	9.2	6.7	30.3	86.7	244.9	222.1	222.1	30.8	13.5
2013	6.4	5.7	3.7	3.8	6.3	34.4	77.1	184.6	239.6	239.6	30.8	15.4
Average	7.6	5.2	4.1	5.2	10.6	35.3	97.7	181.9	205.6	205.6	29.7	13.8

Appendix Table 8: Monthly reference evapotranspiration by Penman-Monteith for Hurumu Metrological station

Monthly ETo Penman-Monteith - C:\Users\Ashu\Desktop\Input data for CROPWAT\ETo Huru...

Country: Ethiopia | Station: Hurumu

Altitude: 1950 m. | Latitude: 8.36 °N | Longitude: 35.78 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.4	28.5	58	76	8.5	20.2	3.82
February	11.5	31.1	44	84	8.1	20.8	4.39
March	12.4	31.0	53	81	6.0	18.6	4.18
April	13.0	29.4	62	93	7.9	21.7	4.59
May	12.6	27.0	78	93	7.4	20.4	4.07
June	11.4	22.7	90	84	5.9	17.7	3.23
July	10.9	19.9	93	95	3.7	14.6	2.56
August	11.0	20.0	93	80	4.8	16.6	2.82
September	10.1	21.8	91	77	6.5	19.3	3.28
October	9.3	23.0	83	77	7.5	20.1	3.46
November	8.5	24.6	75	63	8.8	20.8	3.54
December	8.6	26.6	67	65	7.7	18.6	3.36
Average	**10.7**	**25.5**	**74**	**80**	**6.9**	**19.1**	**3.61**

Appendix Table 9: Effective rainfall of Hurumu station.

Monthly rain - C:\Users\Ashu\Desktop\Input data for CROPWAT\Effective RF.CRM

Station: Hurumu | Eff. rain method: Fixed percentage

	Rain	Eff rain
	mm	mm
January	5.2	4.2
February	3.1	2.5
March	10.3	8.3
April	33.2	26.5
May	162.7	130.1
June	201.1	160.9
July	206.9	165.6
August	207.4	165.9
September	186.1	148.9
October	48.2	38.5
November	15.8	12.7
December	7.2	5.7
Total	**1087.2**	**869.7**

Appendix Table 10: Crop Water Requirement of cabbage

Crop Water Requirements

ETo station Hurumu **Crop** CABBAGE Crucifers

Rain station Hurumu **Planting date** 15/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.70	2.62	15.7	2.0	14.1
Nov	3	Init	0.70	2.60	26.0	2.9	23.2
Dec	1	Init	0.70	2.59	25.9	2.6	23.3
Dec	2	Init	0.70	2.57	25.7	1.7	23.9
Dec	3	Deve	0.72	2.75	30.2	1.6	28.6
Jan	1	Deve	0.78	3.12	31.2	1.6	29.6
Jan	2	Deve	0.84	3.51	35.1	1.4	33.7
Jan	3	Deve	0.91	4.03	44.3	1.2	43.1
Feb	1	Deve	0.97	4.65	46.5	0.8	45.7
Feb	2	Deve	1.03	5.26	52.6	0.5	52.1
Feb	3	Mid	1.07	5.36	42.9	1.3	41.6
Mar	1	Mid	1.07	5.23	52.3	1.7	50.5
Mar	2	Mid	1.07	5.16	51.6	2.2	49.4
Mar	3	Mid	1.07	5.24	57.7	4.4	53.3
Apr	1	Mid	1.07	5.40	54.0	4.2	49.8
Apr	2	Late	1.05	5.42	54.2	4.9	49.3
Apr	3	Late	0.99	4.80	38.4	14.2	20.7
					684.2	**49.1**	**631.9**

Appendix Table 11. Crop Water Requirement of Potato

Crop Water Requirements

ETo station Hurumu **Crop** Potato

Rain station Hurumu **Planting date** 15/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.50	1.87	11.2	2.0	9.6
Nov	3	Init	0.50	1.86	18.6	2.9	15.7
Dec	1	Deve	0.50	1.86	18.6	2.6	16.0
Dec	2	Deve	0.65	2.37	23.7	1.7	22.0
Dec	3	Deve	0.88	3.39	37.3	1.6	35.7
Jan	1	Mid	1.11	4.46	44.6	1.6	43.1
Jan	2	Mid	1.18	4.92	49.2	1.4	47.8
Jan	3	Mid	1.18	5.24	57.6	1.2	56.4
Feb	1	Mid	1.18	5.63	56.3	0.8	55.5
Feb	2	Mid	1.18	5.99	59.9	0.5	59.4
Feb	3	Late	1.14	5.70	45.6	1.3	44.4
Mar	1	Late	1.02	4.98	49.8	1.7	48.1
Mar	2	Late	0.89	4.28	42.8	2.2	40.6
Mar	3	Late	0.80	3.90	15.6	1.6	13.4
					530.9	**23.1**	**507.5**

Appendix Table 12. Crop Water Requirement of Tomato

Crop Water Requirements

ETo station: Hurumu | Crop: Tomato

Rain station: Hurumu | Planting date: 15/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.60	2.25	13.5	2.0	11.8
Nov	3	Init	0.60	2.23	22.3	2.9	19.4
Dec	1	Init	0.60	2.22	22.2	2.6	19.6
Dec	2	Deve	0.63	2.31	23.1	1.7	21.4
Dec	3	Deve	0.77	2.97	32.6	1.6	31.0
Jan	1	Deve	0.93	3.71	37.1	1.6	35.5
Jan	2	Deve	1.07	4.47	44.7	1.4	43.3
Jan	3	Mid	1.17	5.22	57.5	1.2	56.3
Feb	1	Mid	1.18	5.64	56.4	0.8	55.6
Feb	2	Mid	1.18	6.00	60.0	0.5	59.4
Feb	3	Mid	1.18	5.89	47.1	1.3	45.8
Mar	1	Late	1.18	5.73	57.3	1.7	55.6
Mar	2	Late	1.10	5.30	53.0	2.2	50.8
Mar	3	Late	0.98	4.78	52.6	4.4	48.2
Apr	1	Late	0.87	4.36	34.9	3.3	30.7
					614.2	**29.2**	**584.5**

Appendix Table:13 Net irrigation Requirement For the crops commonly grown in study area.

Scheme Supply

ETo station: Hurumu | Cropping pattern:

Rain station: Hurumu

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. CABBAGE Crucifers	95.5	118.6	130.6	104.2	0.0	0.0	0.0	0.0	0.0	0.0	34.7	69.3
2. Potato	131.7	136.0	86.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.5	66.7
3. Tomato	120.8	137.2	131.7	26.4	0.0	0.0	0.0	0.0	0.0	0.0	29.1	65.5
Net scheme irr.req.												
in mm/day	3.9	4.7	3.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.9	2.2
in mm/month	119.4	132.0	111.1	34.0	0.0	0.0	0.0	0.0	0.0	0.0	27.9	67.0
in l/s/h	0.45	0.55	0.41	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.25
Irrigated area	100.0	100.0	100.0	55.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
(% of total area)												
Irr.req. for actual area	0.45	0.55	0.41	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.25
(l/s/h)												

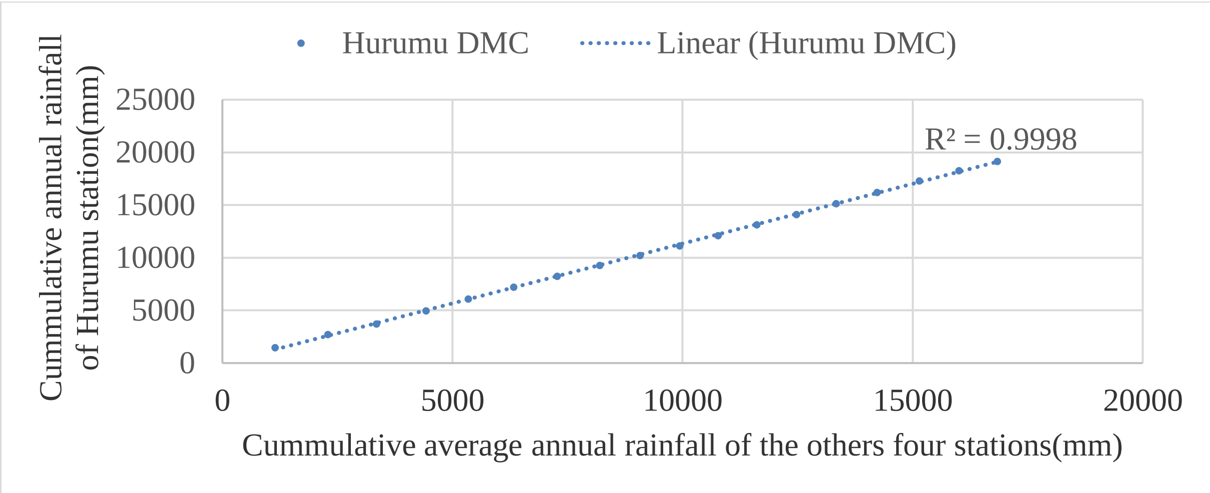
Appendix Table 14: Random consistency Index (RI)

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

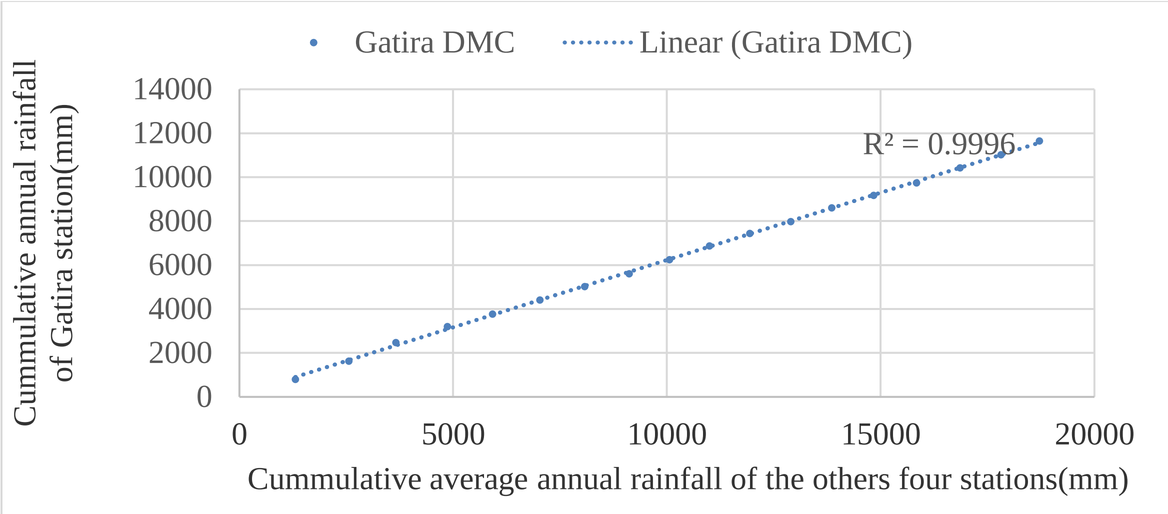
Appendix Table 15: Scale for pair-wise comparisons (Saaty and Vargas, 1991).

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

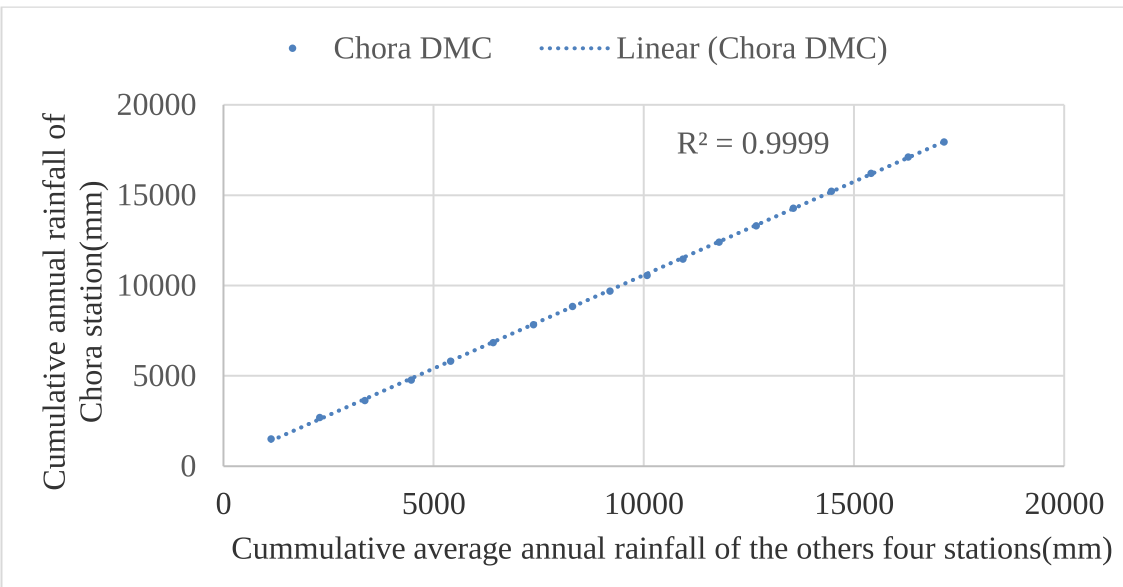
2.Appendix figures



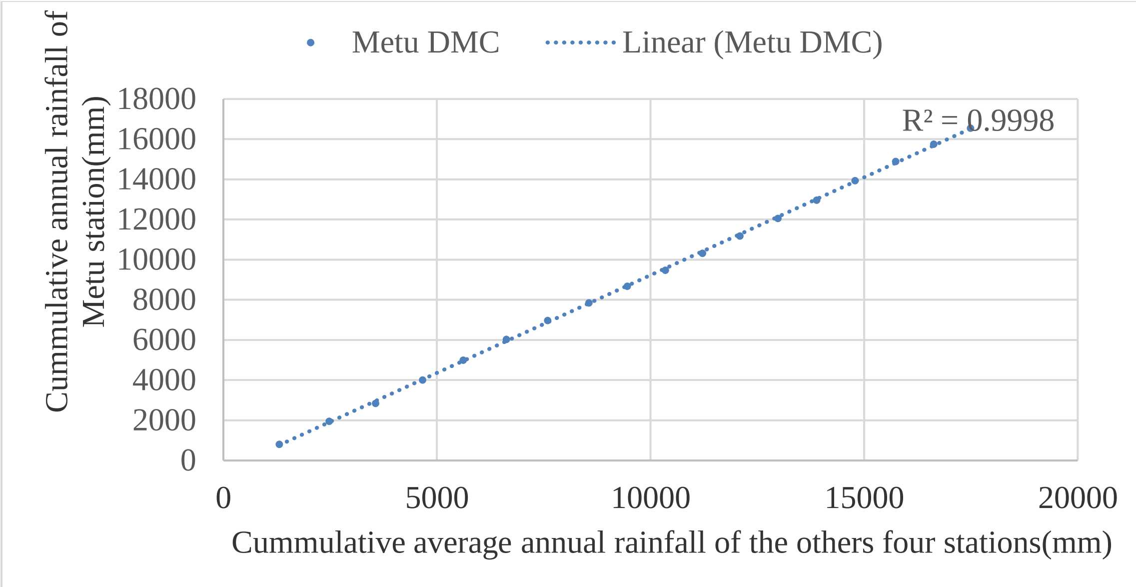
Appendix figure 1: Double mass curve for Hurumu Rain gage station



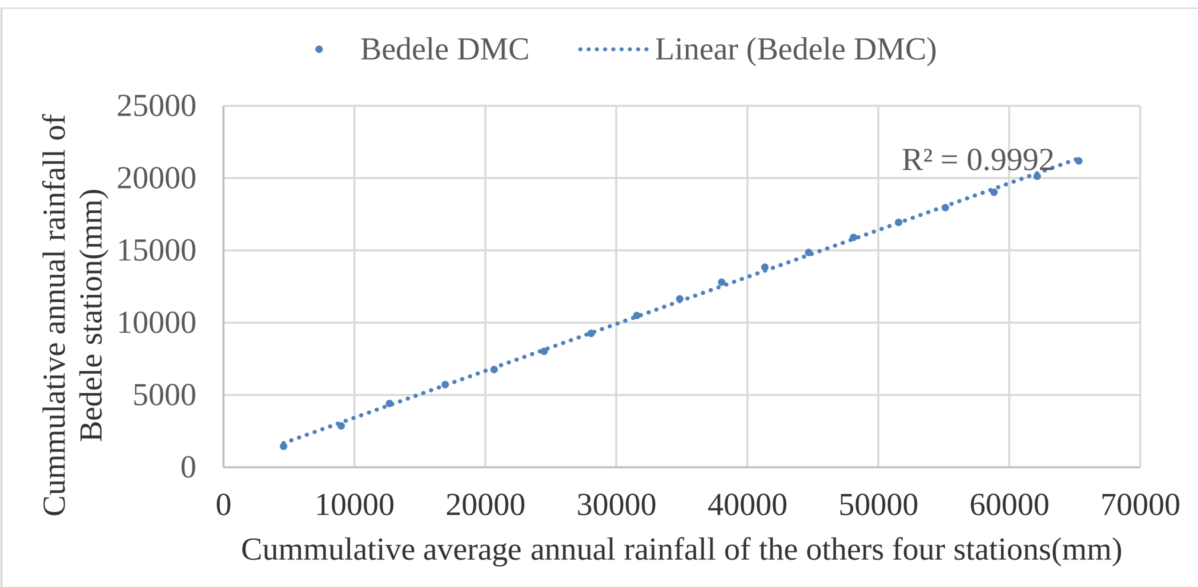
Appendix figure 2: Double mass curve for Gatira Rain gage station



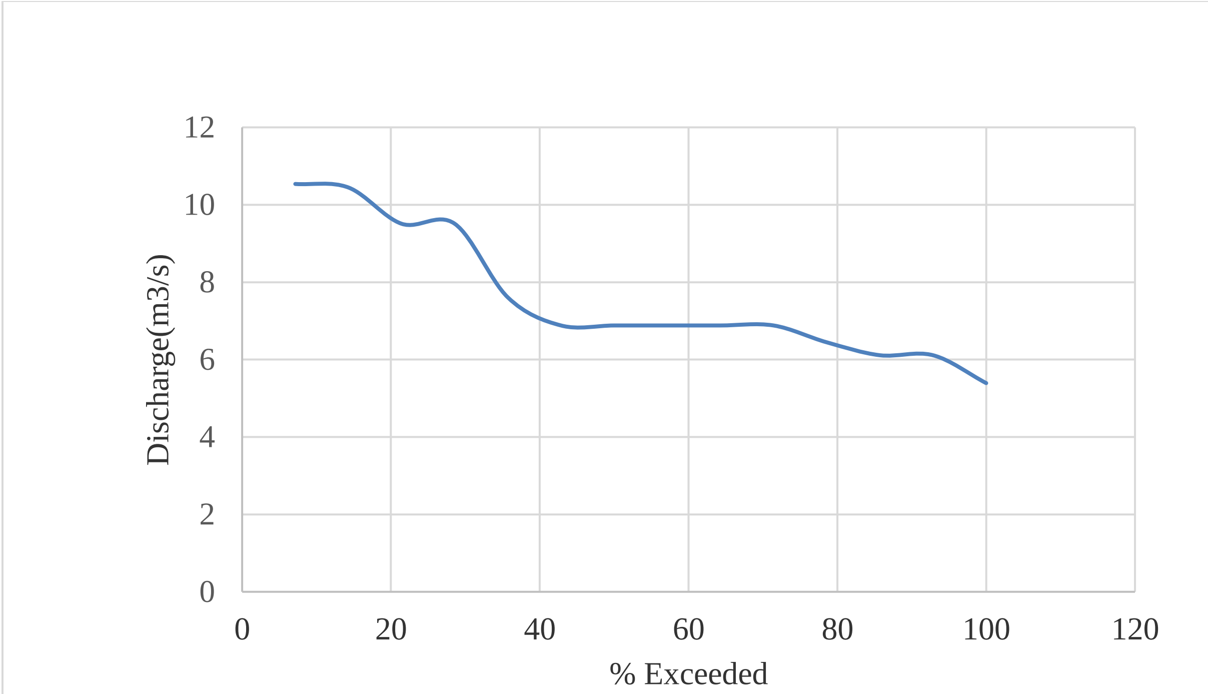
Appendix figure 3 : Double mass curve for Chora Rain gage station



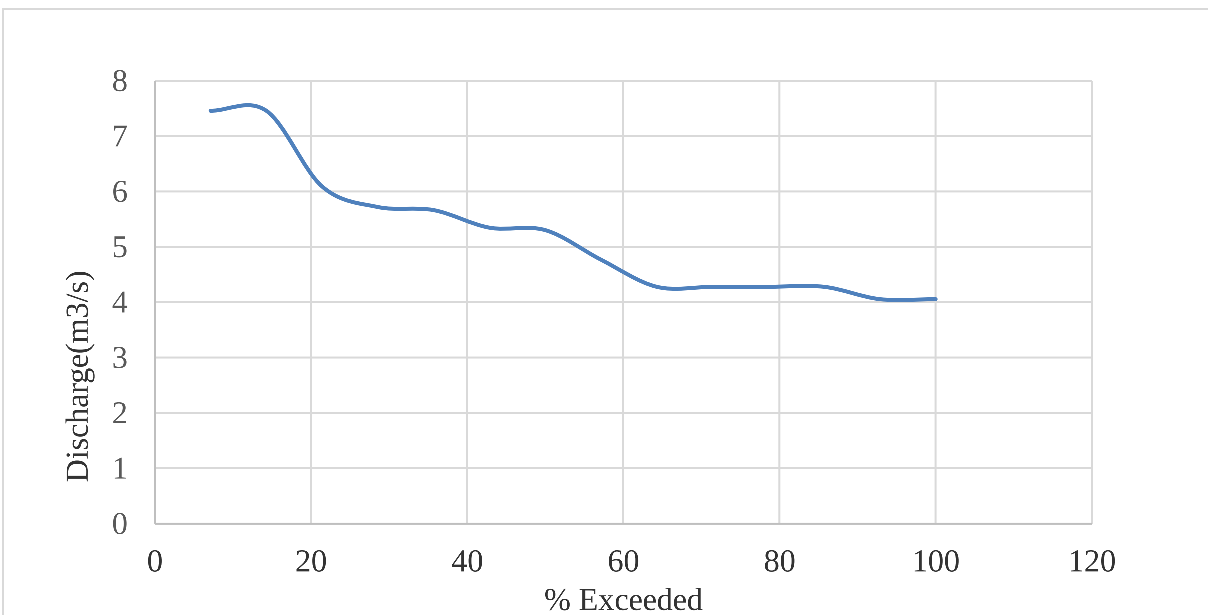
Appendix figure 4: Double mass curve for Metu Rain gage station



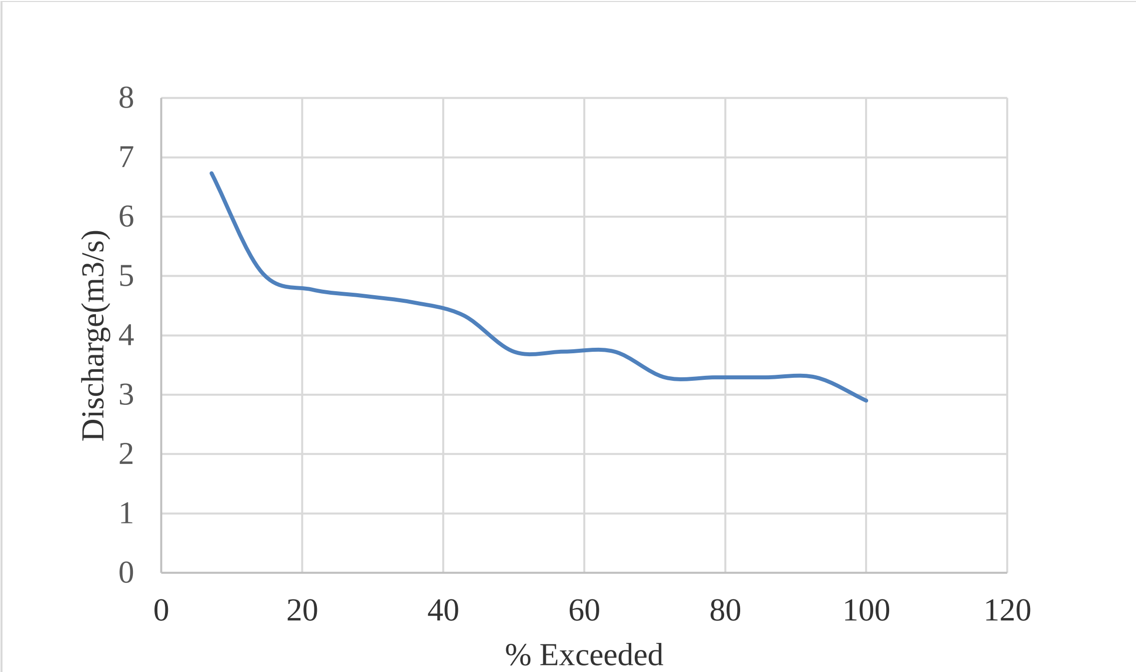
Appendix figure 5: Double mass curve for Bedelle Rain gage station



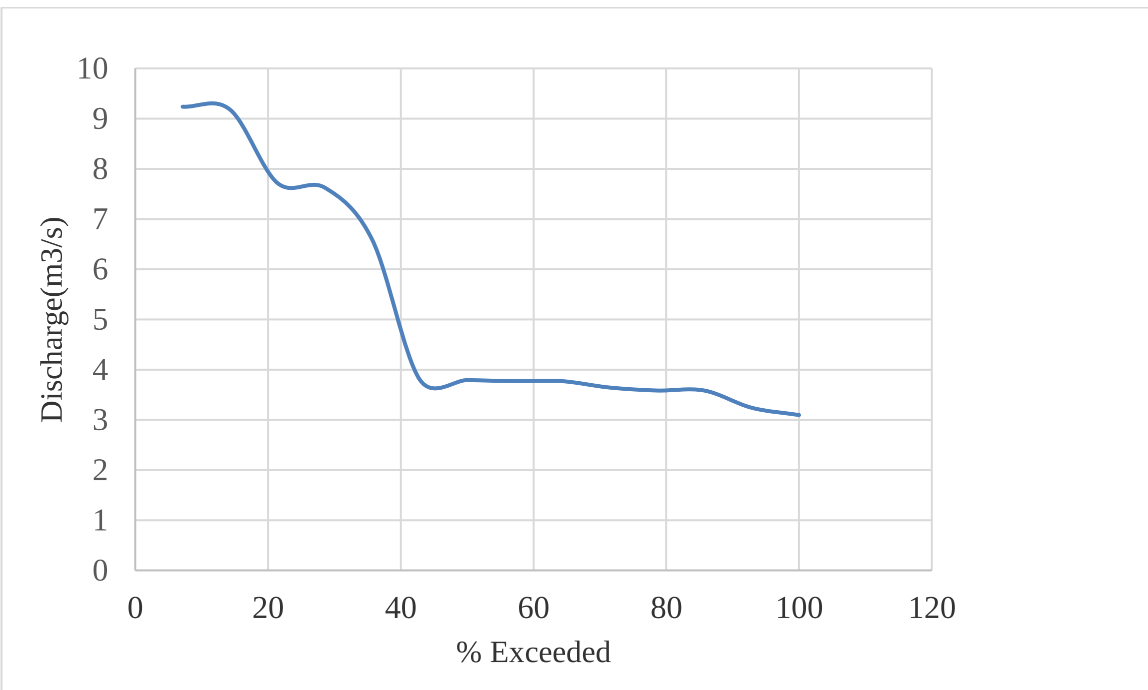
Appendix Figure 6: Flow Duration Curve for January



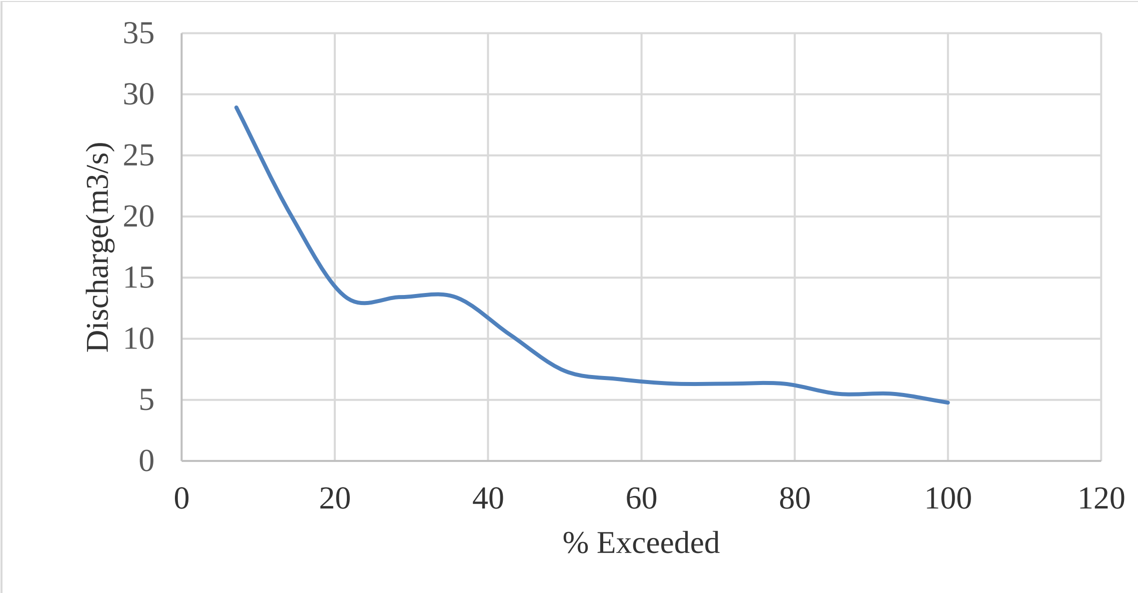
Appendix Figure 7: Flow Duration Curve for February



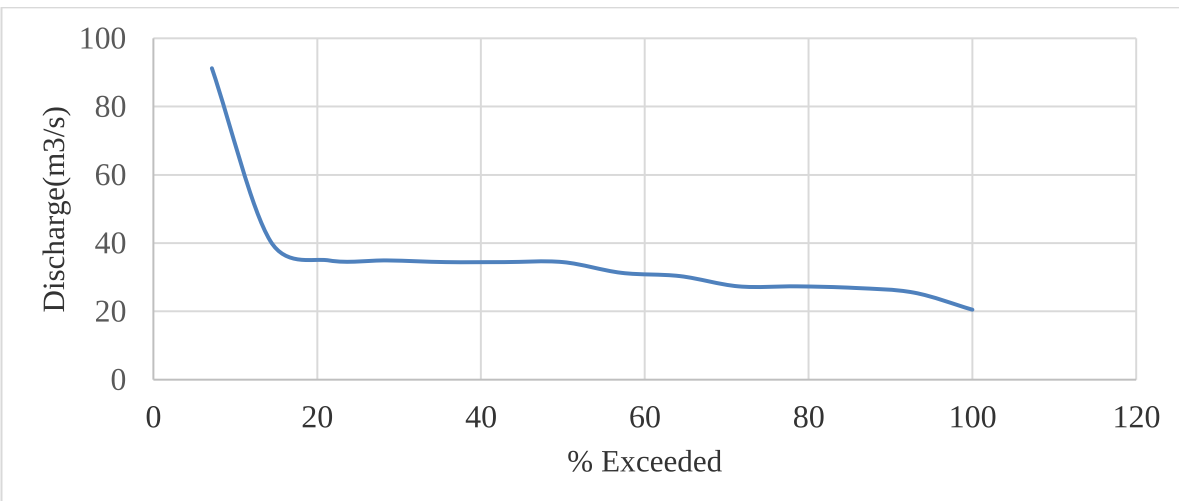
Appendix Figure 8: Flow Duration Curve for March



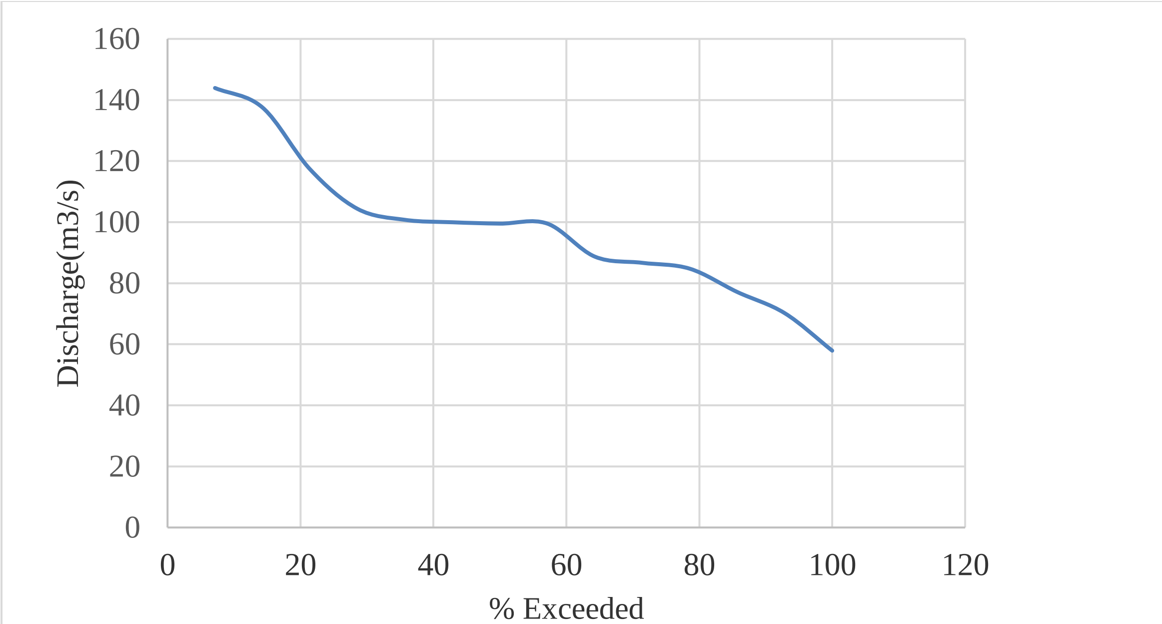
Appendix Figure 9: Flow Duration Curve for April



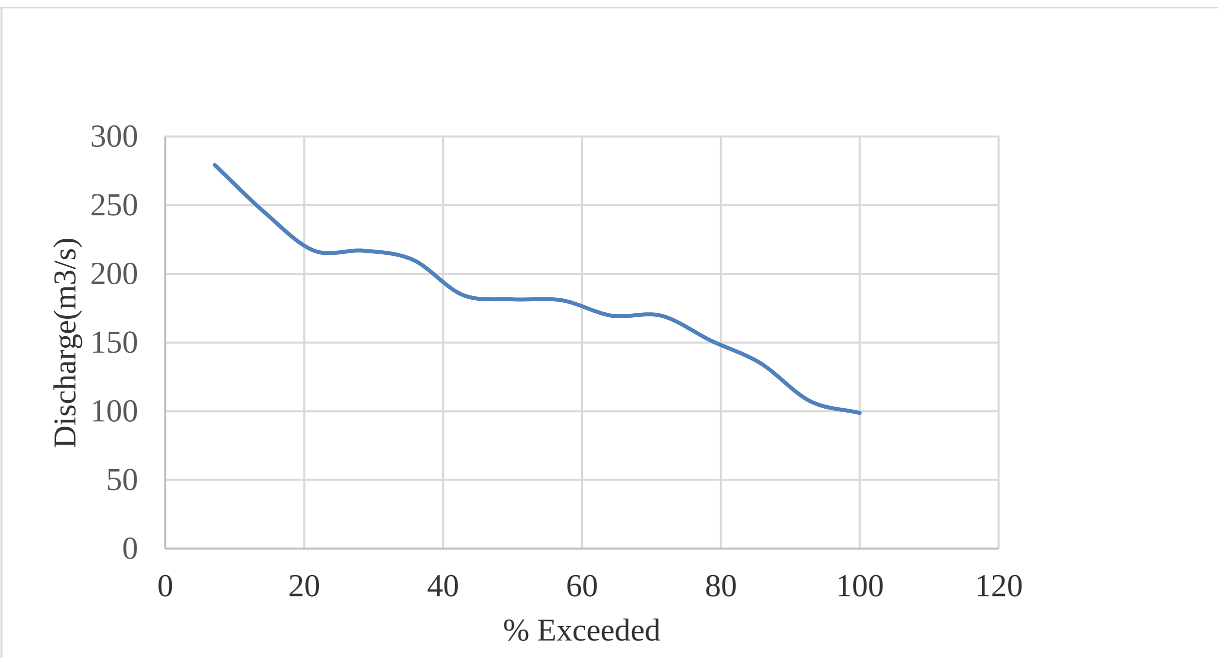
Appendix Figure 10: Flow Duration Curve for May



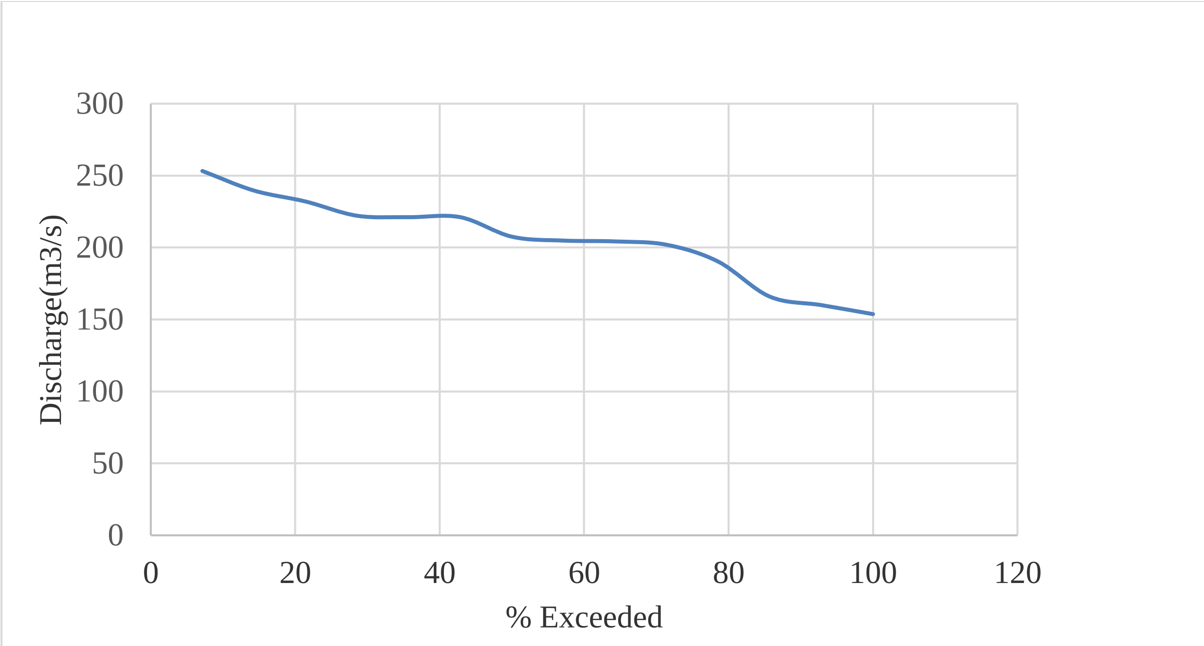
Appendix Figure 11: Flow Duration Curve for June



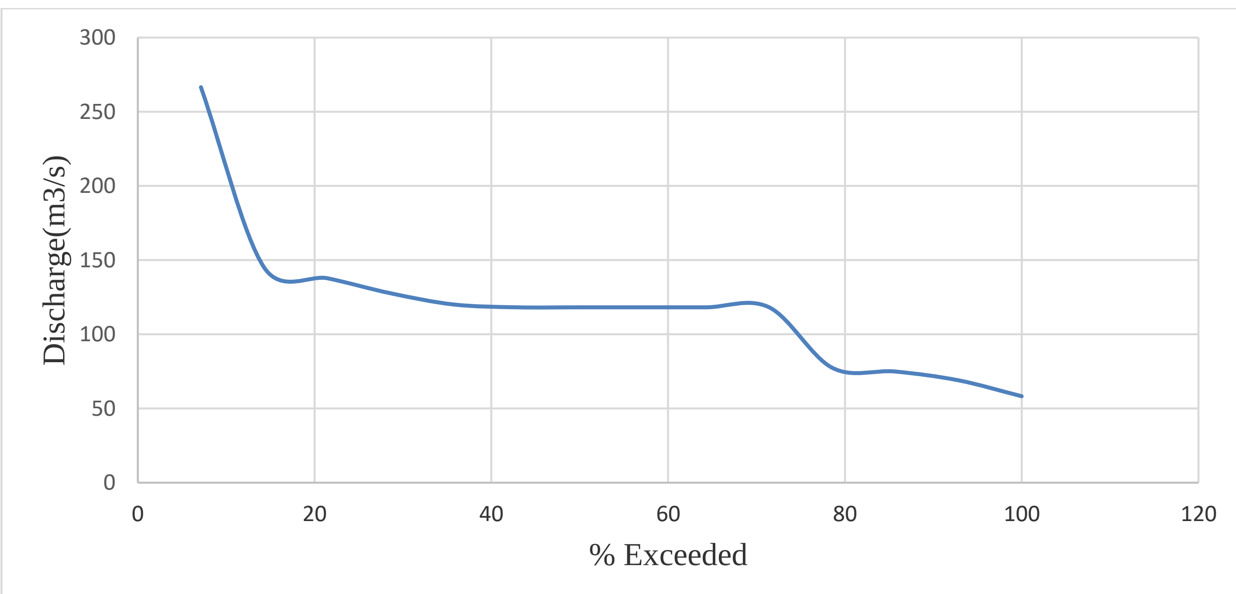
Appendix Figure 12: Flow Duration Curve for July



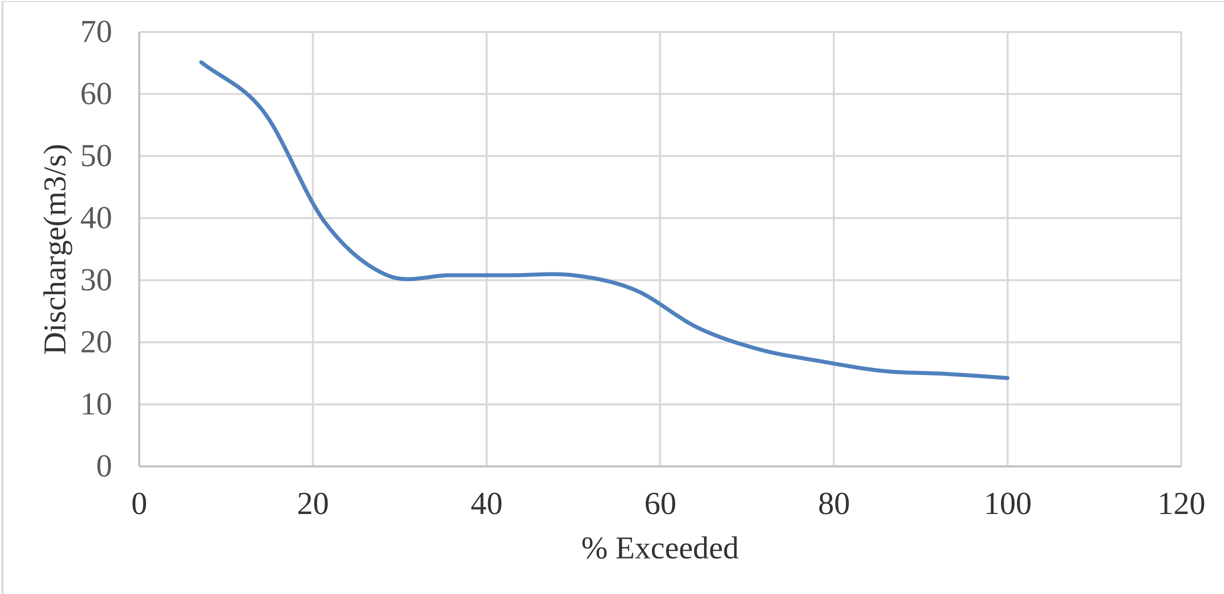
Appendix Figure 13: Flow Duration Curve for August



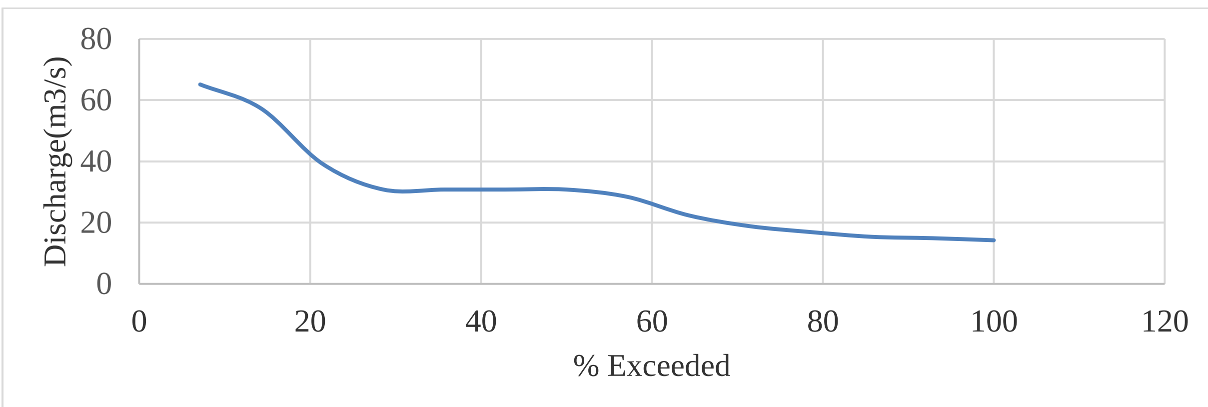
Appendix Figure 14: Flow Duration Curve for September



Appendix Figure 15: Flow Duration Curve for October



Appendix Figure 16: Flow Duration Curve for November



Appendix Figure 17: Flow Duration Curve for December