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SCHOOL OF POSTGRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF HYDRAULIC AND WATER RESOURCES ENGINEERING

MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

GIS BASED MULTI CRITERIA DECISION ANALYSIS OF LAND SUITABILITY EVALUTION FOR SURFACE IRRIGATION METHOD: (A CASE STUDY OF CHEMOGA WATERSHED)

By: Kassa Marew

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering

January, 2021

Jimma, Ethiopia

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Main Advisor: Dr. Dawud Temam

Co- Advisor: Desu Megra (MSc.)

January, 2021

Jimma, Ethiopia

DECLARATION

I, the undersigned declare that the thesis entitled as **"GIS based multi-criteria decision analysis of land suitability evaluation for surface irrigation method (A case study of Chemoga watershed)"** is my own original work and has not been submitted for a degree award in any other University or institute. All the sources of the materials used in this study have been duly acknowledged.

Kassa Marew Signature________ Date ________

This thesis has been submitted for examination with our approval as University supervisors.

Main Advisor: Dr. Dawud Temam Signature ________ Date ________

Co-advisor: Desu Megra (MSc.) Signature ________ Date ________

APPROVAL

The thesis entitled as "GIS based multi-criteria decision analysis of land suitability evaluation for surface irrigation method (A case study of Chemoga watershed)" submitted by Kassa Marew Alemu is approved and accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering at Jimma Institute of Technology.

Name	Signature	Date
Advisor: Dr. Dawud Temam	____________	___________
Co-Advisor: Desu Megra (MSc.)	____________	___________

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

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ABSTRACT

Ethiopia depends on rain fed agriculture with limited use of irrigation for agricultural production. Evaluation of land suitability and water resources availability is very important for irrigation and planning water resources projects. Chemoga River has not been used for irrigation purpose due to this fact agricultural production is very low in this area. This study is initiated with the objective of evaluate the land resources potential of Chemoga watershed for surface irrigation development by using Geographic Information System with multi criteria dissection evaluation and analytical hierarchy process. Irrigation suitability of each land parameters was classified based on the Food and Agricultural Organization guideline for land evaluation in to highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and marginally not suitable (N) suitability classes independently. The factors that were considered for evaluation of the land suitability for surface irrigation were slope, land use/cover, soil depth, soil drainage, soil texture, road access and distance of the river. After evaluating the land capability of surface irrigation, irrigation suitability map was developed. Analytical hierarchy process method was utilized to identify the weight of each criterion from the pair wise comparison matrix. The weighted sum overlay analysis was used to generate the suitability map in a geographic information system environment and the map was classified in to four suitability classes. Land suitability potential was evaluated by overlying the parameters indicate that 42.67 % of slope, 90.68 % of land use/ land cover, 69.08 % of soil depth, 60.98% of soil drainage, 68.02% of soil texture, 89.70% of river proximity and 87.4% of road proximity of the study area were identified to be in the range of highly suitable to marginally suitable for surface irrigation. By weighting analysis of all parameters 15.91% of the study area was found to be highly suitable, 31.94% moderately suitable, 21.20% marginally suitable and 30.95% were not suitable. By comparing the irrigation water demand and available dry months stream flow of the river, irrigation water demand was greater than available stream flow of the dry months. The overall result indicates that most of the Chemoga river watershed was (80093.09 ha) potentially suitable for irrigation development from the total study area for potato, tomato, cabbage and onion. To irrigate this land 118.76m3/s gross irrigation water is supplied to the field for these crops resulted from CropWat software and to irrigate all the identified irrigable area, the decision maker should take the mitigation measure by expand irrigation technology, construct storage structures across a river, exploring water from ground has to be implemented in the sub basin of river.

Key words*:-Arc GIS, Chemoga watershed, Land suitability evaluation, Surface Irrigation method.*

ACKNOWLEDGMENT

First and foremost, I want to thank the almighty God and His Mother, Saint Mary, all his Angels and Saints for his mercy and grace upon me and giving the chance, strength and courage to continue my study and for all things done in my entire life during all my works. I can say it is with the mercy of God and his holy mother that I succeeded in finishing this paper. Next, I would like to forward my sincere gratitude to my main advisor Dr. Dawud Temam and co-advisor Desu Megra (MSc) there important professional support and there kindness to give clear solutions for problems occurred during the entire period of my thesis and for their deep guidance, valuable comments and giving their viable time.

I am also thankful Ethiopian Road Authority (ERA) those sponsor me to study here in Jimma University; I would like to gratefully acknowledge Jimma University (JIT) for granting me by any relevant things and I would also thank the Ethiopian National Meteorology Agency, Ministry of Water irrigation and electricity and GIS department for their help by providing me data to conduct this study without which this research was not possible.

I would like to extend my deepest appreciation to Mr. Chala Hailu and Mr. Nasir Gebi for sharing me there valuable data and smart ideas beyond my expectation. Many thanks go to my classmates and all my friends who have played a big role directly or indirectly for the success of my study.

Finally I would like to express my gratitude to all my families they are with me in every aspects of my life to reach here. For their encouragements and support, especially my father Mr. Marew Alemu and my mother Ms. Lawaysh Debalki for her love, care and support and also pray for me throughout my life.

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ACRONYMS

AHP	Analytical hierarchy process
BMC	Billion Meter Cubic
CI	Consistency Index
CR	Consistency Ratio
CWR	Crop Water Requirement
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
ERA	Ethiopian Road Authority
ETo	Evapo-Transpiration
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GIWR	Gross Irrigation Water Requirement
IWMI	International Water Management Institute
LULC	Land Use Land Cover
MCA	Multi-criteria Analysis
MCDE	Multi-criteria Decision Evaluation
Mha	Million Hectares
MoA	Ministry of Agriculture
MoWIE	Minister of water, irrigation and electricity
WoWR	Ministry of Water Resources
NASA	National Aeronautics and Space Administration
NIWR	Net Irrigation Water Requirement
NMSA	National Meteorological Services Agency
PWCA	Pair Wise Comparison Matrix
RS	Remote Sensing
WLC	Weighted Linear Combination

1. INTRODUCTION

1.1. Background

The world's population reached 7.7 billion in mid- 2019 and global population is expected to reach 8.5 billion in 2030. Ethiopia is the second most populous country in Africa with an estimated population of 112 millions (United Nations, 2019). The increase in population numbers together with the limited availability of agricultural land has pressing effects leading to an improper land use (Rossiter *et al.,* 1996). The health and productivity of global land resources are declining even though their demand is increasing from time to time (Cowie *et al.,* 2018). Ethiopia depends on rain fed agriculture with limited use of irrigation for agricultural production. It is estimated that more than 90% of the food supply in the country comes from low productivity rain fed small holder agriculture and hence rainfall is the single most important determinant of food supply and the country's economy (Belete, 2006).

Ethiopia has a large potential of water and land resources that could be easily developed for irrigation. The country is endowed with ample water resources with 12 river basins with an annual runoff volume of 123.95 billion m³ of water and an estimated 2.86 billion m³ of groundwater potential (Makombe et al., 2011; MoA, 2011a, Kedir M and Yassin M, 2020) and about 73.6 million ha (67%) of the country's area is potentially suitable for agriculture (Fasina, 2012). According to Ayalew, (2018) report, the potential irrigable land in Ethiopia is greater than 5.3 million hectares but the area under irrigation is estimated at 10-12% of this area approximately 55% is traditional irrigation schemes, 20% is modern small-scale, and 25% is medium and large-scale irrigated commercial farms. Field assessments in small-scale irrigation projects indicate, however, that some irrigation schemes are not functional due to shortage of water, damaged structures and poor land management. In order to increase food production and provide food security, crops need to be grown in areas where they are best suited. In order to achieve this, the first and foremost requirement is carrying out land suitability analysis (Murage, 2013).The land evaluation method is the systematic assessment of land potential to find out the most suitable area for cultivating some specific crop. Theoretically, the potential of land suitability for agricultural use is determined by an evaluation process of the climate, soil and water resources and topographical, as well as the environmental components under the criteria given and the understanding of the local biophysical restraints. The use of GIS Multi-Criteria Decision Evaluation methods allows the user to derive knowledge from different sources in order to support land use planning and management (Bobade, 2010). Geographical information system (GIS) is serving as a powerful analytic and decision making tool for irrigation development (Aguilar-Manjarrez and Ross, 1995). Large area extent of GIS as well as its ability to collect store and manipulate various types of data in a unique spatial database, helps performing various kinds of analysis and thus, extracting information about spatially distributed phenomena. In this kind of situation, the factors that are involved for irrigation potential assessment such as soil, land use/ land cover, slope gradient, road access and distance from water supply could be weighted and evaluated using Arc GIS according to their suitability for irrigation. To enable careful planning of the development of the water resources, especially for agriculture, which is by far the largest water user, a good knowledge of the irrigation potential for the country is necessary. Therefore the planning process for irrigation has to integrate information about the suitability of the land, water resources availability and water requirements of irrigable areas in time and place (FAO, 2007).

Conducting research on irrigation land suitability by integrating Multiple Criteria Analysis, Geographical Information System and Analytical Hierarchy Process bring sustainable land resource management. In view of this fact, it is worth investigating irrigation land suitability in East Gojjam zone of Amhara national regional state has abundant water and land resources, but its agricultural system does not yet fully productive and mainly depends on rain-fed agriculture. This resulted from lack of systematic land suitability evaluation, land use planning and lacking of clearly, current land use and irrigation land suitability description for potential natural resource in the area. To introduce improved irrigation technology and expand irrigation investment, irrigation land suitability evaluation is very important tool in terms of agriculture development planning and choosing of suitable irrigation method. Therefore, the aim of this study is to assess the land resources potential of the Chemoga watershed for surface irrigation methods and providing geo-referenced map of these resources using GIS techniques.

1.2. Statement of the Problem

To increase the quality of agricultural production and sustain crop production and alleviate food security problems and also taking into consider the available water resource and suitable irrigable land resources of the country. Proper assessment of the suitability of a command area plays a significant role in the subsequent sustainability of an irrigation scheme. Attempt to evaluate the suitability of an irrigation land has been a growing interest by researchers and development partners. For instance, Abraham, *et al*., (2015) revealed that, in developing supplementary irrigation, evaluating and assessing the potential and suitability of the land area is important for better utilization of land resources. However, in Ethiopia, this is almost ignored and any type of irrigation is practiced without proper investigation on the potential of the area for irrigation purpose. Irrigation planning process requires integration of information about the suitability of the land, water and climatic conditions. Irrigation water supplies and their requirements are important factors in matching the available supply to the requirements.

Chemoga river is a perennial river flow; it has not been used for irrigate purpose. Due to this fact agricultural production is very low in this area. The efforts to establish small, medium and large-scale irrigation schemes in the area are constrained by a number of uncertainties. This is due to lack of information about the availability and suitability of land. From such problem the physical characteristics of the land of the study area were given more emphasis to evaluate the irrigation potential of the river by using multi- criteria decision analysis method since, there is no study which was conducted in the study area based on weighting the land resources for surface irrigation method crop suitability analysis on the study area. This study add some asset to explore the irrigation potential in the study area and also matched with the water requirements of some crops commonly grown in the study area, in which the community is highly reliant on agriculture. Through systematic land suitability assessment and irrigation land suitability description for potential natural resource is needed.

1. 3. Objectives of the Study

1.3.1. General Objective

The main objective of the study is to evaluate land suitability potential on Chemoga watershed for surface irrigation method by using GIS techniques.

1.3.2. Specific Objectives

1. To assess land suitable for surface irrigation system in the watershed.
2. To develop maps based on the suitability parameters for the analyzed irrigable lands.
3. To estimate total irrigation water requirement for the selected crop commonly grown in the area and compare with the potential of the river flow.

1.4. Research Questions

1. How much area of Chemoga watershed is suitable for surface irrigation method?
2. What portion of the land area suitable for surface irrigation in the river watershed?
3. How much are the exploitable river flow potential and irrigation water requirement in the area?

1.5. Scope of the Study

The scope of the study mainly focuses on evaluation of the land resource potential and its suitability for surface irrigation system by multi-criteria decision analysis on geographic information system environment technique without considering chemical property of the soil type. So these work was only investigates soil physical property, land use/cover, river proximity, access of road and land slope for determining land suitability for surface irrigation.

1.6. Significance of the Study

Ethiopian Government policy in the present is to increase the national economy through agriculture led industrialization. The current production of sufficient food and food security in Ethiopia is impossible unless, the agricultural production system shifts to both irrigation and rain fed agriculture. The future trend of development highly depend on how we manage sectors and all other resource, this appeals to knowing total quantity of water and land resource potential for surface irrigation method in Chemoga river sub basin of Abby.

Because of this area is practiced rain fed agriculture once in the year as a result agriculture production practically decreased. After knowing the available water and irrigable area in this watershed, it helps to for planner and decision maker to lunch any physical structures for to store or divert sufficient water for agriculture purpose. So that the population can beneficiary or profitable by producing yields two or three times per year this leads to, the development of Ethiopian economy.

1.7. Limitation of the Study

Shortage of data of the study area was encountered in order to conduct the study, the chemical properties of soil of the study area wear not evaluated for surface irrigation and crops suitability due to shortage of data. Only the physical characteristics of soil, slope of land, river proximity and road proximity of the land wear evaluate for determining the suitability of irrigation. The studies consider only available minimum water resources for irrigation. Thus, the storage requirements, detailed design and the places where it is locate was not determined or considered.

2. LITERATURE REVIEW

2.1. Definition of Irrigation Potential

The definition of irrigation potential is not straight forward and implies a series of assumptions about irrigation techniques, investment capacity, national and regional policies, social, health and environmental aspects, and international relationships, notably regarding the sharing of waters. However, to assess the information on land and water resources at the river basin level, knowledge of physical irrigation potential is necessary. It is the sustainability of available water resource, suitability of soil and slope for irrigation and availability of irrigable land from the watershed (FAO, 2007).

FAO (1997) conducted on physical irrigation potential with a combination of water resource availability match with gross water requirement, area of soils suitable for irrigation and available water resources by basin. If these all parameters are fulfilling in the watershed, is potentially irrigable for surface irrigation. The area which can potentially be irrigated depends on the physical resources soil and water, combined with the irrigation water requirement as determined by the cropping pattern and climate. Therefore, 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. Irrigation is the science of planning and designing a water supply system for the agricultural and to protect the crops from bad effects of drought or low rainfall (Houshyar, 2017).

2.2. History of Irrigation Development in Ethiopia

Sulas *et al*. (2009) in the study conducted to investigate whether irrigation was a key factor in state formation and urban development in the ancient civilization of Axum, Northern Ethiopia, found non-sufficient information regardless of water managements of rain-fed agriculture. However, In Ethiopia, traditional irrigation was practiced before centuries (Bekele B *et al.,* 2012). Most of the traditional irrigated lands in Ethiopia are dominantly supplied by surface water sources, while ground water uses has just been started on a pilot basis in the East Amhara region. Modern irrigation was started in the early 1950's by the bilateral agreement between the government of Ethiopia and the Dutch company jointly known as Ethiopia sugar cane plantation (MoA, 2011a); (Bekele B *et al.,* 2012). According to (MoA, 2011a) pressurized sprinkler irrigation system was once practiced in Fincha State Farm, Eastern Amhara, Southern Tigray and on some private farms in the Rift Valley. The rift valley is a place where modern irrigation in Ethiopia starts especially in the Awash River Basin at which adoption of pump-irrigation commences. Surface irrigation methods predominantly furrow irrigation and basin irrigation methods were practiced for cotton and wheat productions and for commercial fruits such as bananas respectively (Berhanu et at., 2014).

Awulachew *et al.,* (2010) explained that well-managed irrigation development is key in helping Ethiopia overcome major challenges of population pressure, soil and land degradation, high climate variability and low agricultural productivity. Research in the Lake Tana Basin revealed that, on average, household incomes of those that practiced irrigation were 27% higher than those that did not (IWMI, 2015). Another study at Gubalafto District, North Wollo (Mengistie and Kidane, 2016) indicated that irrigation has a great impact on enhancing farmers‟ livelihoods through different dimensions, such as diversification of crops grown, as well as increased agricultural Production, house hold income, employment opportunity and participation in community decisions. (Makombe *et al.*, 2011), noted that irrigation development is a key for sustainable and reliable agricultural development which leads to overall development in Ethiopia. Irrigated agriculture is being practiced under smallholders, medium and large scale farming.

2.3. Land Resources Potential of Irrigation

The population of the world is dependent on land resource for food and other necessities. More than 97% of the total food for the world's population is derived from land, the remaining being from the aquatic systems (FAO, 1993). According to, FAO (1995), Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface. This surface including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.). Land is very limited resource nowadays, it is important to recognize its potential, and optimize its use (Ponjavic *et al.*, 2010).

Therefore, land should be preserved and utilized properly to achieve the possible profit of land. Potential of Irrigated lands now account for about 20 percent of the worlds farmed area and 40 percent of global food production. Increases in irrigated area, cropping intensity, and crop yields have helped to stabilize food production precipitate, even though population and precipitate food intake have grown significantly (MoA, 2011). Land suitability assessment plays an important role in maintaining and developing land use on a spatial basis. It identifies the levels and geographical patterns of biophysical constraints and evaluates potential capacity of land and its sustainable use. Sustainable management of land resource requires sound policies and planning based on knowledge of these resources. So it is very important for agriculture development planning to take land resources assessment (Ashraf andNormohammadan., 2011). On the other hand, inappropriate land use leads to inefficient exploitation of natural resources, destruction of the land resource, poverty and other social problems. Part of the solution to the land-use problem is land evaluation in support of rational land-use planning and appropriate and sustainable use of natural resources (Rossiter, 1996).

2.4. Irrigable Land Potential in Ethiopia

To know irrigation potential for different countries in Africa based on water resources and land suitability the area that 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, 1993). According to Dejen *et al* (2012), in Ethiopia, about 90% of the irrigation potential in terms of land and water resources has not been developed so far. However, there have been many ongoing medium and large-scale irrigation developments in recent years. Modern schemes are those equipped with basic irrigation infrastructure such as water diversion and flow control structures and conveyance and distribution systems.

Ethiopia has 12 river basins which account annual runoff volume 123.95 billion cubic meter of water and 2.86 billion m^3 of ground water potential within an average of 1575 m^3 of physical available water per person per year were estimated (Makombe et al., 2011; MOA, 2011a). (Awulachew *et al.*, 2007; Dagninet A, 2019) show the irrigation potential the country Ethiopia is greater than 5.3 million hectares. They have also been different estimates of the irrigation potential in Ethiopia. Ethiopia has vast cultivable land (73.6Mha), but only about a third of that is currently cultivated (approximately 15 Mha), with current irrigation schemes covering about 640,000 ha across the country (Girma, 2015). However, the study estimates that total irrigable land potential in Ethiopia is greater than 5.3 Mha. This means that there are potential opportunities to vastly increase the amount of irrigated land, as detailed below.

Table 2.1. Surface water potential in Ethiopia

River Basin	Area(km^2)	Water resource		Irrigation potentials (ha)
		Billion m^3	Lt/sec/km^2	
Abbay	199,812	54.4	8.63	815,581
Awash	112,696	4.9	1.41	134121
Tekeze	82,350	8.2	3.16	82,350
Omo-Ghibe	79,000	16.6	6.66	67,928
Rift Valley	52,739	5.64	3.44	139,300
Mereb	77,121	0.72	0.12	77,121
Denakil	74,002	0.86	0.42	158,776
Baro-Acobo	75912	23.23	9.7	1019523
Wabi-Shebell	202,697	3.4	0.53	237,905
Genale-Dawa	171,042	6	1.1	1,074,720
Total		123.95		5,304,354

Source: (Ayalew DW**,** 2018)

2.5. Irrigation Land Suitability Evaluation Criteria

Land suitability is the fitness of a given type of land for a defined use with the availability of water. The land can be classified in its present condition or after improvements for its specified use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defining uses (FAO, 2007). The suitability of the land is characterized depending on the land slope, water availability, drainage condition, rockiness, land use/land cover, soil type and others this all are land evaluation criteria in terms of realistic alternatives for improving the use of that land. (FAO, 2007) Given focus on irrigation, land suitability analysis and particular attention is given to the physical properties of the soil, to the distance from available water sources and to the terrain conditions in relation to methods of irrigation considered. Land suitability is the degree of appropriateness of land for a certain use. Land suitability could be assessed for present condition (actual land suitability) or after improvement potential land suitability (Ritung *et al.*, 2007).

2.6. Land Suitability Classification

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, 2007). Irrigation land suitability analysis is given to the physical and chemical properties of soil and topographic (slope) factors in relation to methods of irrigation considered (FAO, 2007), (Hailegebriel, 2007) and (Meron, 2007). According to (FAO, 1995) there are four categories recognized for classification of land suitability. Land Suitability Orders indicating in the simplest of whether land is suitable(S) or not suitable (N) for specified use. Land Suitability Classes showing the degree of suitability within an order; Land Suitability Sub classes reflection the kinds of limitation or required improvements measures within classes and land suitability units indicating differences in required management within sub classes.

Table 2.2.Categories of suitability classification

Categories of suitability	Description
Land suitability orders	Reflecting kinds of suitability
Land suitability classes	Reflecting degrees of suitability within Orders
Land suitability sub –classes	Reflecting kinds of limitation or main kinds of improvement measures required, within classes
Land suitability Unit	Reflecting minor differences in required Management

Source: (FAO, 1995)

2.6.1. Land Suitability Orders

Land suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. According to FAO (1976) Land Suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. The two orders are represented as S and N respectively.

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

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

2.6.2. Land Suitability Classes

Murage S, (2013) reported that land suitability classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic number, in sequence of decreasing degrees of suitability within the order. The classes are numbered consecutively, by Arabic numbers, in sequence of decreasing degrees of suitability within the order.

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

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

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

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

2.6.3. Land Suitability Sub Classes

Land Suitability Subclasses reflect kinds of limitations, example moisture deficiency, and erosion hazard. Subclasses are indicated by lower-case letters with early significance, example S2m, S2e, and S3me. There are no subclasses in Class S1. The number of Subclasses recognized and the limitations chosen to distinguish them would be differing in classifications for different purposes. The number of subclasses should be kept to a minimum that satisfactorily distinguish lands within a class likely to differ significantly in their management requirements or potential for improvement due to differing limitations. As few limitations as possible should be used in the symbol for any subclass. One, rarely two, letters should normally suffice. Which determines the class should be used alone if possible. If two limitations are equally severe, both may be given. Land within the order not suitable may be divided into suitability subclasses according to kinds of limitation, e.g. N1m, N1me, N1m although this is not essential. As this land will not be placed under management for the use concerned it should not be subdivided into suitability units (FAO, 1986).

2.6.4. Land Suitability Units

Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. This grouping is used to identify land development units having minor differences in management requirements. This can indicate the relative importance of land development works. The units differ from each other in their production characteristics or in minor aspects of their management requirement. Their recognition permits detailed interpretation at the farm planning level. There is no limit to the number of units recognized within a subclass (FAO, 1985).

2.7. Irrigation Land Suitability Evaluation Factors

The basic physical factors in determining the suitability of land for irrigation are soil property, topography, depth, drainage, etc. Water and climate differ from the others in that they are usually uniform throughout the specific area to be investigated (FAO, 1985). Land suitability is the fitness of a given type of land for a defined use. The land may be classified in its present condition or further improvement for its specified use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 2007). Therefore the Land evaluation parameter used to address the suitability of the selected irrigation method were soil depth, soil texture, drainage and slope factors, distance from water sources and land cover/land use types are considered as limiting factors in evaluating suitability of land for surface irrigation method in the study area.

2.7.1. Slope Suitability Analysis

Slope is important to soil formation and management because of its influence on runoff, soil drainage, erosion, the use of machinery and choice of crops and irrigation types. The slope gradient of the land has great influence on selection of the irrigation methods. Gravity (surface) irrigation can be used only on slopes S1 (0-2), S2 (2-5), S3 (5-8) and slopes > 8 is N (non suitable) could be irrigated only with sprinkler or drip systems. To accommodate gravity or sprinkler irrigation systems, land smoothing can be used to modify the slope in a field. According to FAO (1996) standard guidelines for the evaluation of slope gradient, so it is of great significance in gradational process of land escape evolution and soil development (FAO, 1996).

Table 2.3. Slope ranges from irrigated land an interactive multi criteria analysis

Slope in (%)	Factor of rating	Definition
0-2	S1	Highly Suitability
2-5	S2	Moderately Suitable
5-8	S3	Marginally Suitable
>8	N	Not Suitable

(Source; FAO, 1996)

2.7.2. Soils Suitability Analysis

The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such properties include drainage, texture, depth, salinity, and alkalinity (Fasina *et al.,* 2008).Even though they could different types of soil exhibit diverse behavior and physical properties. Soil act as a storehouse of water, supplying plant needs during dry period when rain is inadequate (Meron, 2007). Accordingly, some soils considered not suitable for surface irrigation could be suitable for sprinkler irrigation or micro-irrigation and selected land utilization types.

2.7.3. Land use/Land cover

Definitions of land use or land cover in this way provide a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation. Therefore, matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, present possible lands for new agricultural production, each term has a very specific meaning with some fundamental differences. Land cover on the one hand denotes the biophysical cover over the surface including such features as vegetation, urban infrastructure, water, bare soil or other. It does not describe the use of land, which may be different for lands with the same cover type. On the other hand, land use refers to the purpose the land serves, and describes human influence of the land, or immediate actions modifying or converting land cover (Ellis, 2009).

2.8. Water Availability

According to (Albaji *et al.*, 2015) available water resources will not be able to meet various demands in the near future and inevitably result into the seeking of newer lands for irrigation in order to achieve sustainable global food security. It is important to make sure that there will be no lack of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle (FAO, 2001). Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available (FAO, 1995).

Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source be near the 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 economical (Sileshi *et al.*, 2007).

2.8.1. Abbay River Basin

Abbay river basin has a catchment area of 199,812 Km^2, covering parts of Amhara, Oromiya National Regional State and Benishangul-Gumuz Regional States. It has the major sub- basin of Hangar, Beles, Dabus, DebreMarkos, Didesa, Dindir/Rahid, Fincha,Guder, Jemma, Lake Tana, Mota, and Muger. The major river in the basin is Blue Nile (Abbay) river, which rises in Lake Tana flowing about 1450 Km long, and merges with the White Nile to form the Nile proper. The river basin has a lowest elevation of 500 m and a highest of 4261 m. the total mean annual flow from the river basin is estimated to be 54.4 Bm^3 (Ayalew DW, 2018). The Abbay river basin is well known as the source of Nile, a land of dramatic gorges and mountains. Abbay is the most important river in Ethiopia. It accounts for 20% of Ethiopian's land area, for about 50% of its total average annual runoff which emanates from the Ethiopia highlands, for 25% of its population and for over 40% of its agricultural production. The rivers of the Abbay basin contribute on average about 62 percent of Nile at as wan; together with the contribution of Baro Akobo and Tekeze rivers, Ethiopia accounts for at least 86%of the runoff at Aswan. According to MoWIE data it is identified that Abbay river basin has a potential of 211 irrigation projects, of which 90 are small-scale, 69 are medium-scale and 52 are large-scale. The basin has an estimated total potential of 815,581 ha of potential irrigable land is estimated, Out of these, a potential 45,856 ha are for small-scale, 130,395 ha for medium-scale and 639,330 ha for large-scale development (IWMI, 2012).

2.9. GIS Based Multi-Criteria Analysis of Land Suitability Evaluation

2.9.1. Multi-Criteria Decision Evaluation Approaches

Geographical Information System (GIS)-based multi-criteria decision analysis (MCDE) techniques are capable of handling multiple and heterogeneous factors (Esa And Assen, 2017)**,** Analytical hierarchy process (AHP), one among the multi criteria decision making techniques, has a paramount contribution for evaluating the comparative importance of suitability criteria. Analytical hierarchy process supported by multi-criteria decision making MCDE approaches were developed in the 1960s in order to assist decision makers in incorporating numerous options, reflecting the opinions of concerned parties into a potential or retrospective framework. This framework is primarily concerned with how to combine the information from several criteria to form a single index of evaluation (Saaty, 1980). They were designed to define the relationship between data input and data output. The integration of the GIS and MCDE methods provides powerful spatial analysis functions (Van, 2008), (Voogd, 1983). In the MCDE approach, GIS is best suited for handling a wide range of data criteria at multi-spatial, multi-temporal and multi-scale from different sources for a time-efficient and cost-effective analysis. Therefore, there is growing interest in incorporating the GIS capability with MCDE processes (Houshyar, 2017).

The basic issue in Multi-Criteria Evaluation is concerned with how to combine the information from several criteria to form a single index of evaluation. Weighted Linear Combination (WLC) is most common technique used to create suitability map. Weight is used to develop a set of relative weights for a group of factors in a multi-criteria evaluation. The weights are developed by providing a series of pair wise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. These pair wise comparisons are then analyzed to produce a set of weights that sum to 1. The factors and their resulting weights can be used as input for the MCE module for weighted linear combination. The procedure by which the weights are produced follows the logic developed by Saaty under the Analytical Hierarchy Process (AHP) with a weighted linear combination; applying a weight to each followed by a summation of the results to yield a suitability map combines factors ((Ronald E, 2001).

2.9.2. Multi-Criteria Analysis (MCA)

Multi criteria analysis is one of the most important procedures for GIS-based decision making process (Malczewski, 2000). MCA can be used to define the most suitable areas for agricultural crops. In MCA relative importance of various criteria can be well evaluating to determine the suitability by MCA techniques (Ceballos, 2003). The integration of multi-criteria analysis method with GIS has considerably advanced the conventional map overlay approaches to the land-use suitability analysis. GIS-based multi-criteria analysis can be thought of as a process that combines and transforms spatial and a spatial data (input) into a resultant decision output (Malczewski, 2004).

2.9.3. AHP Application Concept for Land Suitability Analysis

Analytical hierarchy process (AHP), one among the multi criteria decision making techniques, has a paramount contribution for evaluating the comparative importance of suitability criteria. Analytical hierarchy process supported with Geographical Information System (GIS)-based multi-criteria decision analysis (MCDA) techniques are capable of handling multiple and heterogeneous factors (Esa And Assen, 2017) , (Houshyar, 2017). The AHP is a method widely used in MCDM to obtain the required weightings for different criteria (Maddahi *et al.*, 2017), (Mendoza, 2006). It has been successfully employed in GIS-based MCDM since the early 1990 ((Marinoni, 2006). This approach enables us to compare different variants and ranks the factors, criteria and parameters according to their importance. The Analytical Hierarchy Process is a well-known multi-criteria technique that has been incorporated into GIS-based suitability procedures (Saaty, 1980).

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). For the classification of land suitability within our case study area in Sere ban, we utilized the AHP's ability to incorporate different types of input data, and the pair wise comparison method for comparing two parameters, simultaneously. The application of the AHP process involves several steps in order to rank Criteria or factors to the set of suitable criteria. This is usually achieved by domain and experts' opinions: The consistency of the overall set of pair wise comparisons is assessed using its Consistency Ratio (CR) (Elaalem, 2012).

2.9.4. Undertaking the Multi-Criteria Evaluation

Once the weights were established, the module Weighted Overlay tool (for Multi-Criteria Evaluation) was used to combine the factors for undertaking multi- criteria evaluation. With a weighted linear combination, factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map the procedure is optimized for speed and has the effect of multiplying each factor by its weight, adding the results, and then successively multiplying the result by each of the factors. The Eigenvectors weights and weights sum (the total influence for all factors) to 1 and 100 percent respectively. GIS and MCE techniques are globally recognized for its outstanding support in map overlay process for any form of land suitability analysis (Carver, 1991 and Malczewski, 1999).

2.10. Estimation of Crop Water Requirement Using CROPWAT

Water requirement is the quantity of water, regardless of its source, required by a crop or diversified patterns of crops in a given period of time for its normal growth under field conditions at a place. (Sileshi *et al.*, 2007).Calculation of water requirements utilizes inputs of climatic, crop and soil data, as well as irrigation and rainfall data. Its basic function includes the calculation of reference Evaporation crop water requirement and crop and scheme requirement. Reference Evapo-transpiration can be calculated from the actual maximum and minimum temperatures, relative humidity, sunshine and wind speed data, According to Penman-Monteith method (Allen *et al.*, 1998). CROPWAT model is a computer program for irrigation planning and management, developed based on the Penman-Monteith method (Smith, 1992).

2.11. 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. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement (FAO, 2002).

2.12. GIS Application in Irrigation Suitability Mapping

2.12.1. Remote Sensing and GIS Application

Remote Sensing **(**RS) technology produces an authentic source of information about an object without being in physical contact with it for surveying, identifying, classifying, mapping, monitoring, and planning of natural resources and disasters mitigation, preparedness and management as a whole. RS is a technology that has close tie to GIS. RS can provide timely data at scales appropriate to a variety of applications. Land cover mapping is one of the most important and typical applications of RS A GIS is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data Good (Kihoro *et al.*, 2013).

Geographically referenced data are data that describe both the locations and characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface. The ability of a GIS to handle and process geographically referenced data distinguishes GIS from other information systems. It also establishes GIS as a technology important to a wide variety of applications. Using GIS databases, more up- to-date information can be obtained or information that was unavailable before can be estimated and complex analyses can be performed. This information can result in a better understanding of a place, can help to make the best choices, or prepare for future events and conditions (Yared And Quraishi, 2014).

2.12.2. Mapping

For agronomic, environmental and economic reasons, the need for specialized information about agricultural practices is expected to rapidly increase (Bégué *et al.,* 2018). There is no clear idea of errors in the estimation of irrigated area of official reports and figures and data are not spatially distributed. Accurate mapping of the distribution of irrigated land using remote sensing data at a regional scale can facilitate an improved understanding of patterns of water use and food production yet; studies that have used remote sensing to map irrigated lands remain relatively rare (Chance *et al.*, 2017).

2.12.3. Weighted Overlay Analysis

Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope and soil (Lillesand, 2004). Overlay operation is a part of spatial analysis process based on the value of Weightage of each sub class within each thematic map. A Weight overlay used to combine all factor layer maps in to new information to produces individual value for each pixel and new map was produced. The Weightage value used in overlay operation is only performed on raster map (Attual and Fisher, 2014), (Dengize, 2006).

2.12.4. Digital Elevation Model (DEM)

Digital Elevation Models are point elevation data stored in digital computer files. These data consists of x, y grid locations and point elevation or z variables. They are generated in a variety of ways for a different map resolutions or scales. Under an agreement with the National Aeronautics and Space Administration (NASA) and the Department of Defense's National Geospatial Intelligence Agency (NGA), the US Geological Survey (USGS) distribute elevation data from the Shuttle Radar Topographic Mission (SRTM). Shuttle Radar

Topography Mission (SRTM) obtains elevation data on a near-global scale with a radar system that flew onboard a space shuttle. For most parts of the world, this data set provides a dramatic improvement in the availability of high-quality and high-resolution elevation data (Jarvis *et al*., 2004). Digital Elevation Models (DEM) is a commonly used digital elevation source and an important part of using for watershed characterization. Many agencies provide DEM data with 90 m, 30 m and 20 m resolutions. The point elevation data are very useful as an input to the GIS. This data is used to yield important derivative products such as slope, aspect, flow accumulation, flow direction and curvature in process of watershed delineation.

2.12.5. Watershed Delineation

A watershed can be defined as the catchment area or a drainage basin that drains into a common outlet. Simply, watershed of a particular outlet is defined as an area, which collects the rainwater and drains through gullies, to a single outlet. Delineation of a watershed means determining the boundary of the watershed i.e. GIS uses DEMs data as input to delineate watersheds by hydrology tool in Arc GIS spatial analysis (Winchell et al., 2008).

2.13. Previous Land Suitability Evaluation Studies Based on GIS and MCDE in Ethiopia

Several studies have been made to assess the irrigation potential and water resources in Ethiopia by using GIS tool in the past (Negash *et al*, 2004); (Hailegebriel, 2007); (Meron, 2007) and (Kebede, 2010). Negash (2004) conducted a study on irrigation suitability analysis in Ethiopia a case of Abaya Chamo lake basin. It was a Geographical Information System (GIS) based and had taken into consideration soil, slope and land use and water resource availability in perennial rivers in the basin to identify potential irrigable land. Meron (2007) carried out similar work on surface irrigation suitability analysis of southern Abbay basin by implementing GIS techniques. This study, considered soil, slope and land cover/use factors to find suitable land for irrigation with respect to 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. Kebede (2010) conduct a study on GIS-based surface irrigation potential assessment of river catchments for irrigation development in Daleworeda, Sidama zone, SNNP. In this study irrigation suitability factors such as soil type, slope, land use/cover and distance from water supply (sources) were taken into account and weighted overlay analysis of these factors has been accomplish to identify potential irrigable land. As far as the researchers reviewed, in Ethiopia, the combination between FAO procedure, MCA and AHP evaluation technique using GIS and RS for land suitability analysis was experimented in some areas. Aiming at evaluating the physical land characteristics and its quality of the study area for suitability of surface irrigation potential and crops in GIS environment using multi-criteria decision evaluation (MCDE) method, Hailegebriel (2007) conducted a study on irrigation potential and crop suitability. His study is entitled irrigation potential evaluation and crop suitability analysis using GIS and remote sensing technique in Beles sub basin, Beneshangul Gumuz Region and he found out that 65.7 % of the Beles sub basin is classified under suitable for surface irrigation. This study demonstrates the application of the combined (GIS, MCDM and AHP) approach to address the complex decisions of mapping the crop and surface irrigation suitability. Dual (2010) conducted his study. His study aims at evaluating the land suitability using multi-criteria evaluation technique for agricultural crops and producing land allocation map for sustainable land use. Dula's (2010) research was conducted on land suitability for agricultural crop. His study is entitled GIS and remote sensing based land suitability analysis for agricultural crops in Mojo watershed, upper awash sub-basin, Ethiopia and he found out that only 21.1%, 18.3%, and 2.0% of the study area are highly suitable for teff, wheat, and chickpea, respectively. This study N demonstrates the application of the combined (GIS, MCDM and AHP) approach to address the complex decisions of mapping the suitable area for agricultural crop. Henok (2010) conducted his study on land suitability for main agricultural crop. His study aims at evaluating the land physical characteristics and its quality for land suitability of main agricultural crops in Legambo Woreda. His study is entitled land and crop suitability analysis using remote sensing and GIS application; a case study in Legambo Wereda,Ethiopia and he found out that 712 km^2 for maize and 814 km^2 of the study area are exploitable for wheat production purposes. This study demonstrates the application of the combined (GIS, MCDM and AHP) and fuzzy membership function approach to address the complex decisions of mapping the suitable area for main agricultural crop.

3. MATIRIALS AND METHODS

3.1. Description of Study Area

3.1.1. Location

Chemoga watershed is located in Coke Mountains of north western part of Ethiopia in Amhara National Regional State, East Gojjam Zone. It is about 298 km far from Addis Ababa, the capital city of the country and its topography elevation of the watershed ranges between 863m to 3946m above sea level. The geographic location of the study area is found between 09°57’00” N and 10°39’00” N latitude and 37°19’00” E and 37°58’00” E longitude of the Abbay river basin as shown in Figure 3.1. The watershed covers a total drainage area of 1161 km^2 in the Abbay river basin.

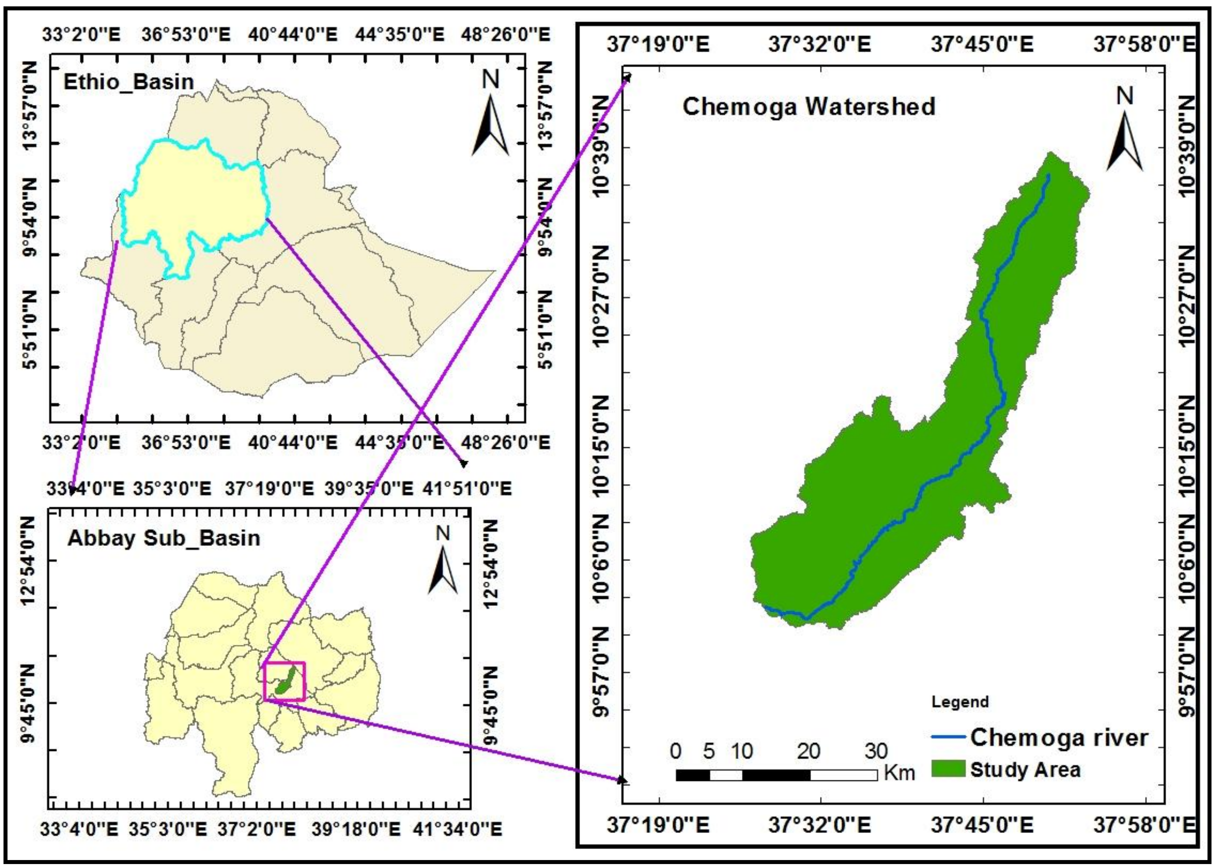

Figure 3. 1.Location of the study area

3.1.2 Topography

The study area which is a watershed of south Gojjam sub basin of Abbay basin consists of variety of landscape, with various topographical features (flat to mountainous) with elevation variation from 863 to 3946 m above mean sea level.

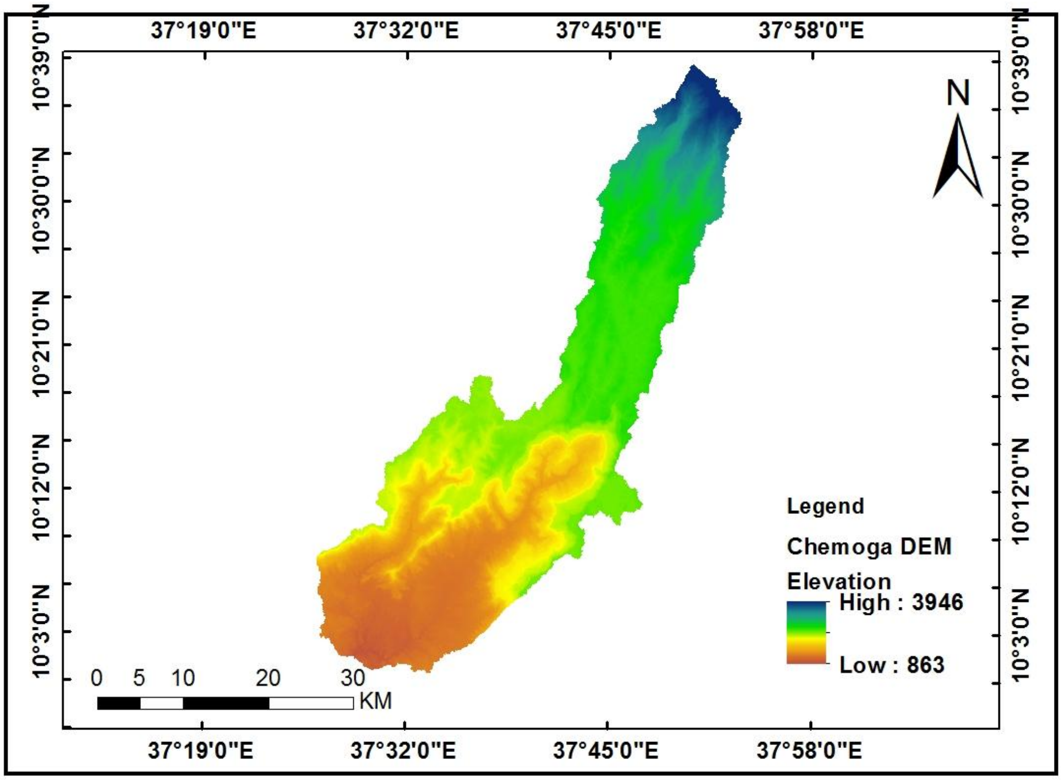

Figure 3. 2 . Elevation map of Chemoga watershed

3.1.3. Agriculture

The agriculture production system in the area is a subsistence type of crop and livestock production system, the watershed is well known by rain fed cereal crops production. A major type of crops grown in the area includes: potato, barely, wheat, maize, teff, sorghum, tomato and small extent oil crops. In this watershed, some farmers also practices traditional irrigation development activities from perennial rivers and springs. In this command area, farmers produce vegetables such as onion, tomato, cabbage, green pepper.

3.1.4. Climate

The climate of Ethiopia can be classified in different ways including the Traditional, Koppel's, Throth Waite's, Rainfall regimes, and Agro-climatic zone classification systems. The most common used classification systems are the traditional and the agro-ecological zones. According to the traditional classification system, this mainly relies on altitude and temperature (Abraham, 2015). Dega (temperate like climate-highlands with 863m-3946m altitude), The main rainfall season which accounts around 70-90% of the annual rainfall occurs from June to September, while small rains also occurs during November to April.

3.1.4.1 Temperature

The mean temperature of Chemoga watershed is in the range 10.2 to 26.4ºC. Monthly mean maximum temperature is varying from 20.0ºC in July and 28.8ºC in April and monthly mean minimum temperature varies from 8.0ºC to 11.8ºC in February and April respectively. Average monthly maximum and minimum Temperature for Deber Markos station from 1994 -2018 can be seen in Appendix F.

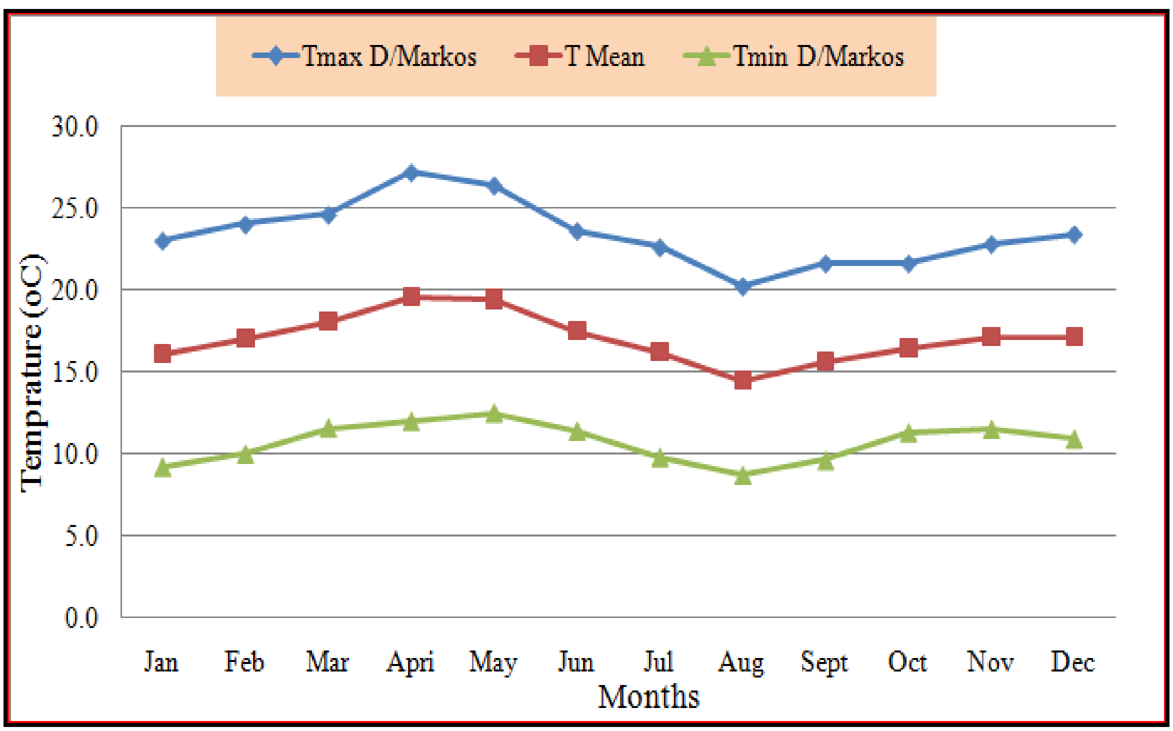

Figure 3. 3. Average monthly maximum and minimum temperature

3.1.4.2 Rainfall

Rainfall is one of the most important components of the water source. Rainfall and other forms of precipitation are measured in terms of depth, the values being expressed in millimeters (WMO, 2008). About 95 percent of all agricultural land and 83 percent of cropland in the world depends on precipitation as the sole source of water for agricultural production (Wood et al., 2000). The highest rainfall is occurred in some part of North West of this watershed. The average maximum and minimum annual precipitation of Chemoga watershed is vary from 1926.7 to 845 respectively. Average maximum and minimum monthly precipitation is varying from 226.9mm and 1.47m respectively. As shown below in the figure maximum and minimum precipitation was record in Deber Markos, Robugebeya, Yejubi, Amber and Dembecha stations in August and March respectively. Generally, the higher elevation receives higher rainfall. Average maximum and minimum annual precipitation of each station is shown in the Appendix A to Appendix E respectively.

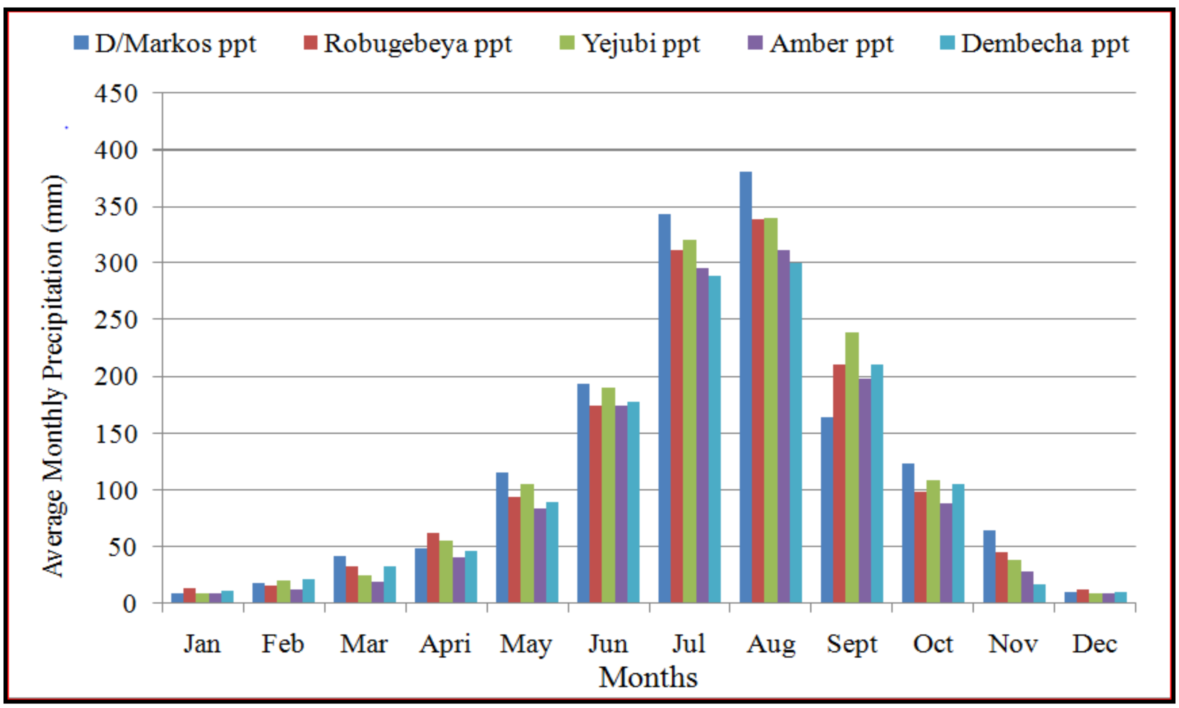

Figure3. 4. Average monthly precipitation of each station

3.1.5. Soils

Soil is the most determinant factor for land suitability evaluation of irrigation in agriculture. Mainly it affects water holding capacity, to identify soil suitability for irrigation FAO geomorphology and soil map of Ethiopia (MWIE) will be used. The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such properties include drainage, texture, depth, salinity, and alkalinity (Fasina *et al.,* 2008). Even though salinity and alkalinity hazards possibly improved by soil amendments or management practices, they could be considered as limiting factors in evaluating the soils for irrigation (FAO, 1997). There are six major soil types group in the Chemoga watershed. From these haplic alisols covers the largest area (51.37%) and Urban covers the smallest area (0.91 %) Accordingly, some soils considered not suitable for surface irrigation could be suitable for sprinkler irrigation or micro-irrigation and selected land utilization types.

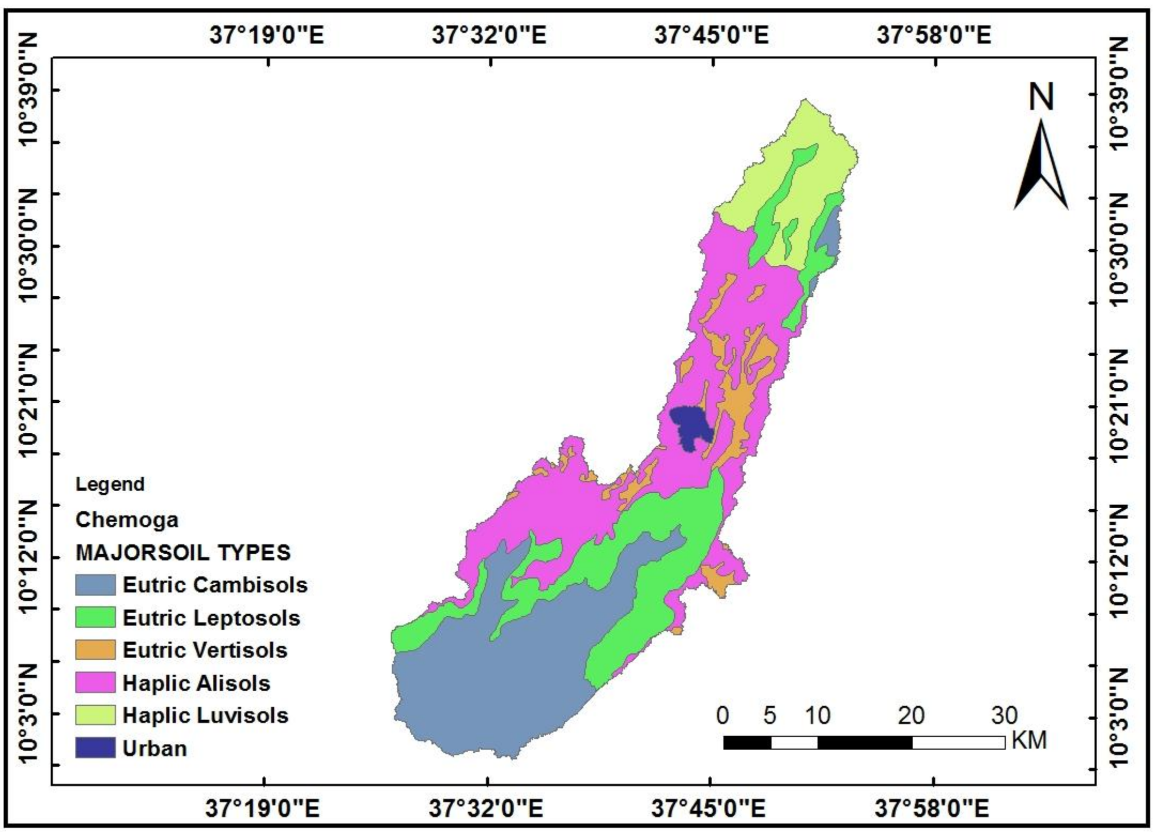

Figure 3. 5.Soil map of the study area

3.2. Materials used

Materials and tools that were used for this study include Arc GIS10.4.1, CROPWAT8.0, XLSTAT2015, Micro soft word and Microsoft excel.

XLSTAT2015: It is used to calculate missing data by multiple imputation method.

CROPWAT8.0: Irrigation water demand estimated by using CROPWAT8.0 software. This software use input data such as climate and agronomic data information.

Arc GIS10.4.1: Geographic information system focusing on the collection, modeling, management display and interpretation of geographical data.

3.3. Data Collection and Source

Primary or secondary data is very important for any researcher to successes their objective. So, to quantify the amount of available water and land resource potential for irrigation the following Secondary data was been collected from any responsible organization. On this study, only secondary data should be collected from MoWIE, NMSA, MoA, EMA, and other organization. The required data for this study includes Digital Elevation Model (DEM), land use/land cover data, and soil data, weather data; Meteorological data and stream flow data.

A. Meteorological: Meteorological data such as precipitation, temperature, humidity wind speed, sunshine was been collected from National meteorological service agency (NMSA). These data was been used to quantify crop water requirement of some selected crops using cropwat8.0 software.

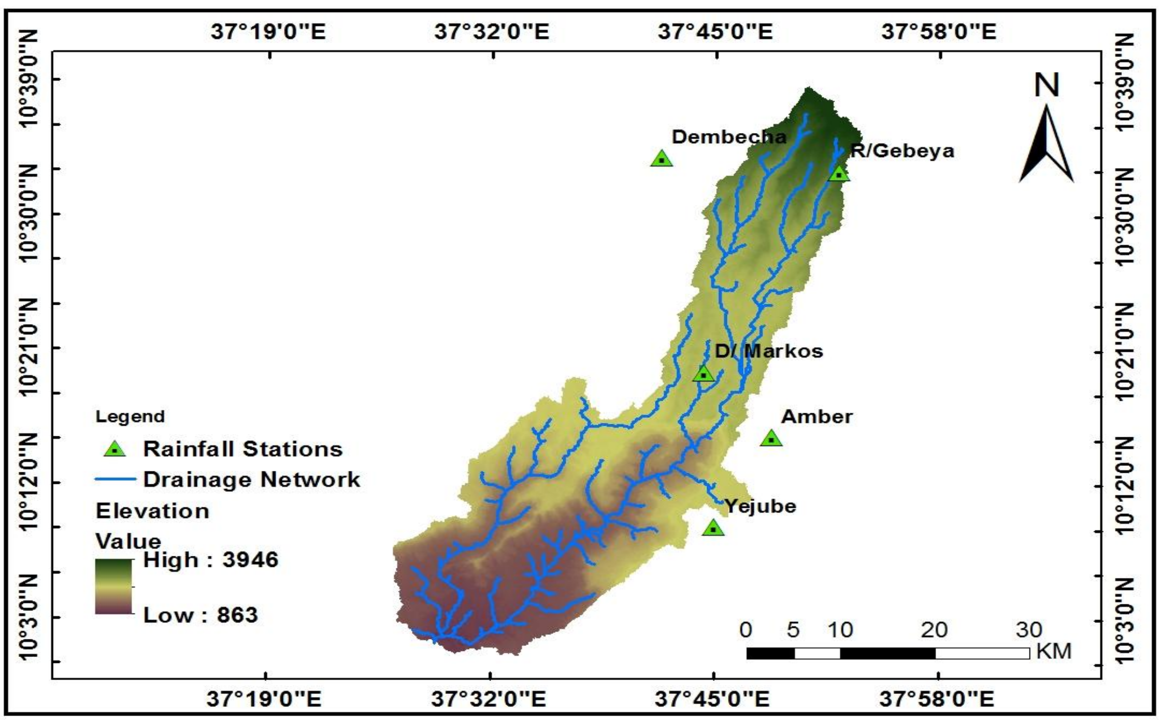

Figure 3. 6.Meteorological station distribution and elevation map

B. Stream flow data: Twenty years discharge data of the gauged station has been collected from hydrology department Ministry of water, irrigation and electricity (MoWIE). This data is important to assess the available water potential to meet the objective.

C. Soil data: Soil data has been collected from GIS department and minister of water, irrigation and electricity, this data was been used to soil suitability analysis for surface irrigation.

D. Land use/cover data: the data was been obtained from MoWIE. This data was one input for assessing land suitability in the study area.

E. River Proximity and Road Access: River proximity is an important factor that decides and prioritizes the areas to be irrigated by using surface irrigation, road access availability is important factor to represent market access and easily address the output of irrigation and the data was been obtained from ERA.

Table 3.1.Important data inputs and sources

No.	Type of Data	Sources of Data
1	DEM 20m*20m	MoWIE, GIS department
2	Land Cover data of 2018	EMA (Ethiopian Mapping Agency)
3	Metrological Data	NMSA(National Metrological Service Agency)
4	Soil Data of 2018	Ethiopian ministry of Agriculture
5	Stream Flow	MoWIE, Hydrology department

3.4. Methods

3.4.1. Data Pre-processing and Quality Checking

The different data inputs which were collected from different data sources contained errors due to failures of measuring device or the recorder. So, before using the data for 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.

3.4.1.1 Missing Data Analysis

Collected data can contain errors due to failures of measuring device or the recorder. So, before using the data for specific purpose, the data have to be checked and errors have to be removed. The analysis was extending to hydrological and meteorological data to prepare input data for water resources assessment and irrigation water requirement estimation by multiple imputation method using the CROPWAT model. Before conducting any hydrological studies/modeling in any river basin for water resources project planning and management, it is important to make sure that data are correct, sufficient and complete with no missing values (Villazón *et al.,* 2010*)*. Errors resulting from lack of appropriate data processing are serious because they can le ad to wrong conclusions (Wong *et al.*, 2016). Some of the techniques which are used to estimate missing rainfall data are the normal ratio method, arithmetic mean, inverse distance method, and multiple imputation analysis methods using datasets from other selected stations in the surrounding and applying appropriate spatial interpolation methods ((Ramos *et al.*, 2011*)*. Thus missing rainfall data analysis was conducted for each station to fill the missed rainfall data from the neighboring rain gauge stations having complete data set. In this study area missing data in the five considered stations are Debre Markos, Robugebeya, Dembcha, Amber and Yegubi gauge stations were executed by using multiple imputation method.

3.4.2. Checking the Consistency of Rainfall Data

To prepare the rainfall data for further application, their consistency was been checked using double mass curve analysis by using Microsoft excel state was used to check the spatial consistency of the rainfall data as it has got wider applications in hydrological areas and is considered to be reliable (Dingman, 2002). According to Dingman, (2002) the method assumes that stations have regional consistency over long time period. Inconsistency is detected by plotting accumulated annual rainfall of reference stations against accumulated annual rainfall of the evaluation station and inspecting for abrupt changes in slope. Slope changes are considered to be significant if they persist for at least five years. A plot of accumulated rainfall data at site of interest against the accumulated average at the surrounding stations was generally used to check consistency of rainfall flow of data.

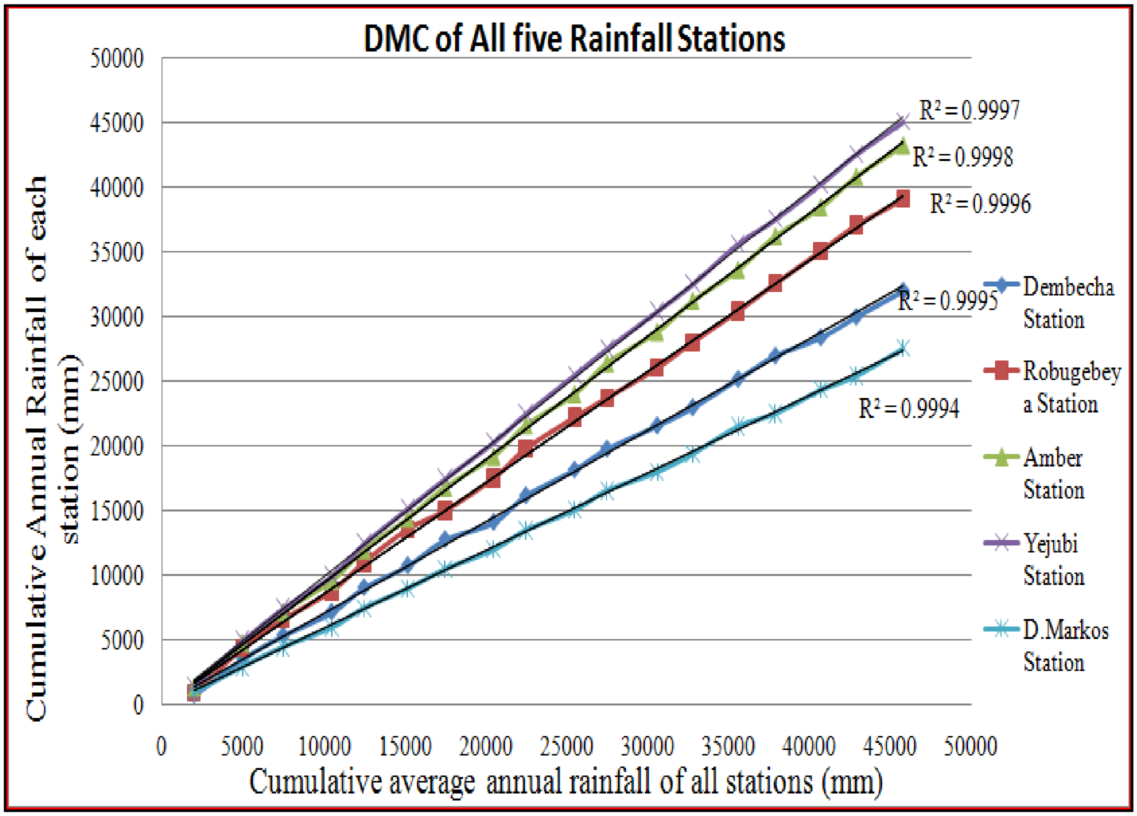

Figure 3. 7. Double Mass Curve of all five rain fall stations

3.4.3. Stream Flow Data

Discharges of Deber Markos station was obtained from Hydrology Department of the Ministry of Water irrigation and electricity which is recorded for twenty years of data. The stream flow data were used to assess water resources potential of the gauged sites for irrigation purpose.

3.4.3.1 Flow Duration Curve Analysis

The flow duration curve shows that in the catchment, there was almost none zero flow, even through the discharge almost reached this state with minimum flow measured in March month. Since the graph slope below the median is relatively mild, it can be stated that base flow contribution seems to be greater, the low flow and maximum flow analysis showed that, a clear trend could be found for neither high flows nor low flows in figure3.8.

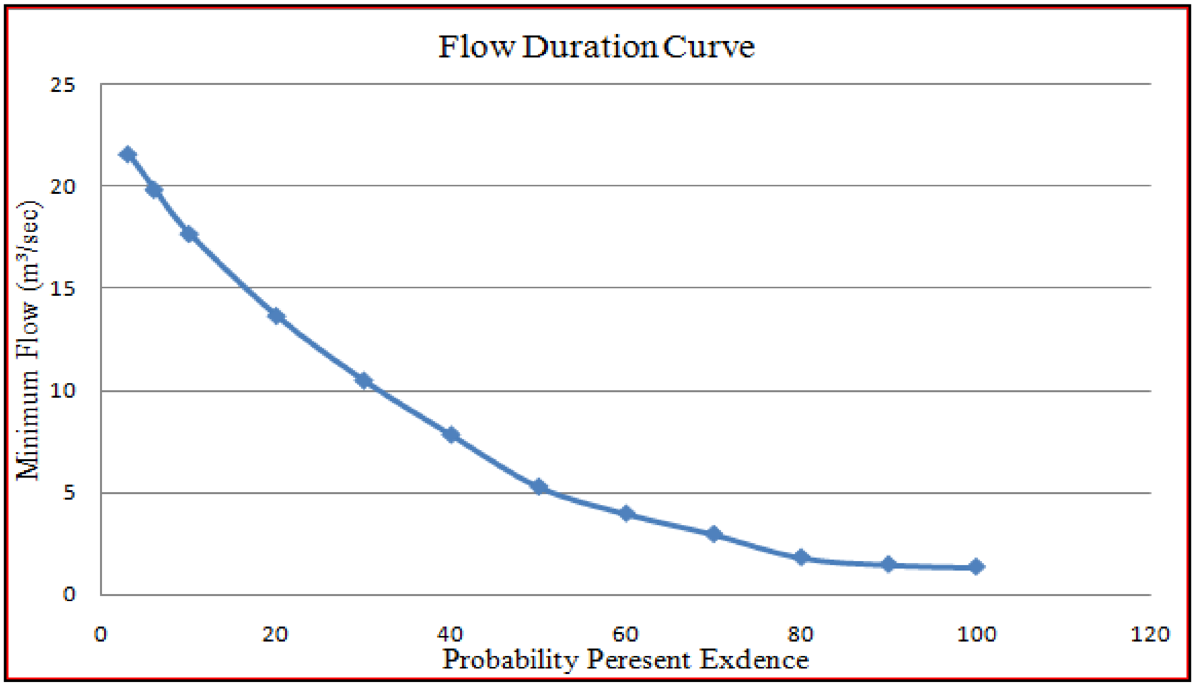

Figure 3. 8. Flow Duration Curve of Chemoga watershed

3.4.4. Watershed Delineation

The first step in creating Arc GIS model input is delineation of the watershed from a digital elevation model (DEM). Before going in hand with spatial input data i.e. the soil map land use/cover map and digital elevation model were projected into the same projection called UTM zone 37N, which is a projection parameter for Ethiopia. The largest spatial level, the watershed, refers to the entire area being represented by the model. To delineate watershed and generate dates using Arc GIS 10.4.1, the following steps were adopted. Load the DEM/importing DEM data. The digital elevation model of sub watershed was projected to UTM coordinate system using Arc Catalog in Arc GIS 10.4.1 the digital elevation model projection setup was done.

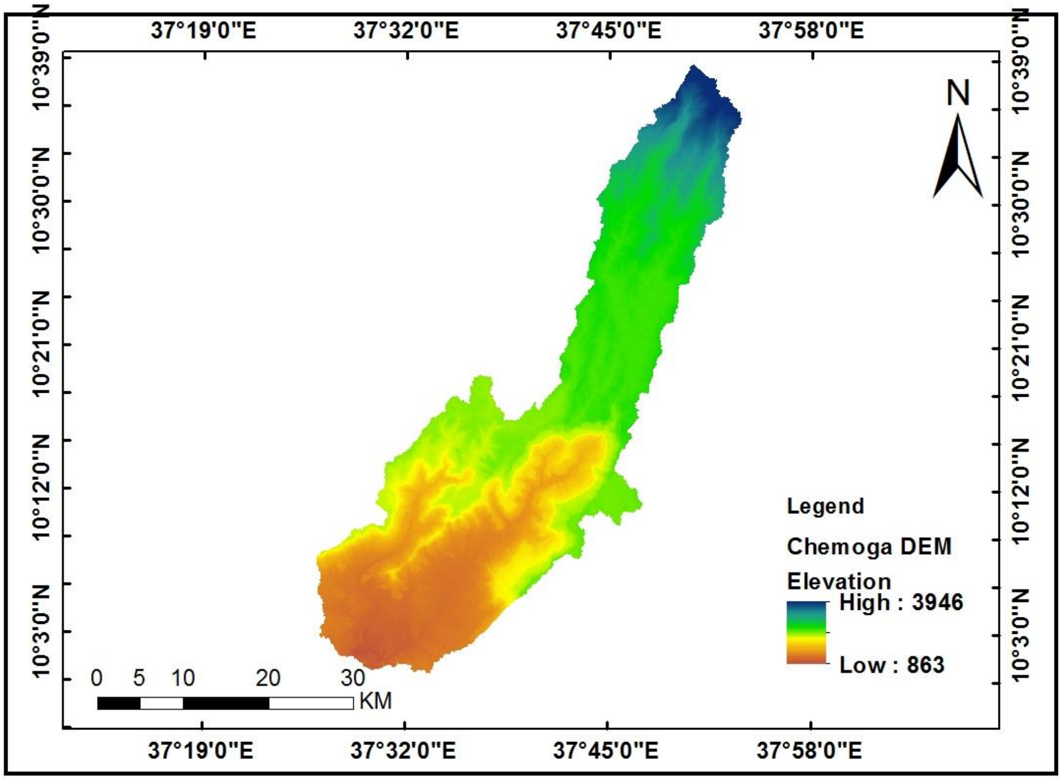

Figure 3. 9. Digital elevation model of the study area

3.5. Identification of Potential Irrigable Sites

Identification of Land suitability for surface irrigation was affected by different factors such as slope, soil, land use/cover, river proximity and road access proximity. All suitability factors were analysis separately and finally suitability were obtained by overlaying these parameter to get land suitability for surface irrigation, each suitability parameter was done as shown below in details.

3.5.1. Slope Suitability Evaluation

Slope is the incline or gradient of a surface and it is commonly expressed in percent. Slope is important for soil formation and management because of its influence on runoff, drainage, erosion and choice of crops. The slope gradient of the land has great influence on the length of the irrigation run, crop adaptability, erosion control practices and irrigation method. With surface irrigation, the following adverse effects occur as the gradient increases, erosion hazard increases, water control becomes more difficult, the practical length of irrigation runs decreases, and crop selection becomes more limited. Slope also order the irrigation method used. These factors intensify as the gradient increases. Steep gradients usually result in lower productivity and higher costs of production. First rating factors were given for each slope gradient of the study area based on literature review and FAO (2007) guidelines using this rating the basin was reclassified in to four classes according to its land qualities and characteristics of the slope for the selection of the land for suitability of surface irrigation.

The classes include highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). This type of land classification is very common and widely used in many researches and also recommended by FAO (1996) guidelines. To derive slope suitability maps of the study area, digital elevation model of the area was clipped from DEM obtained from MoWIE, GIS department, with 20 meter resolution by masking layer of the study area. Then slope maps of the study area were derived using the Spatial Analysis tool in Arc GIS 10.4.1.

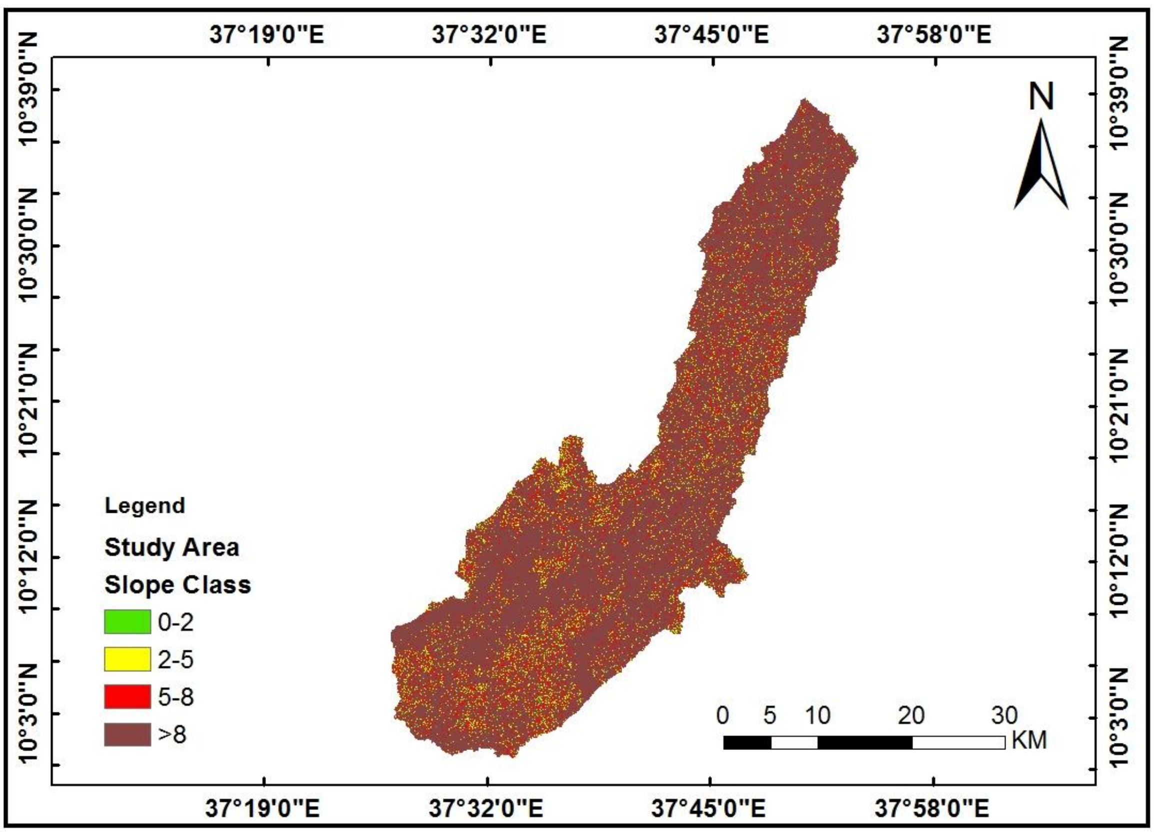

Figure 3. 10. Slope map of the study are

The Slope derived from the DEM was classified based on the classification system of FAO, (1996) using the reclassification tool, which is an attribute generalization technique in Arc GIS. The classified raster data layers were then converted to feature (vector) data layers using the conversion tools in the arc tool box. Further areas of each parcel of land with different slope class were calculated in the attribute table of the slope shape file.

Table 3. 1. Slope range from irrigated land for surface irrigation

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

Source: (FAO, 1996)

3.5.2. Soil Suitability Evaluation

Evaluation of land resource, with particular regard to soil survey is a necessary prerequisite for all agricultural developments, particularly where irrigation is concerned. Soil act as a storehouse of water, supplying plant needs during dry period when rain is inadequate (Meron, 2007). The evaluation of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such properties include drainage, texture, depth, salinity, and alkalinity (Fasina *et al.,* 2008). Even though salinity and alkalinity hazards possibly improved by soil amendments or management practices, they could be considered as limiting factors in evaluating the soils for irrigation (FAO, 1997).

Soil is the most important factor in the land suitability evaluation for surface irrigation development. Accordingly, some soils considered not suitable for surface irrigation could be suitable for sprinkler irrigation or micro-irrigation and selected land utilization types. Several soil characteristics must be evaluated to determine soil suitability for irrigation. To assess soil suitability for irrigation, (FAO, 1997) geomorphology and soil map of Ethiopia was used. The basic physical parameters of the soils in the watershed are depth, drainage and texture classes were used in the suitability analysis. The following soil suitability ratings were used based on FAO guidelines for land evaluation (FAO, 1991) and FAO land and water bulletin

(FAO, 1997). Soil depth, drainage and texture characteristics must be evaluated to determine soil suitability for surface irrigation and the soil vector layer was converted into a raster layer using conversion tools in the Arc tool box of Arc GIS.

Table 3. 2. Soil Suitability Rating Factor

Factors	Factor rating			
Suitability Class	S1	S2	S3	N
Soil Depth	>100	80-100	50-80	<50
Soil Drainage	Well	Moderate	Imperfect	Poor
Soil Texture	C, Si	CL-C, Si-C	SL	S, SC

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

Finally, the rasterized soil map of the study area was reclassified based on soil depth, texture, and soil drainage. By using weighted overlay tool from spatial analysis tool-overlay-weighted overlay of four determinants reclassified raster soil map were performed to determine soil suitability for surface irrigation. Then the new value was reassigned for each soil factor, the new value were given based on common evaluation scale factor rating from 1 to 4 for weighted overlay analysis, 1 represent highly suitable, 2 represent moderately suitable, 3 represent marginal suitable and 4 for not suitable classes.

3.5.2.1. Soil Depth

Soil depth refers to the thickness of the soil materials. Soil depth provides structural support, nutrients, and water for plants. The rooting depth and available soil water for plants require more frequent irrigations. This indicates that soil depth is the major factor that determines plant growth and type of crop suitable within the study area. Plants can extract only the soil water that is in contact with their roots. For most agronomic crops, the root distribution in a deep uniform soil is concentrated near the soil surface (Thomas F, Scherer, 1996). Over the course of a growing season, plants generally extract more water from the upper part of their root zone than from the lower part. The soil depth data was obtained from Ministry of Agriculture. The soil depth of the study area was varied from place to place. It was ranging from less than 50 centimeters to greater than 100 centimeters (Figure3.11). Most crops require deep soil depth than shallow. Soil depth was identified in soil map morphological characteristics of FAO in the study area (FAO, 1988). Due to this classification soil depth range vary from <50 to>100cm. According to soil depth range of soil was classified into four parts<50, 50-80, 80-100, >100 and soil depth of the study area was analysis in Arc GIS 10.4.1 version.

Table 3. 3.Factor rating for suitability of soil depth

Factor	Suitability Class			
	S1	S2	S3	N
Soil Depth	>100	80-100	50-80	<50

Source: (FAO, 1988)

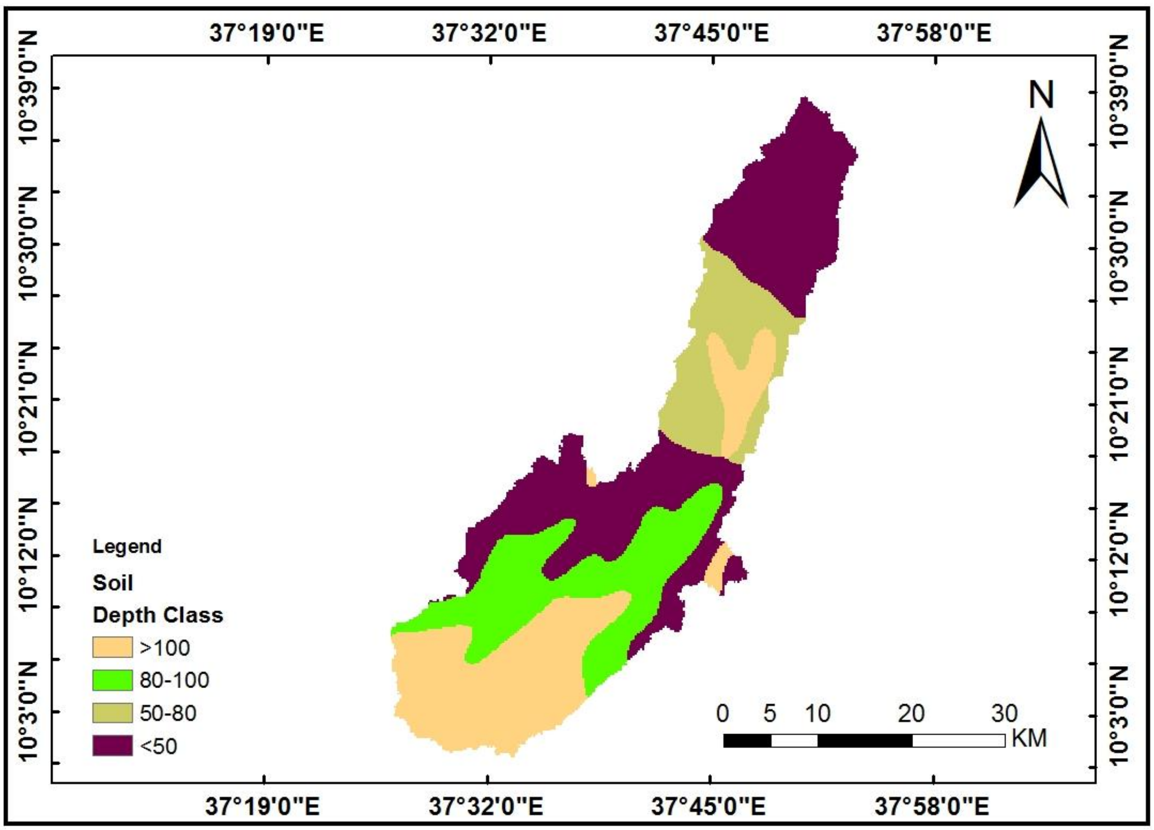

Figure 3. 11. Soil depth map of Chemoga watershed

3.5.2.2. Soil Texture

Soil texture is one important characteristic of the soil. The watershed was dominated by fine textured soils. Texture of a given soil affects infiltration capacity and water retention capacity. Fine textured soils have high water holding capacity and low infiltration rate, whereas coarse textured soils have low water holding capacity and a high infiltration rate. As Soil textural classes of investigating soils in the study area vary from fine to course, i.e. clay to sandy loam based on soil particle sizes, soils are divided in to three major type soil textures. These include clay, silt and sand soils. These major types have mixtures like silt-clay, clay-loam, sandy loam etc. Generally, clay, clay loam and silt clay loam are classified as fine-textured soils while sandy clay loam, loam, and silt loam classified as medium textured soils and the others like sandy soils are classified as coarser-textured soils, the infiltration rate may influence selection of the irrigation method, length of irrigation runs, field size, irrigation development costs, and crop selection. Fine-textured soils will have higher available moisture than coarser-textured soils. However, soils with extremely high clay content may actually have less available water than medium-textured soils. The dominant soil textures of the study area were clay loam and Silt loam, the Figure 3.12 indicates the identified soil textural classes in the area.

Table 3. 4.Soil texture and their classes

Texture	Factor rating	Description
Clay	S1	Highly suitable
clay loam, Silt clay	S2	Moderately Suitable
Silt loam	S3	Marginally Suitable
Sandy clay, Sandy	N	Not Suitable

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

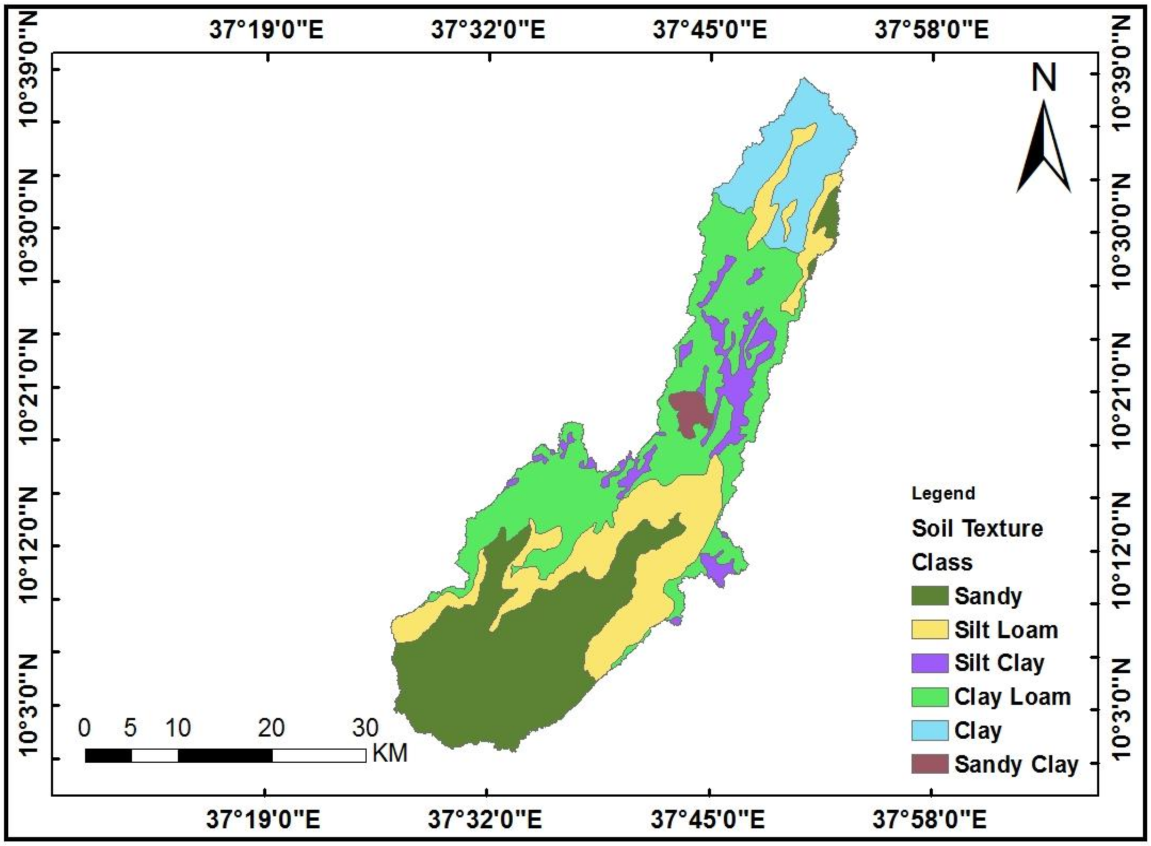

Figure 3. 12. Soil texture map of Chemoga watershed

3.5.2.3. Soil Drainage

Soil drainage is one among very important parameter of evaluation of the area for irrigation and also soil drainage permits normal plant growth. Evaluation of the soil drainage requirement is a critical element in selecting land for irrigation, particularly with diversified upland crop production (FAO, 1997). Soil drainage refers to the length and duration of saturation. Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. Soil permeability of water is one of the major factors that determine crop production. The soil drainage of the basin was dominantly characterized by imperfect and poor drained area. According to FAO (2007) standard guidelines, soil drainage of a specified area can be divided in to four classes. These are well drained, moderately drained, imperfectly drained and poor drained. Therefore, the Chemoga catchment was classified into well drained, moderately drained, imperfectly drained and poorly drained in the figure 3.13 below shows that the identified soil drainage classes in the catchment.

Table 3. 5. Factor rating for suitability of soil drainage

Factor	Factor Rating			
	S1	S2	S3	N
Soil Drainage	Well drained	Moderately drained	Imperfectly drained	Poorly drained

Sources: (FAO, 2007)

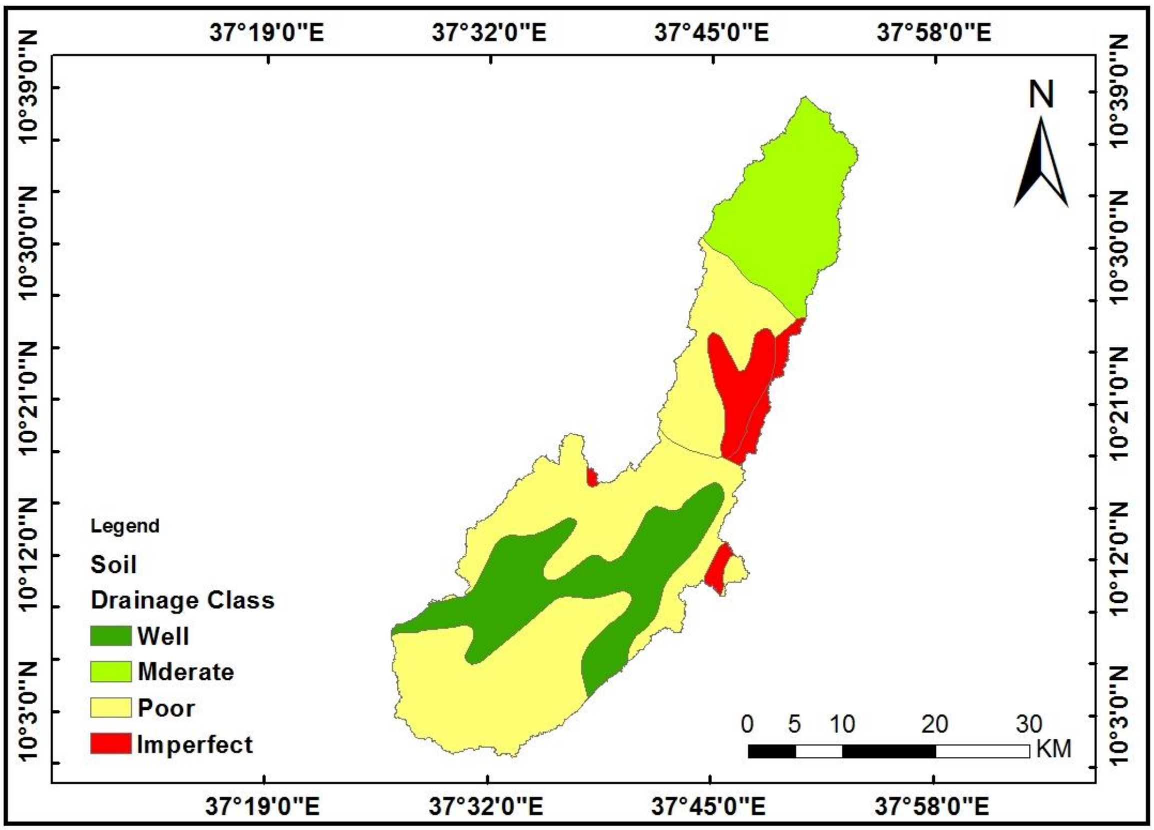

Figure 3. 13. Soil drainage map of Chemoga watershed

3.5.3. Land Use Land Cover Suitability

Land use / land cover is used to evaluate the land for irrigation. Different land use land covers map of the watershed were identified in the study area that clipped from Abbay basin shape file (2018), from Ethiopian Mapping Agency. LULC was taken as one input for the evaluation of land qualities for irrigation for the study area. Vegetation and rock are the most common cover types that require removal for successful irrigation. Rocks may also be a factor in construction of farm distribution and drainage systems and in land grading operations; it may have little effect on the choice of irrigation method for a specific area (FAO, 2007). The type of LULC in the study area included woodland, wetland, sparse forest, perennial crop, open shrub, lava filed, dense forest, closed shrub, closed grass, bare soil and annual crop are the major LULC of the study area (Table 3.6).different suitability classes were given to each land use land cover types based on personal knowledge and review of related journal. Based on the suitability classes, land use land cover map of the catchment was rasterized and used in the evaluation process to identifying suitable areas for surface irrigation system using geographical information system software. In the evaluation process to identifying availability of suitable areas for surface irrigation system the recent i.e. 2018 land use land cover map was used.

Table 3. 6.Land covers evaluation criteria description

Types of LULC	Suitability Class
Cultivated… closed Grass	Highly Suitable (S1)
Woodland…Open, closed shrub land… closed grass,	Moderately Suitable (S2)
Spares forest, Forest….Open shrub, dense forest	Marginally Suitable (S3)
Lava field …… Bare soil	Not suitable (N)

Source: (Esa And Assen, 2017)

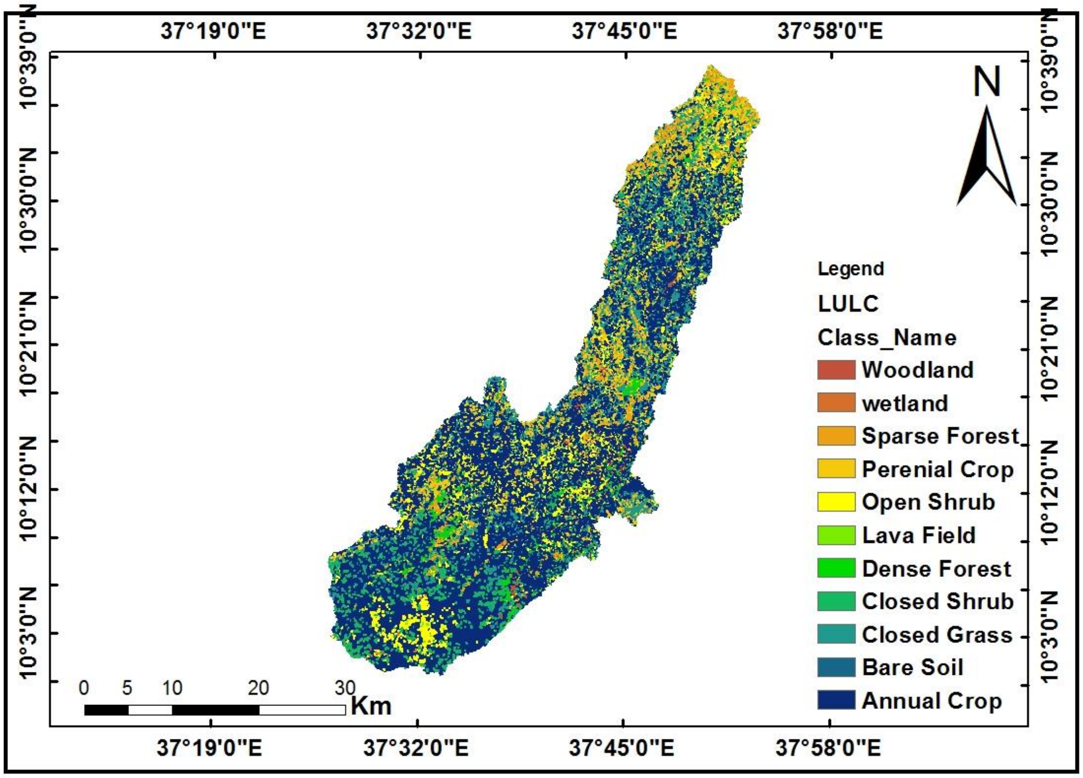

Figure 3. 14. Land use land cover map

3.5.4. Distance from Water Supply (River)

To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from watershed outlets was calculated using DEM of 20 m * 20 m cell size and reclassified in to four classes, Euclidean distances were generated from the watershed rivers and were reclassified as shown in figure 3.15 below, the reclassified distance map was used for weighted overlay analysis along with other factor maps.

Table 3. 7.Description of Distance proximity class

Distance (km)	Factor rating	Description
0.03-5	S1	Highly Suitable
5-10	S2	Moderately Suitable
10-20	S3	Marginally Suitable
>20	N	Not Suitable

Source: (Kassaye *et al.*, 2019)

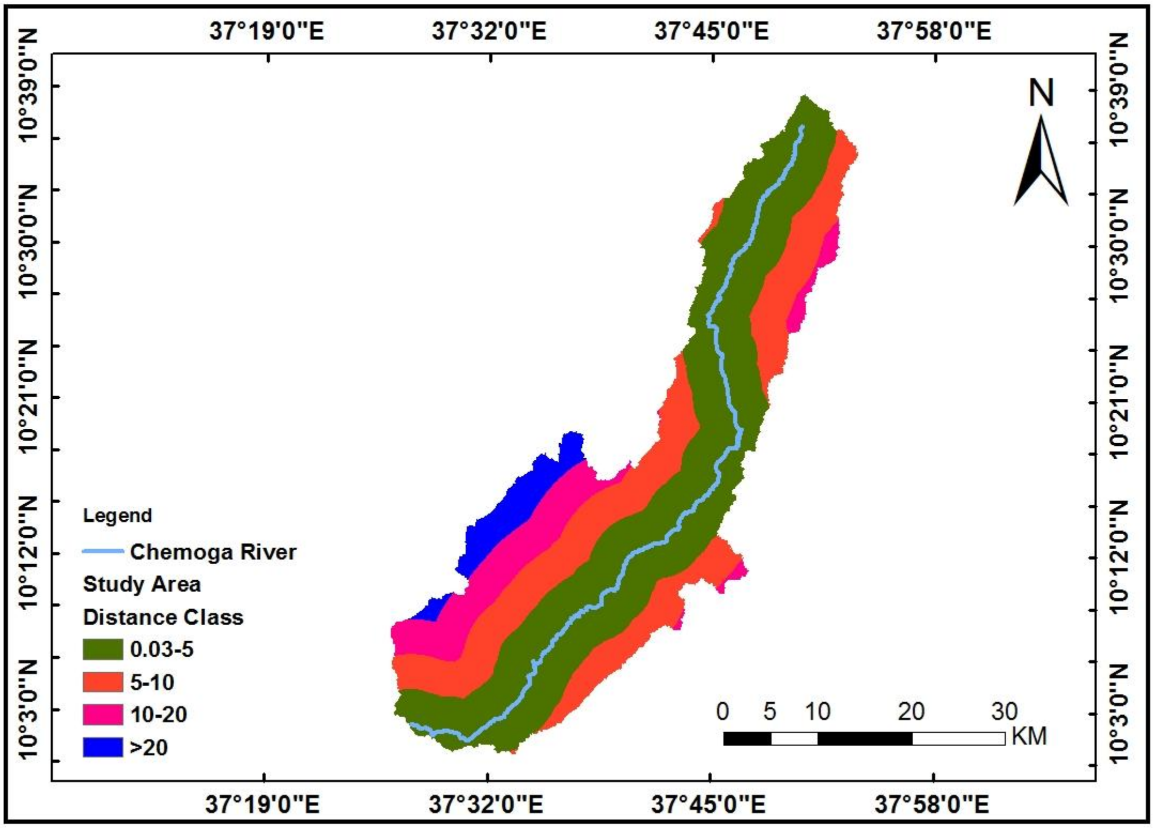

Figure 3. 15. River proximity map

3.5.5. Road Access Proximity

Road proximity is another factor that represents market access. Vector data showing asphalt and gravel road network for the entire country was collected from the Ethiopian Road Authority (Abeyou *et al.*, 2017), (Yalew et al., 2016). A distance map from asphalt and gravel road was calculated using Euclidean distance in kilometer at a required grid as shown in the figure 3.16 below.

Table 3. 8.Description of Distance proximity class

Road Access (km)	Factor Rating	Description
0-3	S1	Highly Suitable
3-6	S2	Moderately Suitable
6-10	S3	Marginally Suitable
>10	N	Not Suitable

Source: (Yalew *et al.*, 2016)

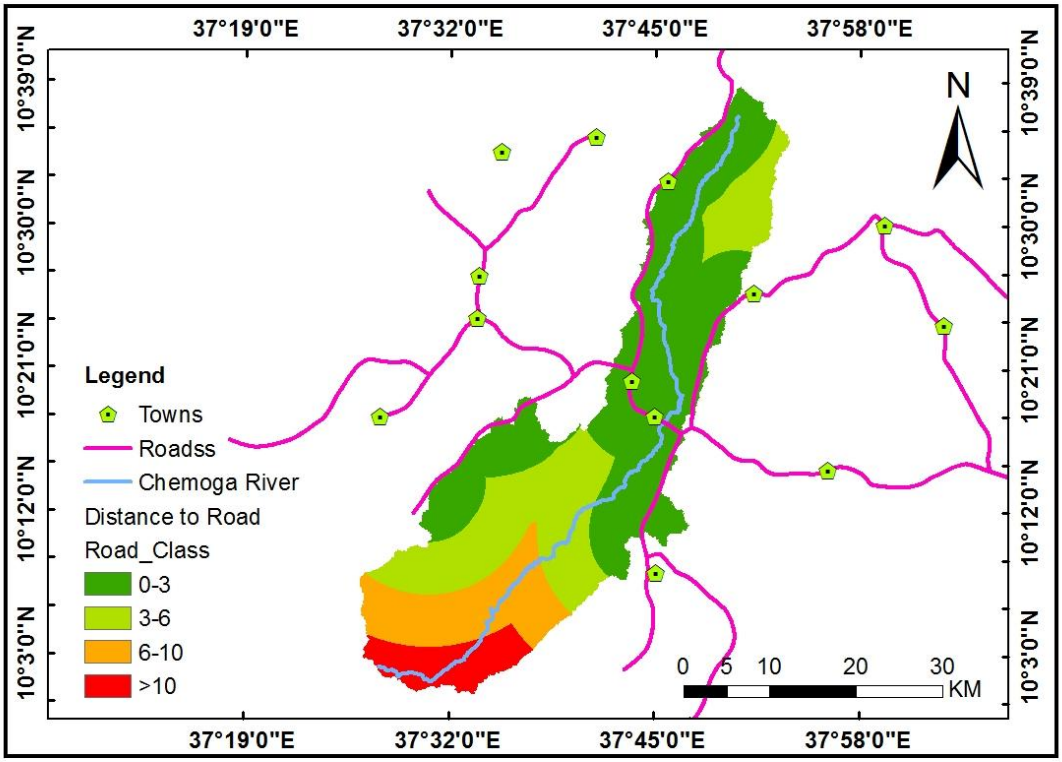

Figure 3. 16. Road proximity map

3.6. Weighing of Irrigation Suitability Factors to find Potential Irrigable Sites

3.6.1. Basic Principles of Multi-Criteria Evaluation

The basic aim of MCE analysis techniques is 'to investigate a number of choice Possibilities in the light of multiple criteria and conflicting objectives' (Voogd, 1983). In doing so it is possible to generate compromise alternatives and rankings of alternatives according to their attractiveness (Janssen and Rietveld, 1990). Given the current emphasis on site location via a process of map overlay, the problem facing decision makers concerns the identification of best compromise sites on the basis of an evaluation of a finite number of choice alternatives by a finite number of attributes, while taking into account conflicting views and objectives.
The term 'choice alternative' refers to any available option in the .choice set, here defined as an individual site. The basic starting point of any MCE analysis is the construction of an evaluation matrix, the elements of which reflect the characteristics of the given set of choice Multi-criteria evaluation and GIS alternatives on the basis of a specific set of criteria. The MCE techniques used for evaluating choice alternatives are many and varied (Voogd, 1983).
Table 3. 9. Scale for pair wise comparisons

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

Source: (Saaty, 1980)

3.6.2. Applying AHP and Assigning Weight of Factors

To determine relative importance or weight of the land suitability factors, AHP method of MCE was used. In order to compute the weights for each land suitability factors, 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). Once the pair wise matrix is made, Saaty‟s method of Eigenvectors or relative weights is calculated.AHP identifies and takes into account the inconsistencies of the decision makers which are one of the strength (Saaty, 2008) .The pair-wise comparisons of various criteria were organized into a square matrix. The diagonal elements of the matrix were 1.

The principal Eigen value and the corresponding normalized right eigenvector of the comparison matrix gave the relative importance of the factor being compared. The elements of the normalized eigenvector were weighted with respect to the factor and rated with respect to the alternatives (Bhushan and Rai, 2004).When performing pair wise comparison, some inconsistencies may typically arise. The AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision maker. In the AHP, the pair wise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (CR) is less than 10% (0.1) (Triantaphyllou and Mann, 1995). To calculate CR, the consistency index (CI) is estimated by multiplying judgment matrix by the approximated eigenvector. Each component of the resulting matrix is then divided by the corresponding approximated eigenvector. This yields an approximation of the maximum Eigen value (λ max). Then, the CI value is calculated by using the formula:

$$CI = \frac{\lambda max - n}{n-1} \qquad 3.1$$

Finally, the CR is obtained by dividing the CI value by the Random Index (RI) generated by Prof. Saaty as show table below (Saaty, 2008).

Table 3. 10. Random index Values (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0.00	0.00	0.58	0.90	1.12	1.24	**1.32**	1.41	1.45	1.49	1.51	1.48	1.56

3.6.3. Undertaking the Multi-Criteria Evaluation

GIS and MCE techniques are globally recognized for its outstanding support in map overlay process for any form of land suitability analysis (Carver, 1991) and (Malczewski, 1999). The primary issue in MCE is concerned with how to combine the information from several criteria to form a single index of evaluation (Eastman, 2001). Prioritization and selection of criteria's influence was executed by reviewing important literatures related to this study and supplemented by opinion of experts in the field and other stake holders based on their preliminary knowledge and fair judgment (Eastman, 2006). The basic advantages of using MCE techniques are related to possibilities to evaluate all factors at different scales. Moreover, it enables the researchers to merge information gathered from different criteria. Decision theory is concerned with the logic by which one arrives at a choice between alternatives. What those alternatives are varies from problem to problem.

They might be alternative actions, alternative hypotheses about a phenomenon, alternative objects to include in a set. The primary issue in multi-criteria evaluation is concerned with how to combine the information from several criteria to form a single index of evaluation. Weighted Linear Combination (WLC) is most common technique used to create suitability map. Weight is used to develop a set of relative weights for a group of factors in a multi-criteria evaluation. The weights are developed by providing a series of pair wise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. These pair wise comparisons are then analyzed to produce a set of weights that sum to 1. The factors and their resulting weights can be used as input for the MCE module for weighted linear combination. The procedure by which the weights are produced follows the logic developed by T. Saaty under the Analytical Hierarchy Process (AHP) with a weighted linear combination; applying a weight to each followed by a summation of the results to yield a suitability map, i.e., combines factors (Ronald Eastman J., 2001). Environment, raster maps were overlaid using the weighted overlay analysis and an agricultural land suitability map was generated. The weights of the criteria were multiplied with the score of the sub criteria this multiplication was performed in raster format on the map using raster calculator in GIS operation. The result was then reclassified as four classes of suitability: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N), according to the following formula (Khan, 2014).

$S=\sum W_iX_j$……………………………………………………………...…………3.2

Where: S = suitability

Wi = weight of factor i

Xj = criterion score of factor i

The equation was also used in this paper to develop the suitability map of land for surface irrigation potential in the study area. In order to develop suitability map there are procedures to be followed when using weighted linear combination techniques.

3.7. Evaluation of Irrigation Water required for the estimated Irrigable Area

Irrigation water requirement of the potentially irrigable command area was computed using the CROPWAT 8.0 software. Crop types which are commonly grown in the study area were selected for collecting crop data like length of growth stages, crop coefficient (Kc) and root depth at different growth stages. The respective crop coefficients for these crops were selected based on FAO (1998). Climate data such as temperature (maximum and minimum), rainfall, wind speed, sunshine hour, and relative humidity were used as data input in CROPWAT 8 software. In addition to climate data inputs the software were used crop and soil data to compute crop water requirements. According to Allen *et al.*, (1998) the crop water requirement (CWR) is calculated as a product of the potential Evapo transpiration (ETo) and the crop coefficient (Kc).

$ETc=Kc*ETo$………..……………………………………………………………………3.3

Where: ETc is crop water requirement for the growing period, Kc is crop coefficient for crop, ETo is Reference crop Evapo-transpiration.

3.7.1. Component of Irrigation Water Requirement

All the data inputs were entered to, CROPWAT 8 software has been carried out standard calculations for reference crop evapo-transpiration, effective rain fall, crop water requirements and irrigation water requirements of the selected crops automatically, and more specifically the design and management of irrigation schemes.

3.7.2. Reference crop Evapo-Transpiration (ETo)

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 (FAO, 2006). ETo is the rate of evaporation, it is a climatic parameter and can be computed from meteorological data (temperature, humidity, wind speed, sunshine hour). There are different formulas to calculate ETo, but Penman-Monteith method is considered to be the most accurate method for estimating ETo, though it requires relatively more data than others. The method is considered to offer the best results with minimum possible error in relation to a living grass reference. The formula used in penman method is.

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \frac{\gamma 900}{\mathrm{T}+27.3}\mathrm{U2}(\mathrm{es} - \mathrm{ea})}{\Delta + \gamma(1 + 0.34\mathrm{U2})} \quad \ldots\ldots 3.4$$

Where: ETo =reference Evapo-transpiration [mm/day]

Rn=Net radiation at the crop surface [MJ/day m^2]

G= Soil heat flux density [MJ/day m^2]

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

u2= wind speed at 2m height [m/s]

es= saturation vapor pressure [k Pa]

ea =actual vapor pressure [k Pa]

es –ea =saturation vapor pressure deficit [k Pa]

Δ=Slope vapor pressure curve [k Pa/ ^{o} C]

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

The equation uses standard climatologically records of solar radiation (sunshine), air temperature, humidity and wind speed for daily, weekly or monthly calculations. After determining the reference potential evapo-transpiration by penman method, the next step will be calculating crop water requirement. Evapo-transpiration from disease-free well fertilized crops, grown in large fields under optimum soil water conditions and achieving full production under the given climatic conditions. The values of ETc and CWR (Crop Water Requirements) are identical, where by ETc refers to the amount of water lost through Evapo-transpiration and CWR refers to the amount of water that is needed to compensate for the loss. ETc can be calculated from climatic data by directly integrating the effect of crop characteristics into ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc) are used to relate ETc to ETo, ETc will be calculated using FAO CropWat version 8. Kc values presents relationship between reference ETo and crop Evapo-transpiration. The values of kc are varying with the crop, its stage of growth, growing season and the prevailing weather condition.

3.7.3. Irrigation Water Requirement (IWR)

Using the climatic, rainfall, crop and soil data inputs crop water requirement and irrigation water requirement of each crop was calculated by the following expressions in CROPWAT8.0 software.

IWR = ETc-Peff……………………………………………………………………..…… 3.5

Where: IWR = Irrigation water requirement (mm)

Peff = effective rainfall (mm)

ETc = crop evapo-transpiration for a given crop (mm/day)

3.7.4. Effective Rainfall and Gross Irrigation Water Requirement

Effective rain fall (Peff) is the portion of a rain, falling during the growing period of the crop which is available to meet the consumptive water need or the evapo-transpiration requirement of the crop. It does not include precipitation loss due to deep percolation below the root zone. According to FAO based on analysis carried out for different arid and sub-humid climates and is more suitable for Ethiopia (FAO, 2002). Effective rainfall (Peff) was calculated on a daily soil balance based on the empirically determined formula from FAO CROPWAT model.

Pef = P-c x p…………………………………………………………………….……… 3.6

Where: Peff = effective rainfall, P = daily rainfall (mm), C= constant equal to 0.2

The gross irrigation water requirement (GIWR) was computed according to FAO (2001) of crops at the identified potential irrigable sites were estimated by considering application efficiency of 50% for surface irrigation as follows.

$$GIWR = A\left(\frac{NIWR}{\eta}\right) \quad \text{............} 3.7$$

Where: GIWR = Gross irrigation water requirement (m3/month)

NIWR = Net irrigation water requirement A crop - The potential irrigable area to be cultivated with selected crop (ha) η -Irrigation efficiency (%). Finally the effective irrigable area can be estimated in each month using the following equation.

$$Aeff = \frac{Ac*Eff*Min\ Flow}{GIWR} \quad \text{............} 3.8$$

Where Aeff = effective irrigable area, Ac = Area covered by crop, Eff= irrigation efficiency and GIWR= gross irrigation water requirements (m^3/s)

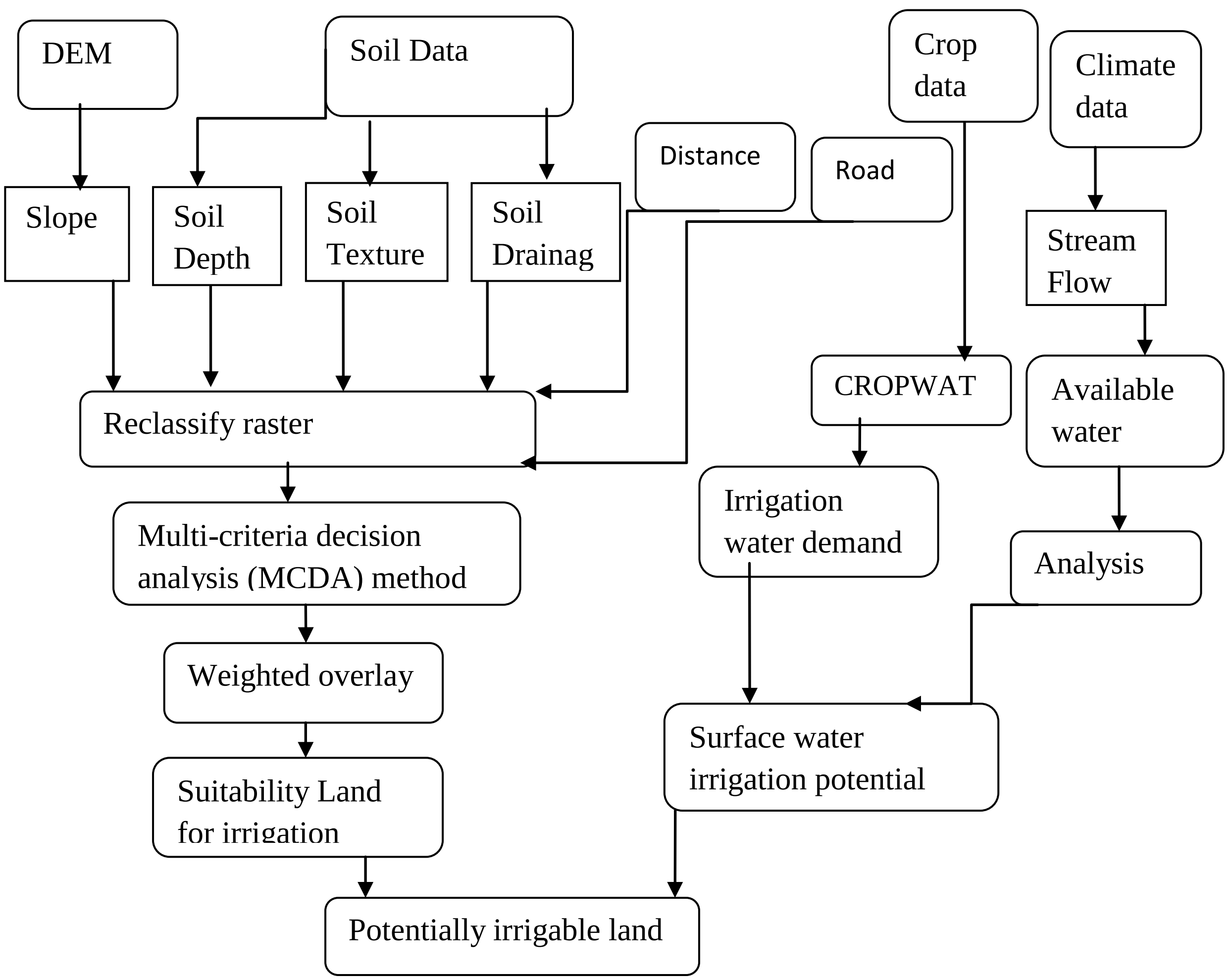

Figure 3. 17. Conceptual frame work of the study

4. RESULTS AND DISCUSSIONS

4.1. Land Suitability Evaluation for Irrigation

Land evaluation is a process for predicting the land suitability for a specific land use type or irrigation in a given area. Land evaluation provides a rational basis for land use planning The Physical properties of soil and the river proximity factors of the land as well as road access proximity are the major factors that determine irrigation potential of a given land (FAO, 1987). However the factors, which were evaluated to analyze suitability of the land for surface irrigation under the study area, The Irrigable area which is suitable for surface irrigation. Land suitability for surface irrigation was affected by different factors such as slope, soil depth, soil drainage, soil texture, river proximity, road access and land use/cover. All suitability factors were analysis separately and finally suitability were obtained by overlaying these parameter to get land suitability for surface irrigation. Each suitability parameter was done as shown below in details.

4.1.1. Slope Suitability

Slope map of the study area was reclassified into four suitability classes. The classification was referenced on the suitability of the slope for the development of surface irrigation method. The classes were highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). Slope suitability map of the sub basin and area coverage of each suitability class were described in the Figure4.1 and Table4.1 below.

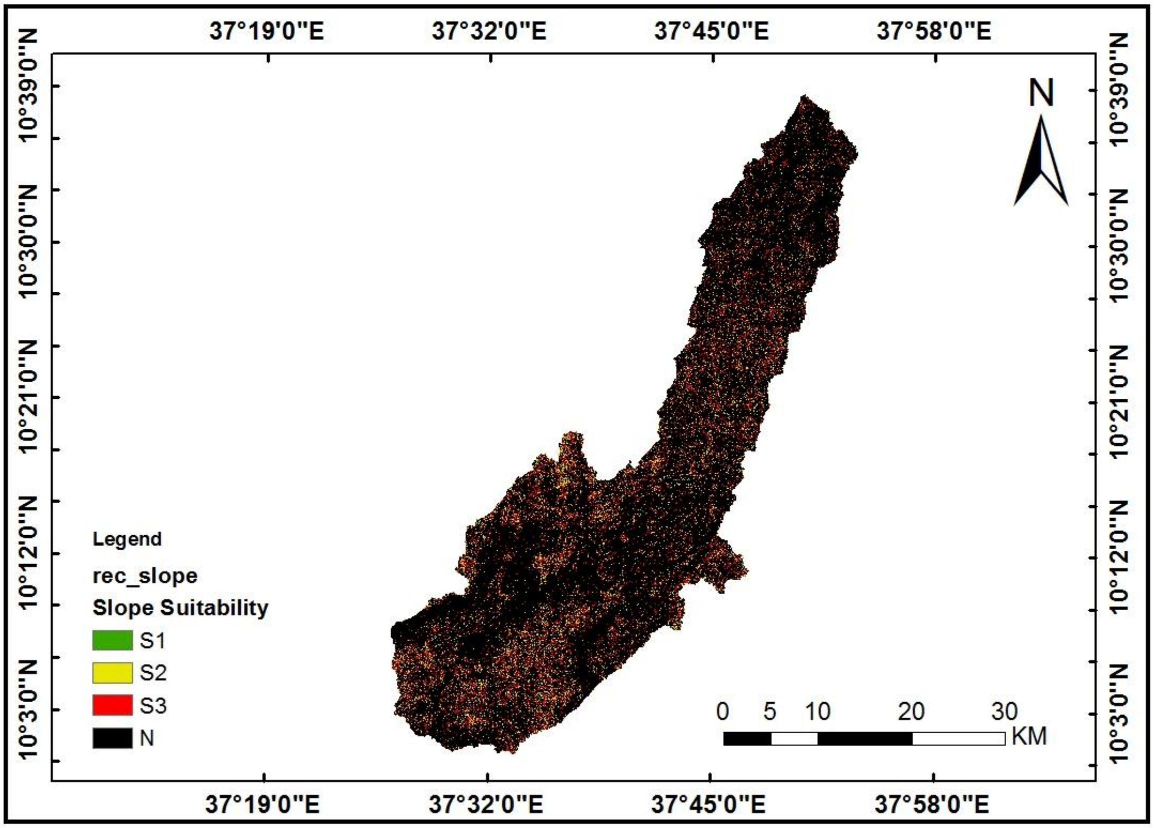

Figure 4. 1. Slope suitability map of Chemoga watershed

The area coverage of suitability classes are presented in (Table 4.1) below, indicated that 2.98% (3460.15ha) is highly suitable, 14.89% (17287.63ha) is moderately suitable, 24.80% (28792.82ha) is marginally suitable and 57.33% (66559.40ha) is marginally not suitable for surface irrigation systems due to high slope range.

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

Slope range (%)	Factor rating	Definition	Area (ha)	% of total area
0-2	S1	Highly Suitability	3460.15	2.98
2-5	S2	Moderately Suitable	17287.63	14.89
5-8	S3	Marginally Suitable	28792.82	24.80
>8	N	Not Suitable	66559.40	57.33

As indicated in the Table 4.1 above, around 42.67 % (49540.60 ha) of the land within the range of highly suitable to marginally suitable for surface irrigation in respect of slope, however, more than 57.33 % (66559.40 ha) of the total area not suitable for surface irrigation but the land of slope in these case may be more suitable for sprinkler and drip irrigation methods.

4.1.2. Soil Suitability Evaluation

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

4.1.2.1. Soil Depth Suitability

Based on soil depth requirement of most common crops, soil depth of the study area was divided in to suitability classes to select surface irrigation potential. Rating factor was given for the value of soil depth and weighting them to evaluate the suitability of surface (gravity) irrigation potential of the study area and rating factor was adopted from FAO guidelines Table 4.2 below.

Table 4. 2.Soil depth and their suitability

Soil depth(cm)	Rating factor	Definition	Area (ha)	% Area
>100	S1	Highly Suitable	18575.33	16.00
80-100	S2	Moderately Suitable	24506.46	21.11
50-80	S3	Marginally Suitable	37130.18	31.98
<50	N	Not Suitable	35899.29	30.92

Based on the given weighting factors for each soil depth of the study area, soil depth suitability map of the study area for surface irrigation potential was developed Figure 4.2 below.

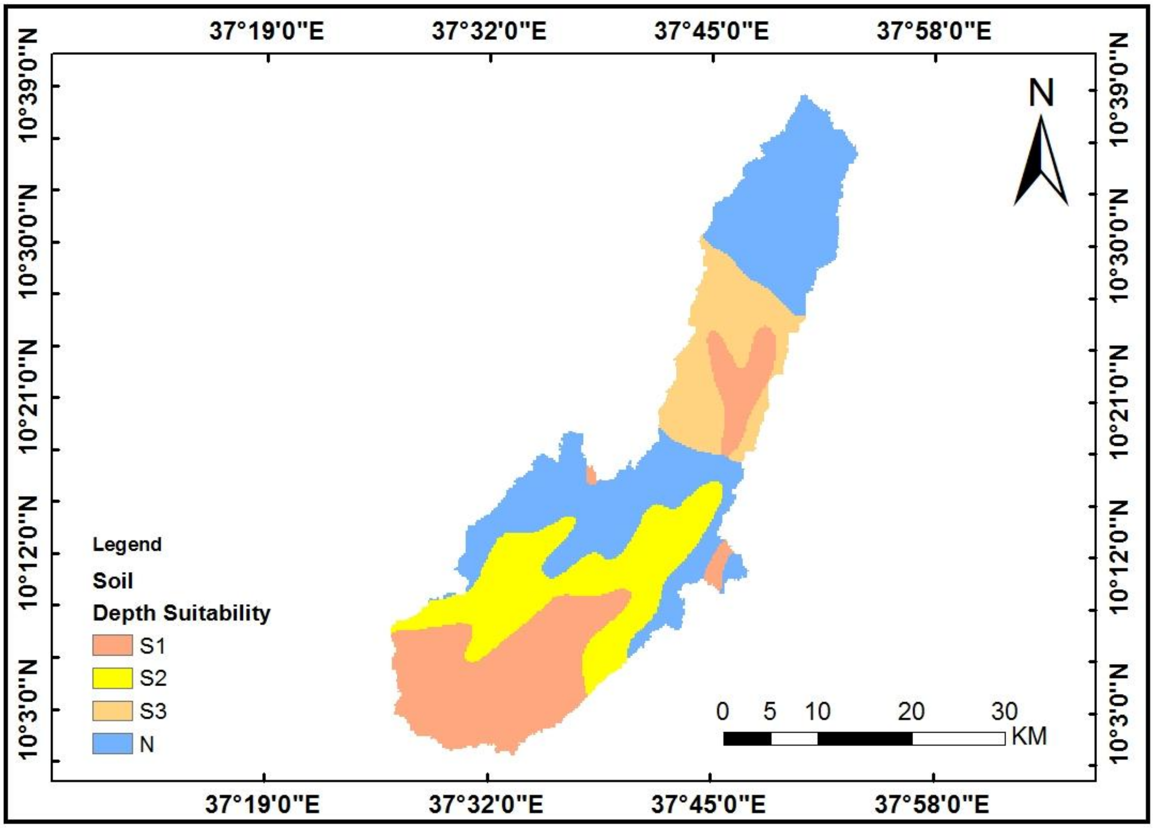

Figure 4. 2. Soil depth suitability map

The soil depth suitability of the study area for the development of surface irrigation system show in (Figure 4.2) and area coverage of suitability classes are presented in Table 4.2 above, indicated that 16.00% (18575.33 ha) is greater than 100 cm and highly suitable, 21.11% (24506.46 ha) is between 80-100 cm and moderately suitable, 31.98 % (37130.18 ha) is 50-80 cm and marginally suitable and 30.92 % (35899.29 ha) is less than 50 cm are marginally not suitable for surface irrigation systems. Soil having soil depth between 50-80, 80-100 and greater than 100 cm was classified as suitable; including S1, S2 and S3 for irrigation and covered 69.09% part of the study area and soil depth less than 50 cm was classified as N Marginally not suitable class. Hence, the majority of the study area is highly suitable to marginally suitable for surface irrigation in terms of soil depth suitability. Due to suitable range of soil depth currently 80211.97 ha of land are moderately suitable for surface irrigation purpose.

4.1.2.2. Soil Texture

Soil texture suitability for irrigation was evaluated according to FAO (2007) guide line for land evaluation. Texture of a given soil affects infiltration capacity and water retention capacity. The results of texture class analysis shows that the area was covered by fine (clay, silt clay, silt loam, sandy, sandy clay and clay loam) textured soils. Fine textured soils have high water holding capacity and low infiltration rate, the map below shows that the geographic distribution of the identified soil textural classes and their suitability in the catchment on Figure 4.3 below.

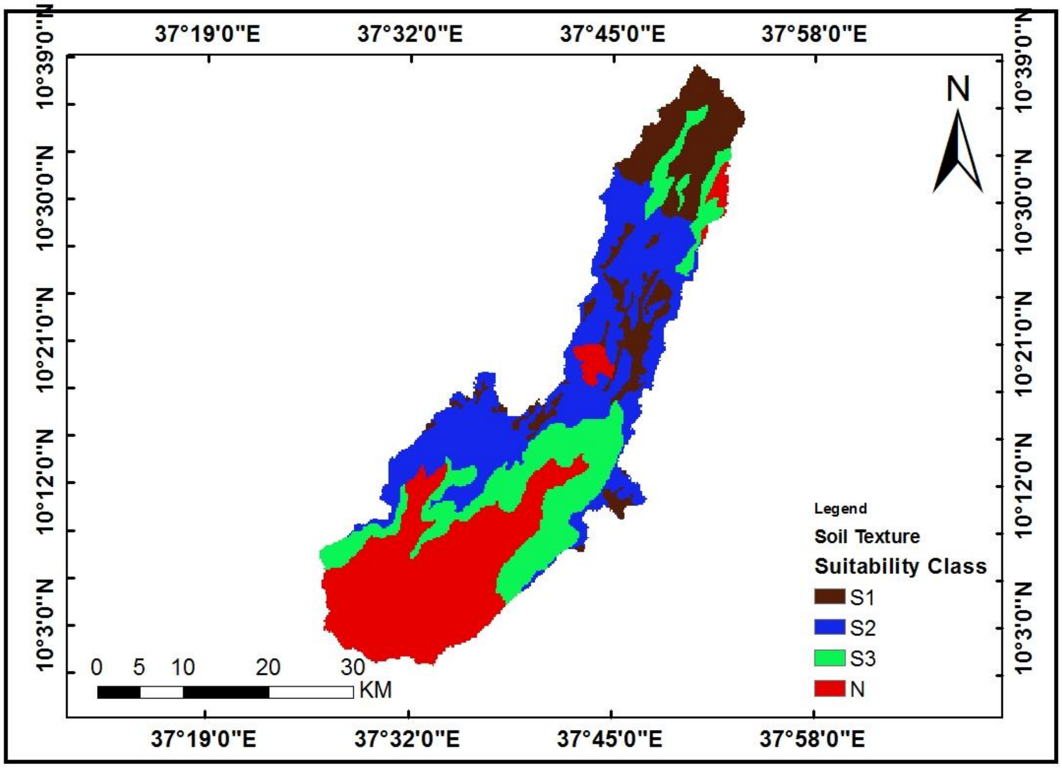

Figure 4. 3. Soil texture suitability map

Table 4. 3. Soil texture and their suitability

Soil texture	Rating factor	Definition	Area (ha)	% Area
Clay	S1	Highly Suitable	25947.97	22.35
silt clay, clay loam	S2	Moderately Suitable	34457.79	29.67
Silt loam	S3	Marginally Suitable	18575.33	16.00
Sandy, sandy clay	N	Not Suitable	37130.18	31.98

As shown above in the Table 4.3 above around 22.35 % of soils in the area were under highly suitable in respect to the textural classes. Around 29.67 % of the area's soil was categorized under moderately, 16.00 % to Marginally Suitable class and 31.98 % of the area was under not-suitable class for surface irrigation development in the study area catchment in terms of soil texture suitability.

4.1.2.3. Soil Drainage Suitability

According to FAO (2007) evaluation techniques used for evaluation of permeability of soil properties of the land, soil drainage area can be classified as well drained, moderately drained, imperfectly drained, poorly drained and very poorly drained. Therefore the soil drainage properties of the study area was classified in to well, moderately and imperfectly and poorly drained in the Table 4.4 and Figure 4.4 below.

Table 4. 4.Result of drainage suitability on the study area

Soil drainage	Rating factor	Definition	Area (ha)	% Area
Well drained	S1	Highly Suitable	21284.07	18.33
Moderately drained	S2	Moderately Suitable	23880.90	20.56
Imperfectly drained	S3	Marginally Suitable	25548.81	22.01
Poorly drained	N	Not Suitable	45296.64	39.02

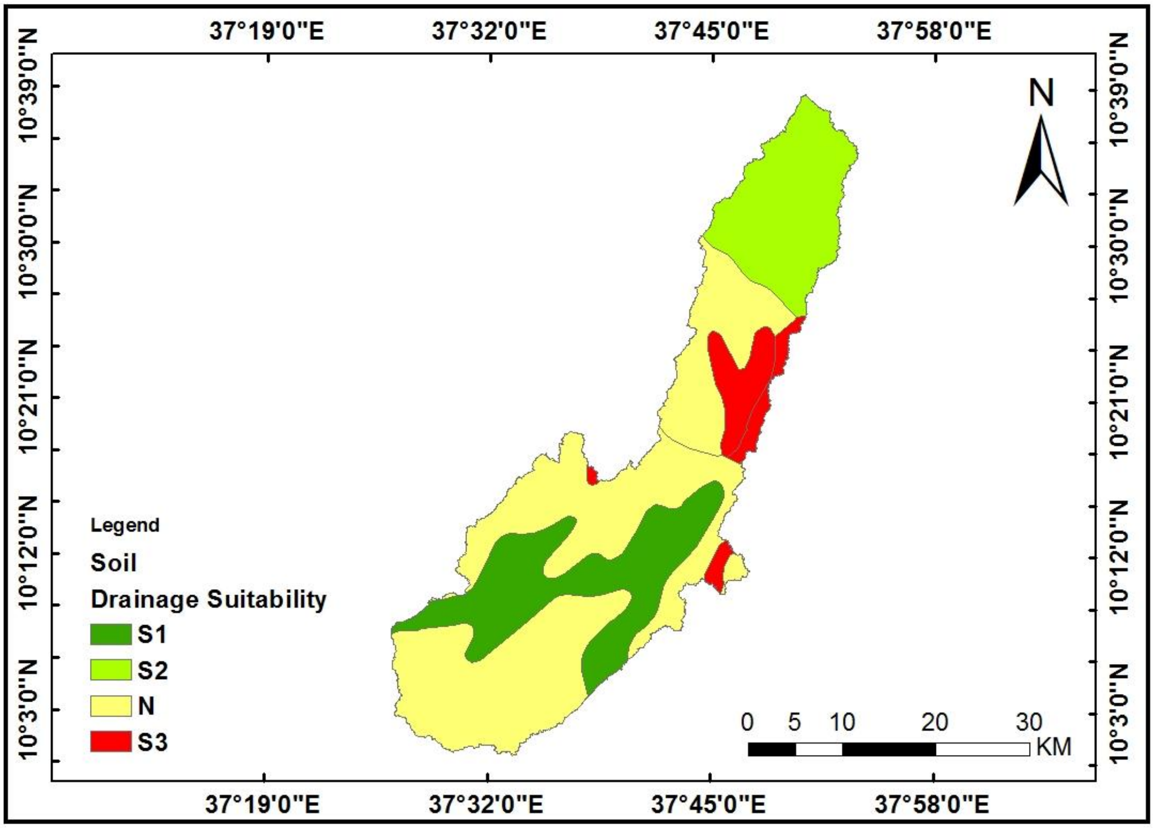

Figure 4. 4. Soil drainage suitability map

According to this classification, The results in table above revealed that 18.33% (21284.07 ha) and 20.56 % (23880.90 ha) of the total area of the Chemoga watershed had been highly suitable and Moderately suitable for surface irrigation system with respect to soil drainage respectively, whereas the remaining 22.01 % (25548.81 ha) and 39.02 % (45296.64 ha) classes in the study area were classified as marginally suitable and not suitable for surface irrigation.

4.1.2.4. Overall Soil Suitability

The three physical parameters of a soil; which is depth, textural and drainage classes were analyzed by implementing Arc GIS. In the suitability analysis of each parameter, soil depth has three suitability classes (highly suitable, moderately suitable and not suitable classes) for use of surface irrigation system. The second suitability parameter are the soil textural class that has three classes (highly suitable, moderately suitable and not suitable classes) and soil drainage class also have three classes in the watershed (highly suitable moderately suitable and not suitable classes). To identify potentially suitable soils for the intended irrigation system, the three soil suitability parameters were used in this study (depth, texture and drainage) were evaluated on Arc GIS 10.1. In the suitability evaluation of a percent influence for weighted overlay analysis were taken 1 by 5 by 1 (a scale for overlay analysis). The 1, 2, 3, 4 and 5 represents highly suitable class, moderately suitable class, marginally suitable class and unsuitable classes respectively and the % of influence were given to soil in an equal manner in the weighted overlay analysis on Arc GIS 10.1. The next map shows the procedure of weighted overlay analysis based on depth, drainage and texture of soil physical properties.

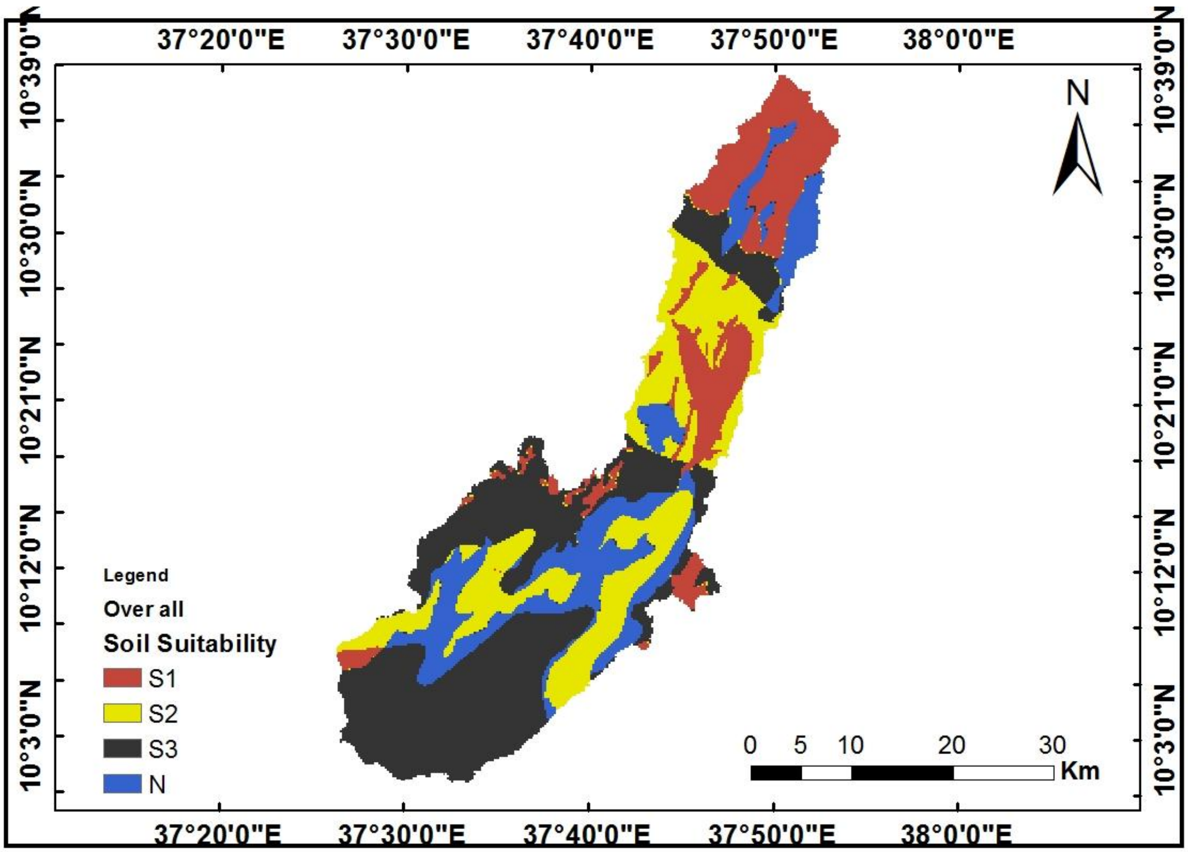

Figure4. 5. Weighted Overlay of Soil Suitability

The soil suitability classes indicate 18.40 % of the area of the watershed were in the range of highly suitable, about 23.51 % of the watershed were categorized under moderately suitable, 39.49 % also categorized under marginally suitable and the rest 18.60 % were categorized as not suitable classes with respect to combined effect of soil texture, depth and drainage class and the area coverage of the suitability rate are summarized in the next Table 4.9.

Table 4. 5 Soil Suitability Class of the Study Area

Rating factor	Definition	Area (ha)	Area %
S1	Highly Suitable	212.02	18.40
S2	Moderately Suitable	271.04	23.51
S3	Marginally Suitable	455.25	39.49
N	Not Suitable	214.38	18.6

4.1.3. Land Use/ Land 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. The land use type was reclassified in to four suitability classes, highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and marginally not suitable (N) Table 4.5.

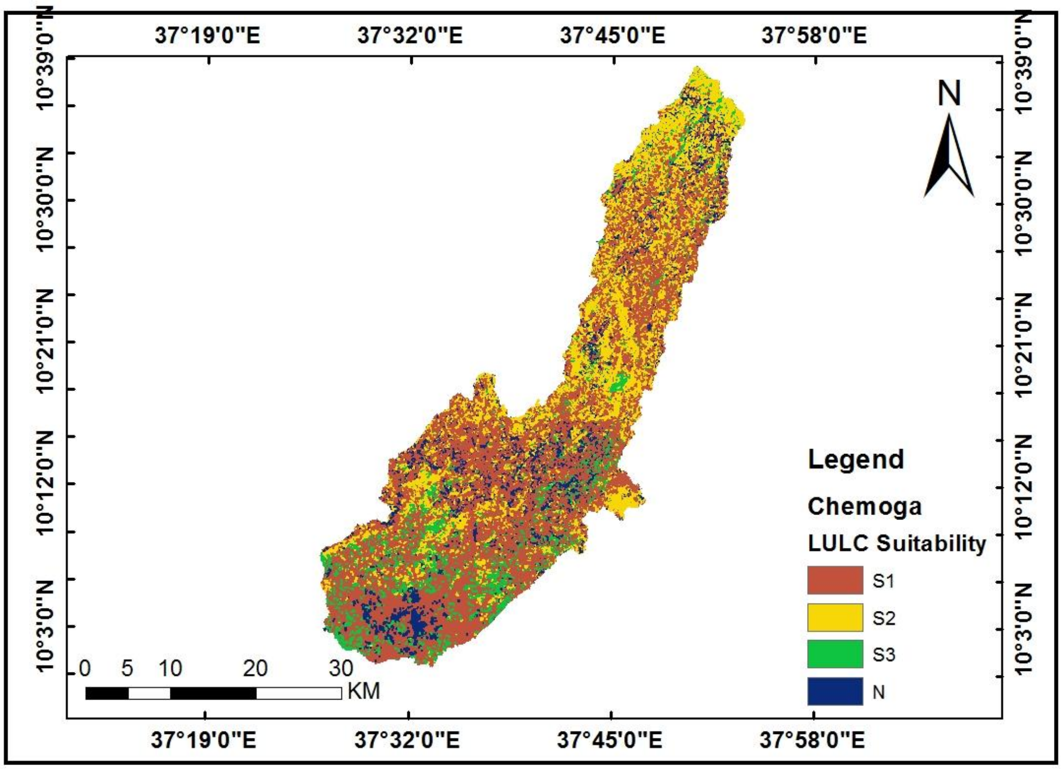

Figure4. 6. Reclassified land use land cover suitability

The rasterized land use/cover classifications were divided into four parts such as, highly suitable, moderately suitable, marginal suitable and not suitable. Based on these classification land use/cove map of the study area is generated and given above in Figure 4.5. According to land use/cover classification, most of the study area were highly suitable covered by Cultivated land which accounts 60097.87ha (51.76%) shown in the table below.

Table 4. 6.Land use land cover suitability

LULC	Rating factor	Definition	Area (ha)	% Area
Cultivated land	S1	Highly Suitable	60097.87	51.76
Open shrub	S2	Moderately Suitable	32765.72	28.22
Dense forest	S3	Marginally Suitable	12418.39	10.70
Bar land, Lava field	N	Not Suitable	10822.88	09.32

The land use land covers suitability class. And the rest of the area is moderately suitable and marginal suitable which covers 32765.72 ha (28.22 %) and 12418.39 ha (10.70) is covered by open shrub and dense forest respectively and finally bare land and lava land are not suitable for surface irrigation which covers from the total area 10822.88 ha (09.32 %) summarized in tabulated table above.

4.1.4. Distance from Water Supply (River) Suitability

To identify irrigable land close to the water supply (river), straight-line (Euclidean) distance from watershed outlets was calculated using DEM of 20m*20m cell size. Based on the main factors that were considered in distance suitability classification were; power and capacity of the pumping engine, cost for the high power pumping engines and cost for construction and maintenance of canals and water lost from canal specially for small scale and medium scale irrigation, the command area was reclassified into four suitability class; highly suitable (S1) covers 44690.82ha (38.49%), moderately suitable (S2) 35224.36ha (30.34%), marginally suitable (S3) 24235.26ha (20.87%) and not suitable (N) 11961.38ha (10.30%). Because of these factors irrigation suitability is decreased as distance increase away from the water source river and reclassified as shown in Figure 4.6 below.

Table 4. 7.Distance proximity suitability with percentage area coverage

River proximity (km)	Rating factor	Definition	Area (ha)	Area %
0.03-5	S1	Highly Suitable	44690.82	38.49
5-10	S2	Moderately Suitable	35224.36	30.34
10-20	S3	Marginally Suitable	24235.26	20.87
>20	N	Not Suitable	11961.38	10.30

By considering the delineated watershed, command areas which were closest to the water supply (Chemoga River) were classified as high suitable land for irrigation. The areas far away from the water source were classified as not suitable especially for small scale and traditional irrigation. The final reclassified result of the distance suitability analysis of the irrigable land was used for weighting overlay for further analysis together with other factors.

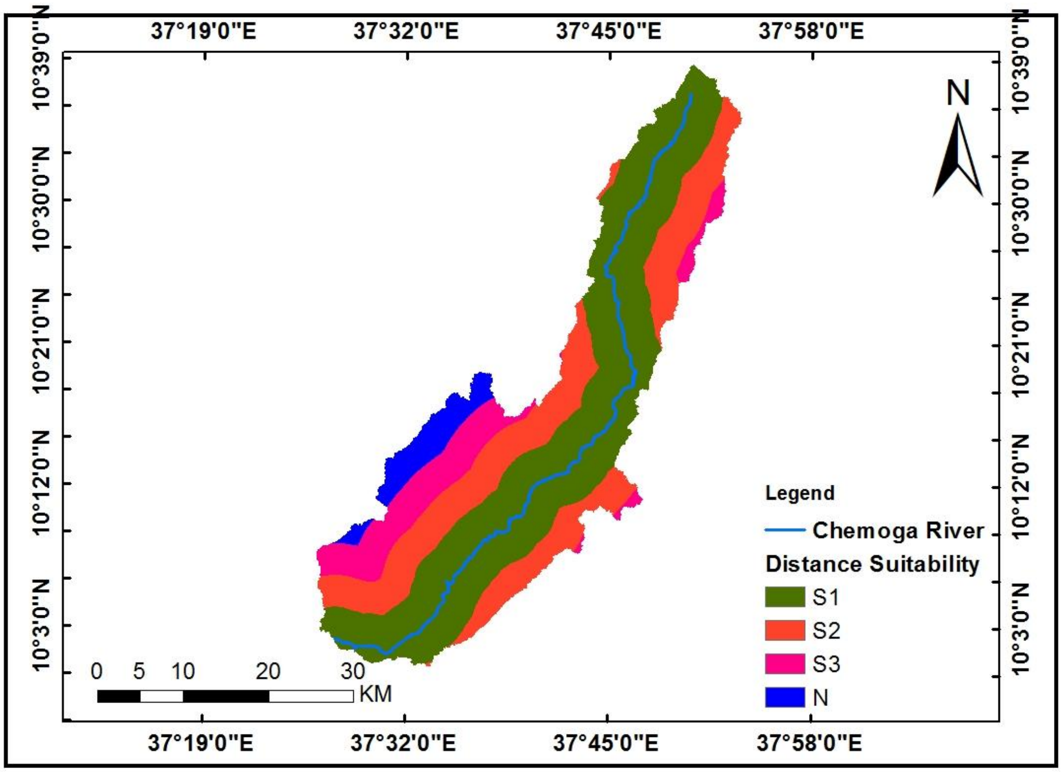

Figure 4. 7. Reclassified distance map of command area from Chemoga River

4.1.5. Road Access Proximities of the Study Area

The data will be obtained from (ERA), road access availability is important factor to represent market access and easily address the output of irrigation. The command area was reclassified into four suitability class; highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N).

Table 4. 8.Road access proximity suitability with percentage area coverage

Road proximity (km)	Rating factor	Definition	Area (ha)	Area %
0-3	S1	Highly Suitable	45837.38	39.48
3-6	S2	Moderately Suitable	34430.33	29.66
6-10	S3	Marginally Suitable	21218.27	18.28
>10	N	Not Suitable	14625.43	12.60

As shown the area coverage of suitability classes are presented in (Table 4.7) above, indicated that 45837.38ha (39.48%), is highly suitable, 34430.33ha (29.66%) is moderately suitable, 21218.27ha (18.28%) is marginally suitable and 14625.43ha (12.60%) is not suitable for surface irrigation systems. Hence, the majority of the study area is highly suitable to moderately suitable for surface irrigation in terms of distance factor suitability.

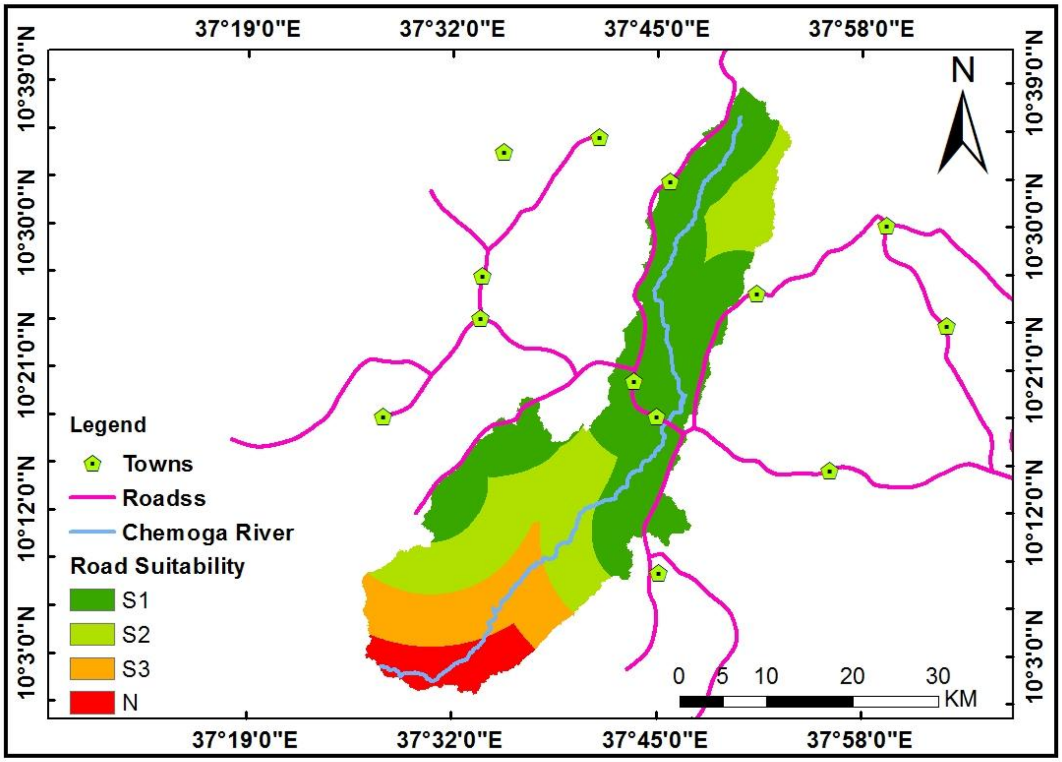

Figure 4. 8. Road access proximity suitability map of the study area

4.2. Land Suitability Evaluation for Surface Irrigation

In order to find the potential land suitability for irrigation, weighting of irrigation suitability factors such as slope, land use/cover, soil, distance proximity from river and road access proximity was needed. For weighted overlay analysis the Wight of each factor was needed. To do that Irrigation factors were compared by using analytical hierarchy process derived scales of values for pair wise comparisons, developed pair wise comparison matrix to calculated relative weights. Pair wise computation matrix, based on the relative importance of each factor.

4.2.1. Standardizing the Factors

All the criteria are in different unit's so to perform weighted overlay they need to be in same units and hence needed to be standardized. Standardization makes the measurement units uniform, and the scores lose their dimension along with their measurement unit (Malczewski and Rinner, 2005).Vector layers were converted to raster further which were reclassified for the input to the weighted overlay which finally gave the suitability map. Reclassify tool in spatial analyst in Arc GIS standardizes the value of all criteria for comparison. Pair wise technique was used for standardizing the factors. Ratings were given for all factors on a 9-point continuous scale (Table 4.8). For example, if one feels that proximity to slope gradient is very strongly more important than road proximity in determining land suitability evaluation for surface irrigation, one will enter a 7 on this scale. If the inverse is the case (road proximity was very strongly more important than slope gradient), one will enter 1/7. But the value given for the factors was based on requirements of surface (gravity) irrigation and reviewed from different literature. Since the matrix is symmetrical, only the lower triangular half actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half.

Table 4. 9. Pair-wise comparison matrix for evaluating the relative importance of the criteria

Factor	Slope	Distance	Depth	Drainage	Texture	LULC	Road
Slope	1.000	3.000	3.000	3.000	5.000	5.000	5.000
Distance	0.333	1.000	3.000	3.000	5.000	5.000	7.000
Depth	0.333	0.333	1.000	3.000	3.000	3.000	7.000
Drainage	0.333	0.333	0.333	1.000	3.000	5.000	3.000
Texture	0.200	0.200	0.333	0.333	1.000	3.000	3.000
LULC	0.200	0.143	0.333	0.200	0.333	1.000	3.000
Road	0.200	0.143	0.143	0.333	0.333	0.333	1.000
Total	2.600	5.152	8.143	10.867	17.667	22.333	29.000

To establish a set of weights for each of the factors, In Saaty's technique, taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria can derive weights of this nature. All the Seven factors, which were selected for the evaluation of irrigation potential in the basin, were weighted using pair wise comparison. After the pair wise comparison matrices were filled, the weight module was used to identify consistency ratio and develop the weights.

4.2.2. Establishing the Parameter Weights

This is the second step in MCDE to establish a set of weights for each of the factors. The technique described here and implemented that of pair wise comparisons developed by Saaty

(1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). In Saaty's technique, taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria can derive weights of this nature. The purpose of weighting is to express the importance or preference of each factor relative to other factor affect on crop yield and growth rate. To avoid and reduce the individual biases of factor weighting, the weights in the study were determined by using a pair wise comparison method as developed by Saaty (1980) in the context of the analytical hierarchy process (AHP). Pair wise comparisons are based on forming judgments between two particular elements rather than attempting to prioritize an entire list of elements. A matrix is constructed, where each factor is compared with the other factors, relative to its importance, on a scale from 1 to 9. Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the pair wise comparisons. If the CR > 0.10, then some pair wise values needs to be reconsidered and the process is repeated till the desired value of CR < 0.10 is reached. In this paper pair wise comparison was used for weighting the factors. All the seven factors, which were selected for the evaluation of Land suitability in the study area, were weighted using pair wise comparison. After the pair wise comparison matrices were filled, the weight module was used to identify consistency ratio and develop the best-fit weights.

Table4.9 below shows the irrigation suitability criteria of the watershed calculated with spreadsheet.

Steps (a) and (b) showed calculation of criteria weights. Step (c), (d) and (e) showed calculation of consistency ratio (CR) to evaluate the consistency of the data.

The steps followed for the determination of weight of criteria as:

A) Each decimal matrix is divided by the sum of the numbers in each column and the quotient is the normalization matrix

B) The summation of the normalization matrix in each row is divided by the number of factors and the quotient is the weight of criteria and the result shown in table 4.9 below.

Table 4. 10. Normalized matrix of (PWCM)

Factor	Slope	Distance	Depth	Drainage	Texture	LULC	Road	Weight
Slope	0.385	0.582	0.368	0.276	0.283	0.224	0.172	0.327
Distance	0.128	0.194	0.368	0.276	0.283	0.224	0.241	0.245
Depth	0.128	0.065	0.123	0.276	0.17	0.134	0.241	0.162
Drainage	0.128	0.065	0.041	0.092	0.17	0.224	0.103	0.118
Texture	0.077	0.039	0.041	0.031	0.057	0.134	0.103	0.069
LULC	0.077	0.028	0.041	0.018	0.019	0.045	0.103	0.047
Road	0.077	0.028	0.018	0.031	0.019	0.015	0.034	0.032

C) To compute lambda (λ)

The weight of slope is multiplied by decimal matrix of slope is added to the weight of LULC is multiplied by the decimal matrix of LULC is added to the weight of depth is multiplied by the decimal matrix of depth the weight of drainage is multiplied by the decimal matrix of drainage is added to the weight of texture is multiplied by the decimal matrix of texture is add to the weight of distance is multiplied by the decimal matrix of distance and the weight of road access multiplied the value of road access in the same row. Finally the result is divided by the weight of the soil. This was done for all rows.

λ max= (8.070+8.146+7.850+7.657+7.459+7.255+7.380) / 6 = 7.688

D) The Consistency Index (CI) is (λ max – n) / (n – 1)

Where: - n = number of factors, n =7

CI = (7.688 – 7) / (7 – 1) = 0.114685

RI is the Random Consistency Index (RI) = 1.32 from table 3.12

E) The Consistency Ratio (CR) = CI / RI, where RI is the Random Consistency Index

CR = 0.114685/1.32 = 0.0869

As shown in the last step above, the consistency ratio (CR) was found to be 0.0869. This was less than 0.1, the maximum allowable as recommended in Saaty (1990), cited in Mendoza et al. (2008) for consistent pair wise comparison of 10 %. If the data obtained through scoring process are acceptable, the weight proceeds to criteria map creation. Weighted linear combination method for this study is selected based on Eastman’s framework.

4.2.3. MCE and Weighted Linear Combination

The function of Weighted Linear Combination, (WLC) procedure multiplies each standardized factor maps or each raster cell within each map by its factor weight and then sums the results using spatial analysis in GIS by calculating sum to one, the resulting suitability map will have the same range of values as the standardized factor maps that were used (Si) (Mendoza, 1997b), (Ronald E, 2001).

Therefore: $Si. = \Sigma (Gi \times Wi)$……………………………………………………………...4.1

Where: Si = suitability map

Gi = criteria and sub criteria map grid value the factor i

Wi = relative importance or weight of factors or parameters i

The suitability (Si) ranges of the factors that define the lowest and greatest suitability levels were determined based on FAO suitability ranges. Raster calculator was used to combine the standardized criterion map and their corresponding weights to obtain irrigation suitability map of the study area. The formula weighted linear combination was used for Suitability map multiplying the reclassified factors map based on the given weights and adding them by Raster calculator technique in spatial analyst module in Arc GIS 10.4.1 software obtained the final evaluation of land suitability map of the basin of irrigation land S =0.327*Sl+0.245*Di 0.162*De+0.118*Dr+0.069*Te+0.047*Lu+0.032*Ro where S is the suitability irrigation area. Sl is the slope, Di is the distance proximity, Ro is the road access proximity, De is soil depth, Dr is the soil drainage, Te is the texture, and Lu is the land use land cover. The result was given with values in to four classes. These classes were changed with suitability classes. The overall land suitability map was divided in to four suitability classes. These were highly suitable, moderately suitable, marginally suitable, and not suitable and the result suitability map of the study area as shown below Figure 4.8, sandy soil in the texture and generally it is lowland (desert) at the lower portion of the study area shows it is more marginally not suitable.

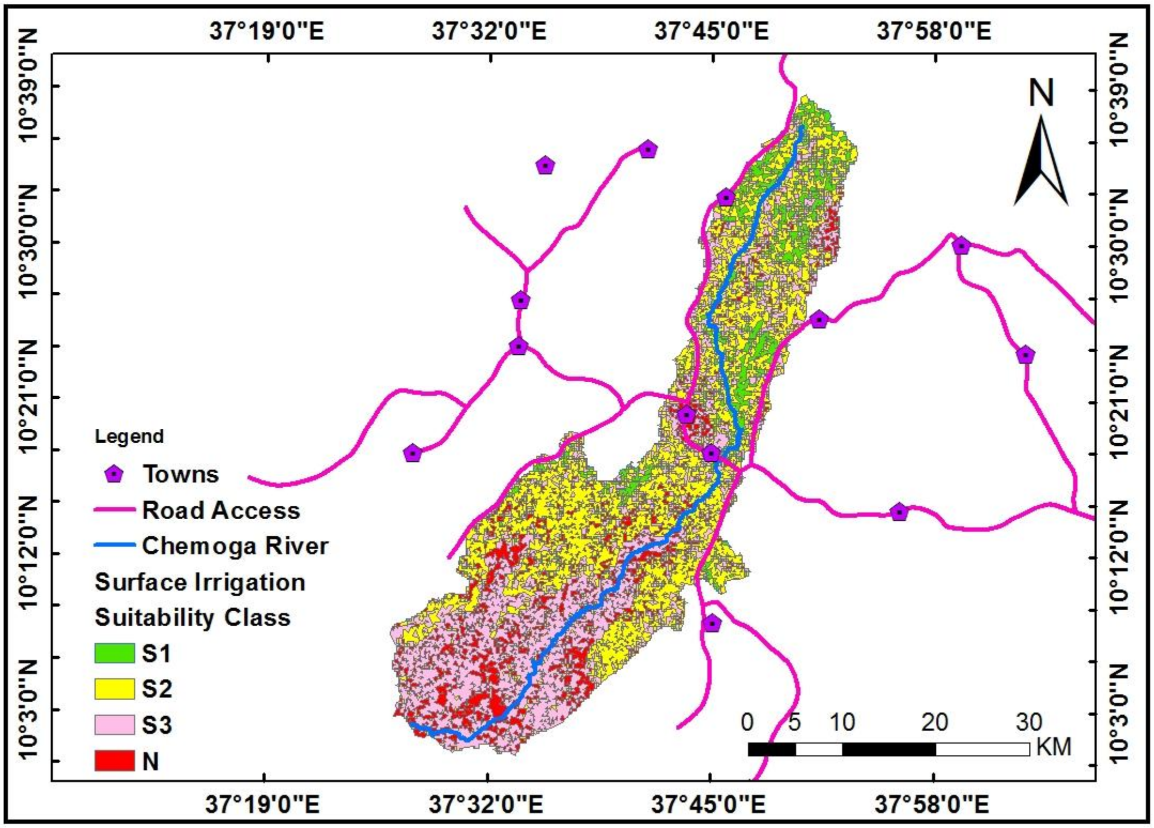

Figure 4. 9. Land Suitability Map of the Chemoga watershed for Surface Irrigation

Table 4. 11. Result of land suitability of the Chemoga watershed

Rating factor	Definition	Area (ha)	Area %
S1	Highly Suitable	18481.18	15.91
S2	Moderately Suitable	37034.64	31.94
S3	Marginally Suitable	24577.27	21.20
N	Not Suitable	35860.33	30.95

In the above table shows from the total land of the basin 18481.18hectare (15.91%) was highly suitable, 37034.64hectare (31.94%) moderately suitable, 24577.27 hectare (21.20%) marginally suitable, and 35860.33hectare (30.95%) was not suitable for surface irrigation.

4.3. Crop and Irrigation Water Requirements

The potential evapo-transpiration (ETo) of the area was computed by CropWat version 8.0 models, which uses the Penman-Monteith formula calculating ETo from temperature (minimum & maximum), wind speed, solar radiation and relative humidity data, the average ETo of the area was 3.48 mm/day and total effective rainfall was 607.3 mm. whereas Effective rainfall (Eff rain) uses mean monthly rainfall data, as can be seen from appendix M and N respectively. Comparison of the mean monthly rainfall and ETo reveals that, for the maximum crop production in the area, irrigation is the most important parameter, a substantial amount of water is needed to fill the evapo-transpiration needs of different crops. Calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No. 24"Crop water requirements" and the Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop and soil data. Once all the data is entered, CROPWAT8.0 automatically calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly to determine irrigation water demand, crops such as onion, tomato, cabbage and potato were identified in the study area. These crops were selected based on their suitability for irrigation practice and their extent in comparing with other irrigated crops grown in the region. Irrigation water demand for each selected crop was determined by using Deber Markos meteorological station. Since, this station has full metrological data which is an input for CROPWAT 8 software in appendix F.

Crop water requirement (CWR), net irrigation requirement (NIWR) and gross irrigation water requirement (GIWR) of each crop were calculated for each months using Equations 3.4, 3.5 and 3.6 respectively and summarized in Table 4.11. The monthly total net irrigation water requirement (TNIWR) was computed by summing net irrigation water requirement of each crop. According to FAO (1997), recommendations on the irrigation efficiency of different irrigation schemes, irrigation efficiency for Ethiopian highlands is given as 50%. Thus, the annual total gross irrigation water requirement was found to be 118.76m^3/s for the study area Table4.11 below.

Table 4. 12. Irrigation water requirements and gross irrigation water requirements of Crops

Month		Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETO(mm/month)		2.69	3.13	4.08	3.74	4.21	4.28	4.2	3.78	3.57	2.66	2.96	2.55
Eff RF (mm/month)	Crop	8.1	9.3	27.6	34.2	47.2	69.9	148	137	66.8	32.8	15.6	11.1
Etc (mm/month)	Tomato	55.5	83.7	118.1	80	9.3	0.00	0.00	0.00	0.00	0.00	2.01	34
	Potato	64.7	97.2	132.2	55.8	0.0	0.00	0.00	0.00	0.00	0.00	1.10	28.3
	Cabbage	60.5	74.8	91.8	88.5	61.9	0.00	0.00	0.00	0.00	0.00	0.00	26.7
	Onion	59.5	86.3	123.2	44.5	0.0	0.00	0.00	0.00	0.00	0.00	2.20	34
NIR (mm/month)	Tomato	47.4	74.4	109.5	45.8	0.0	0.00	0.00	0.00	0.00	0.00	0.00	22.9
	Potato	56.6	87.9	104.6	21.6	0.0	0.00	0.00	0.00	0.00	0.00	0.00	17.2
	Cabbage	52.4	65.5	64.2	54.3	14.7	0.00	0.00	0.00	0.00	0.00	0.00	15.6
	Onion	51.4	77	95.6	10.3	0.0	0.00	0.00	0.00	0.00	0.00	0.00	22.9
TNIR (Mm^3) Area (ha)													
24027.93	Tomato	11.39	17.9	26.31	11	0.0	0.00	0.00	0.00	0.00	0.00	0.00	5.5
20023.27	Potato	11.33	17.6	20.94	4.33	0.0	0.00	0.00	0.00	0.00	0.00	0.00	3.44
16018.62	Cabbage	8.394	10.5	10.28	8.7	2.355	0.00	0.00	0.00	0.00	0.00	0.00	2.5
20023.93	Onion	10.29	15.4	19.14	2.06	0.0	0.00	0.00	0.00	0.00	0.00	0.00	4.59
GIR (l/s/ha)*50%Eff	Tomato	22.78	35.8	52.62	22	0.0	0.00	0.00	0.00	0.00	0.00	0.00	11
	Potato	22.67	35.2	41.89	8.65	0.0	0.00	0.00	0.00	0.00	0.00	0.00	6.89
	Cabbage	16.79	21	20.57	17.4	4.709	0.00	0.00	0.00	0.00	0.00	0.00	5
	Onion	20.58	30.8	38.29	4.12	0.0	0.00	0.00	0.00	0.00	0.00	0.00	9.17
GIR (m^3/s)	Tomato	8.508	3.4	6.64	8.21	0.0	0.00	0.00	0.00	0.00	0.00	2.01	4.11
	Potato	8.466	3.1	13.63	3.23	0.0	0.00	0.00	0.00	0.00	0.00	1.10	2.57
	Cabbage	6.27	7.84	7.676	6.49	1.759	0.00	0.00	0.00	0.00	0.00	0.00	3.42
	Onion	7.688	11.5	14.3	1.54	0.0	0.00	0.00	0.00	0.00	0.00	2.20	3.43
Total Monthly GIWR m^3/s		30.62	25.9	32.25	19.5	1.759						5.31	13.53

4.4. Irrigation Potential on Chemoga Watershed

After evaluation of the suitability land for irrigation, it is very necessary to examine the irrigation water availability for crops production in the study area. Irrigation potential of the river was obtained by comparing irrigation water demand of the four crops commonly grown in the study area, in considering to the identified suitable land for irrigation and the 90% dependable monthly flow of Chemoga River. According to (FAO, 1997) the surface irrigation potential was obtained by comparing irrigation water requirement in identified irrigable land and the available stream flow of watershed. In the whole Growing season from November-May irrigation water demand was greater than the available stream flow. Minimum monthly stream flow and grosses irrigation water requirement of each crop were calculated for each month using Equations 3.8 and the result wear summarized in the table below.

Table 4. 13. Irrigation demands and available river flows in the study area

Month	Tomato	Potato	Cabbage	Onion	Sum of GIWR	90%probability river flow (m³/s)
Jan	8.508	8.466	6.27	7.69	30.62	1.37
Feb	3.4	3.148	7.84	11.5	25.9	1.13
Mar	6.638	13.633	7.68	4.3	32.24	1.06
Apr	8.21	3.228	6.49	1.54	9.47	1.11
May	0.00	0.00	1.75	0.00	1.749	4.63
Jun	0.00	0.00	0.00	0.00	0.00	13.65
Jul	0.00	0.00	0.00	0.00	0.00	19.84
Aug	0.00	0.00	0.00	0.00	0.00	21.58
Sep	0.00	0.00	0.00	0.00	0.00	17.67
Oct	0.00	0.00	0.00	0.00	0.00	8.49
Nov	2.01	1.10	0.00	2.20	5.31	2.69
Dec	4.11	2.573	3.42	3.43	13.53	1.78
Total	32.866	32.048	33.45	23.46	118.76	95

The area was assigned for each crop based on their productivity and profitable in traditional farming system in Gozamen woreda agriculture and development office Based on the Minimum available water, As shown in the appendix T, the effective irrigable area can be estimated in each month using equation 3.9, The result of effective irrigable area of each month is varies from month to month due to variation of minimum flow. Due to lack of available water, most of irrigable area is not irrigated and is not covered by agricultural production, finally the result wear summarized in appendix T.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The evaluation of land suitability of Chemoga river sub basin of Abbay basin was conducted in East Gojam zone, Amhara region, and the watershed covers 115953.42 ha area. Factors which were considered to evaluate irrigation land suitability were, slope, LULC, soil, river proximity and road proximity. Irrigation land suitability was evaluated based on FAO guideline such as S1, S2, S3 and N. The surface irrigation development maps of suitable sites were also presented on Arc GIS model. Based on the analysis, 42.67 % of slope, 90.68 % of LULC, 69.08 % of soil depth, 60.98% of soil drainage, 68.02% of soil texture, 89.70% of river proximity, and 87.4% of road proximity of the study area were identified to be in the range of highly suitable to marginally suitable for surface irrigation. Whereas, 57.33% of slope, 09.32% of LULC, 30.92% of soil depth, 39.02% of soil drainage, 31.98% of soil texture 10.30% of river proximity, 12.60% of road proximity were classified as not suitable for surface irrigation.

Multi criteria evaluation method used for weighted overlay of the factors by using model builder in Arc GIS to evaluate the overall suitability of the area for surface irrigation from which the analysis of irrigation suitability map was developed. From the total area of the study 80093.81 ha (69.05%) is suitable for surface irrigation and the rest of 35860.33ha (30.95%) is not suitable. Irrigation water demand was assessed by using stream flow; the irrigation water requirement was calculated using FAO-Penman-Monteith methods. By using CROPWAT version 8.0 models, crops which identified in the study area are potato, tomato, cabbage and onion. The irrigation water requirement of the selected crops was calculated and the result implies that irrigation water requirement was higher at driest months of the year. The land evaluation of surface irrigation was identified by comparing available stream flow and grosses irrigation water requirement. The available minimum stream flow is less than the irrigation water demand. The overall result indicates that most of the Chemoga river watershed was (80093.09 ha) potentially suitable for irrigation development from the total study area. To irrigate the whole irrigable area of the land, 118.76m3/s annual Grosse irrigation water demand is needed.

5.2. Recommendations

Irrigation investment plays an important role in maintain sustainable food security by improving the agricultural production which is the core foundation for Ethiopia's economy, growth and long-term food security. However this can be achieved, by evaluating land suitability and water resources for irrigation. Therefore, identified surface irrigation potential of the watershed in the study area can assist in policy and decision makers for irrigation development to alleviate the recurrent domestic food shortage facing the country particularly in Chemoga watershed.

The current land suitability evaluation was in terms of slope, LULC, soil depth, soil drainage, soil texture, river proximity and road access of the study area only, but other suitability factors like environmental, economic, water quality and social terms and should be assessed to get a reliable result. This study considered only physical properties of soil used for evaluating the soils for surface irrigation method, other chemical properties of soil should be evaluated.

In this study, the gross irrigation water demand was more than the supply of the watershed. So a storage structures were necessary to solve the problem by implementing semi to detailed design document analysis and/or to balance the crop water demand and supply a single crop (one variety) of a crop should be used.

Suitability analysis of land for irrigation was done by considering only surface irrigation. Furth investigates is recommended to increase suitability of land for irrigation by considering other irrigation methods.

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APPENDICES

Appendix A: Deber Markos Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
1994	9.35	5.00	35.2	42.70	139.6	147.6	281.2	301	218.1	7.4	13.2	0.5	1200.8
1995	0.00	1.02	20.31	90.4	146.6	126.4	246.1	344.6	151.2	14.4	12.4	95.5	1248.9
1996	27.61	4.61	74.11	108	228	291.7	252.3	360.5	152.1	33.1	35.2	23.27	1590.4
1997	14.32	0.51	29.6	97.51	118.7	151	286.8	338.8	205.8	183.5	85	6.794	1517.7
1998	1.90	2.21	21.00	4.40	152.4	86	203.2	252.6	270.7	200.8	6.7	0.12	1201.9
1999	72.61	0.00	2.80	43.22	46.28	180.7	252.1	340.3	164.3	210.5	2.5	28.34	1344.1
2000	0.64	0.00	2.95	110.5	29.05	174.9	281.7	211.1	271	265.9	32.7	12.36	1392.5
2001	0.31	3.72	58.12	101.2	129.6	154.7	365.2	322.3	170.3	66.9	0	2.25	1374.2
2002	57.9	0.51	92.26	75.2	11.2	155.9	276.3	335.5	234.6	3.9	2.2	61.53	1305.5
2003	3.62	57.41	69.62	19.2	5.3	212	205.5	351.6	256.8	10.7	0.3	18.86	1210.8
2004	4.12	7.62	13.83	120.15	19.8	195	286.6	317.7	205.2	87.5	37.7	23.21	1318.3
2005	2.36	0.69	110.68	42.92	43.7	150.4	314	220.5	235.3	90.2	41.5	0.09	1252
2006	3.54	20.71	87.86	67.44	104.5	190.9	364.1	281.1	301.5	37.1	30.7	32.32	1521.6
2007	1.78	15.63	77.51	71.00	162.9	188	250.6	325.9	269	37.9	0.4	0.00	1400.5
2008	0.61	0.00	0.00	15.71	169.9	290.3	250.5	273.9	195.1	71.2	39.1	9.54	1315.2
2009	11.75	21.15	41.92	22.75	16.89	159.3	276.7	452.3	98.5	103	10.9	21.81	1236.7
2010	18.74	22.82	35.45	84.76	153.4	151	210.9	339.6	307	17	16.7	5.62	1362.2
2011	2.32	3.15	110.43	68.92	237.8	143	231.1	288.3	282.9	7.5	97.3	11.5	1483.8
2012	13.91	0.85	33.11	33.17	23.42	124.2	372.2	250.9	362.4	21.3	30.9	7.15	1272.5
2013	3.65	4.72	16.42	11.86	125	161.3	282.8	245.4	194.8	147.3	34.2	0.00	1227.3
2014	9.12	8.68	42.98	138.42	130.1	101.9	274.6	257.1	255.5	100.5	9.2	9.21	1337.1
2015	6.87	14.60	45.52	20.18	244.1	119.1	149.7	237.7	129.4	12.7	65	16.05	1059.9
2016	0.00	18.11	53.84	25.59	168.4	117.1	236.1	243.6	249.5	54.8	0.00	0.02	1166.9
2017	0.98	34.16	65.40	77.55	344.9	107.9	285.6	246.6	193.2	60.5	2.45	0.00	1418.1
2018	0.25	221.73	125.41	78.77	123	188	250.6	325.9	269	37.9	0.44	11.02	1631.8
Average	10.52	18.69	50.63	62.83	123	162.7	267.5	298.6	225.7	75.34	24.26	15.83	1336

Appendix B: Robugebeya Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
1994	26	18.3	38.7	28	100.8	211.2	329.3	326.5	186.8	14.3	25	37.7	1344.2
1995	0	4.1	61.5	140.6	140.7	97.7	333.1	247.3	247.6	8.1	14	99.2	1393.8
1996	4.8	19	134	163	148	143.7	313.1	215	194.5	4.5	68	34.5	1442.1
1997	0.8	0.8	68.8	102.4	122.8	194.8	254.3	253.1	116.4	180.7	135	54.9	1485.2
1998	1.2	98.6	25.7	38.3	191.2	205.2	340.9	160.5	35.4	31.6	1.8	0.7	1131.1
1999	0.0	4.5	25.7	44.9	212.1	429.4	379.5	215.8	273.7	14.5	38	3.3	1617.2
2000	3.6	8.1	25.7	137	188.1	257.3	270.8	213.1	188.5	109.9	40	0.5	1442.8
2001	8.1	77.2	25.7	147.4	243.3	344.3	368.5	67.6	138.9	66.9	24	73.6	1586
2002	1.6	177	25.7	28.7	271.3	323.1	288.4	175.1	110.1	56.9	7.2	16	1481.1
2003	0.0	105	86.9	43.7	6.8	202.7	339.2	436.3	210.6	112.1	85	25.6	1655.1
2004	5.3	18.3	39.2	183.3	126.8	230	378.4	243.6	192.3	88.9	31	51.4	1589
2005	1.7	9.5	133	59.4	60.3	177.5	327.9	170.9	74.3	39.9	0.0	2.3	1057.3
2006	26	89.7	83.5	128.1	183.8	374.4	367.8	201.5	75.2	28.8	50	33.1	1643.1
2007	19	61.2	86.7	222.0	284.6	278.1	276.6	197.3	75.8	29.5	0.0	11.9	1543.1
2008	0.1	0.0	83.5	142.2	205.2	258.8	278.8	115.6	59.1	4.5	38	82.2	1268
2009	35	22.4	129	339.5	276.8	68.2	128.5	12.8	65.0	50.9	33	26.5	1188.9
2010	10.4	73.7	111	188.2	284.4	274.4	196	32.5	64.1	33.6	16	20	1287.6
2011	54	93.3	112	126.0	225.0	145.7	221.5	10.8	94.2	14.4	0.0	0.0	1098.2
2012	0.0	0.0	104	34.4	52.8	116.5	268.9	192.8	167.5	13.1	93	11.6	1055
2013	2.7	16.8	67.4	23.4	172.3	209.7	323.8	270.3	97.2	85.9	61	0.0	1331.2
2014	27	18.2	89.2	72.4	161.7	100.4	200.2	237.4	194.8	86.2	56	6.8	1250.5
2015	6.7	13.0	27.0	67.5	40.4	152.5	119.3	227.5	188.5	156.1	26	29.9	1055.1
2016	3.9	12.0	86.0	56.9	109.0	107.1	227.1	320.1	118.3	73.8	8.9	1.1	1124.2
2017	0.0	86.6	54.4	73.8	160.1	140.8	287.8	327.1	260.8	30.7	12	0.0	1434.2
2018	0.0	7.0	265	188.2	284.4	274.4	196	32.5	64.1	33.6	16	5.1	1366.9
Aver ag	9.61	41.4	79.9	111.2	170.1	212.7	280.6	296.1	139.7	54.77	34.4	24.3	1354.8

Appendix C: Amber Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
1994	6.62	16.64	1.31	9.45	86.8	156.9	202.1	365.1	188.7	111	55.5	42.3	1242
1995	0.28	9.56	33.6	98.75	59.14	91.8	231.5	258.4	16.6	18.2	25.6	67.8	910.3
1996	36.5	6.41	109.5	57.41	94.5	245	181.2	307.2	41.3	0.5	49.5	13.4	1142
1997	14.12	0.52	37.1	126.4	132.4	325.6	335.5	426	212.5	171.8	35.3	15.7	1832
1998	0.09	2.61	67.7	15.9	246.8	219.2	370.6	401.4	287.3	306	0.1	0.85	1918
1999	34.21	0.85	0.9	7.41	110.9	143.1	245.5	179.4	99.8	99.6	171.7	6.6	1099
2000	0.95	0.64	0.61	81.1	45.5	263.3	602.7	171.5	33.1	10.1	0.80	0.62	1207
2001	2.45	2.12	28.5	85.3	38.4	210.5	316.9	188.1	159	56.13	55.3	3.2	1145
2002	8.21	0.96	83.9	15.3	51.6	158.4	438.4	312.7	103.8	26.3	0.41	0.82	1198
2003	0.84	4.65	46.6	12.1	121.3	237.5	421.8	320.2	238.8	106.8	111.5	89.5	1711
2004	6.71	22.41	28.1	78.4	198.5	243.2	276	303.8	262.2	90.8	30.9	0.46	1541
2005	22.21	0.58	0.99	62.6	225.4	243.6	283.3	296.1	181.3	86.4	44.6	12.4	1458
2006	0.89	12.64	70.51	40.5	12.7	162.6	329.2	388.3	136.5	109.8	14.9	5.5	1283
2007	0.41	4.25	18.94	41.3	145.6	242.8	400.5	322.7	244.1	134.8	50.7	30.2	1636
2008	20.23	0.86	78.65	47.7	148.2	213.1	237	232.4	341.2	23.3	87.1.	10.4	1439
2009	2.49	2.52	42.22	103.3	182.7	136.1	316.5	262.4	124.5	26.6	15.56	0.74	1214
2010	15.91	0.65	32.81	27.1	61.45	155.9	151.3	326.3	279.3	121.4	18.34	0.56	1190
2011	0.84	76.22	43.74	121	86.3	223.4	257.3	88.4	34.41	35.12	0.25	0.21	965.3
2012	0.69	53.63	11.28	102	110.7	133.4	376.1	187.1	264.2	12.32	6.41	3.12	1260
2013	0.87	10.89	24.25	127.8	217.6	227.2	172.4	103.7	57.99	40.91	1.35	0.85	983.8
2014	13.12	25.72	115.7	178.2	106.9	209.2	294.1	214	87.78	40.14	1.81	0.21	1287
2015	0.56	0.12	31.21	188.5	137.8	112.6	204.5	172.1	21.85	77.45	35.84	5.93	987.2
2016	4.75	0.58	28.92	0.86	250	132.8	273.1	248.9	163.3	69.81	25.91	0.54	1197
2017	2.49	2.52	42.28	103.3	182.7	136.1	316.5	262.4	124.5	26.61	15.31	2.30	1214
2018	2.45	2.57	42.26	103.3	182.7	136.1	316.5	262.4	124.5	26.65	15.12	1.02	1214
Average	7.652	10.18	40.78	73.32	129.4	190.4	302	264	153.1	73.07	34.68	12.6	1291

Appendix D: Yejubi Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1994	1.461	74.3	174.1	119.5	35.3	185.7	505	480.1	326.7	17.12	7.64	0.981	1926.7
1995	2.451	25.1	111.5	1267	132.6	152.6	206	242.5	121.2	35.9	0.78	7.45	1163.4
1996	3.305	30.9	22.3	66.3	44.4	115.3	187	220.9	111.4	137.1	23.9	39.71	1002.5
1997	1.741	16.7	24.3	161.9	133.7	171	371.2	280.6	148.5	121.2	0.52	0,025	1430.1
1998	0.798	6.3	37.7	35.4	126.4	149.2	418.6	338	143.7	0.78	1.35	0.451	1256.6
1999	0.512	3.8	19.71	45.3	91.5	99.2	225.2	242.1	65.2	2.53	6.56	44.22	845
2000	5.13	0.0	132.6	91.5	135.8	155.9	125.7	231.1	132.8	128.8	89.4	126.9	1355.6
2001	140.4	6.1	63.62	80.3	92.1	203	177.8	184	72.7	59.12	54.1	10.22	1143.6
2002	0.951	0.51	75.11	7.9	185.1	95.5	334.4	374.2	126.8	183	37.4	0.91	1419.4
2003	4.81	0.51	0.956	33.7	82.1	179.5	390.2	259.9	75.6	277.5	2.25	7.83	1313.3
2004	0.416	0.84	0.302	133.9	32.1	132.4	316.1	324.4	128.1	27.33	131	118.5	1343.9
2005	152.2	112.	120.5	103.3	137.4	209.5	377.2	225.6	132.5	53.13	3.55	4.98	1632.2
2006	36.62	6.44	33.3	43.9	13.3	201.7	403.2	314.2	80.5	0.62	0.85	10.54	1143.8
2007	0.485	30.1	60.1	30.9	0.6	145.2	261.5	222.1	108.9	2.97	9.61	2.36	873.1
2008	14.41	9.7.3	23.7	66.84	8.2	211	230.5	223.3	150.8	74.65	12.3	125.4	1150.2
2009	17.31	0.94	53.6	84.12	58.9	125.1	232.7	161.4	154.2	39.13	32.5	0.1	959.05
2010	3.102	13.2	114.3	69.15	92.2	125.7	481.4	300.9	267.4	28.48	7.88	35.31	1539
2011	10.31	22.5	40.2	72.14	129.8	152.1	287.9	227.9	198.9	16.26	0.99	105.3	1263.6
2012	0.0	0.84	0.315	21.35	101.2	167.7	323.6	180.3	122.9	81.48	69.4	0.74	1068.2
2013	8.701	11.2	37.8	42.5	18.2	46.4	292.5	321.4	99.3	113.9	5.24	26.31	1023.4
2014	3.551	23.3	38.8	81.4	190.1	72.1	258.8	281.3	222.1	19.11	20.5	1.32	1212.3
2015	3.256	0.0	96.8	53.6	178.7	116.2	254.6	262.8	106.6	20.12	92.3	0.0	1184.8
2016	0.861	0.86	79	53	38.3	153.3	357.5	233.1	176.4	42.55	2.84	0.65	1135.9
2017	3.712	0.64	12.6	31	143.8	244.4	317	288.7	65.6	42.46	12.8	0.89	1161.8
2018	0.518	45.2	22.4	93.3	129.2	52.8	142.7	191.1	180.4	65.41	24.8	0.36	947.36
2019	0.561	6.68	0.0	21.2	124.7	182.7	107.9	212.2	94.2	14.28	108	22.7	895.75
Average	15.8	17.1	53.6	68.1	94.4	147.9	291.8	262.5	139	61.78	29	26.5	1207.3

Appendix E: Dembecha Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
1994	0.86	0.88	28.3	16.7	136	330	398	275	178	25.8	52.3	4.59	1446
1995	0.45	9.32	5.55	158	125	242	277	273	137	12.9	27.2	35.7	1302
1996	18.5	7.00	81.2	72.7	191	386	493	150	76	14.5	70.5	4.97	1563
1997	4.15	0.00	48.3	81.7	195	255	240	275	266	170.	88.4	16.6	1640
1998	0.99	63.6	0.84	92.7	246	338	358	183	164	23.2	0.64	45.1	1515
1999	0.52	0.0	34.4	81.4	159	381	266	315	226	33.8	9.62	2.88	1508
2000	0.58	0.64	69.2	23.4	212	207	185	281	206	140.	0.45	11.4	1334
2001	0.35	11.3	125	50.1	193	123	221	369	166	103.	20.9	25.1	1408
2002	7.31	57.5	13.3	11.6	199	263	324	116	22	0.52	72.3	0.69	1086
2003	0.95	14.4	47.1	22.5	93.1	249	370	273	221	110.	4.83	5.87	1320
2004	2.56	2.87	28.6	85.3	38.2	211	317	188	160	56.8	56.9	3.24	1145
2005	8.45	0.94	84	15.4	51.5	158	438	313	104	26.38	0.96	0.89	1198
2006	0.25	4.68	46.7	12.2	121	238	422	320	239	106.8	112	89.5	1711
2007	6.72	22.4	28.1	78.4	199	243	276	304	262	90.81	30.9	0.98	1541
2008	22.3	0.61	0.89	62.6	225	244	283	296	181	86.42	44.6	12.5	1458
2009	0.54	12.6	70.5	40.5	12.7	163	329	388	137	109.8	14.9	5.51	1283
2010	0.89	4.25	19	41.3	146	243	401	323	244	134.8	50.3	30.3	1636
2011	20.4	0.91	78.6	47.7	148	213	237	232	341	23.31	87.2	10.1	1439
2012	0.98	0.08	23.5	13.2	72.7	113	219	300	284	51.62	19.7	0.47	1096
2013	0.25	0.64	0.46	2.21	149	203	211	167	85	65.64	62.4	0.25	945
2014	0.26	0.25	50.4	123	226	99	294	259	274	124.6	14.7	0.54	1462
2015	1.19	6.25	29.8	19.1	199	178	199	221	195	49.93	98.8	72.3	1269
2016	0.79	22.1	19.8	34.1	218	210	277	298	144	41.21	28.5	0.56	1265
2017	0.23	33.2	9.41	112	183	139	274	292	250	78,98	32.9	0.09	1403
2018	0.78	5.24	15	142	213	241	396	355	310	123.4	65.8	46.3	1911
average	3.63	11.0	38.1	579	154	226	308	270.5	194	72.1	41.45	16.84	1395

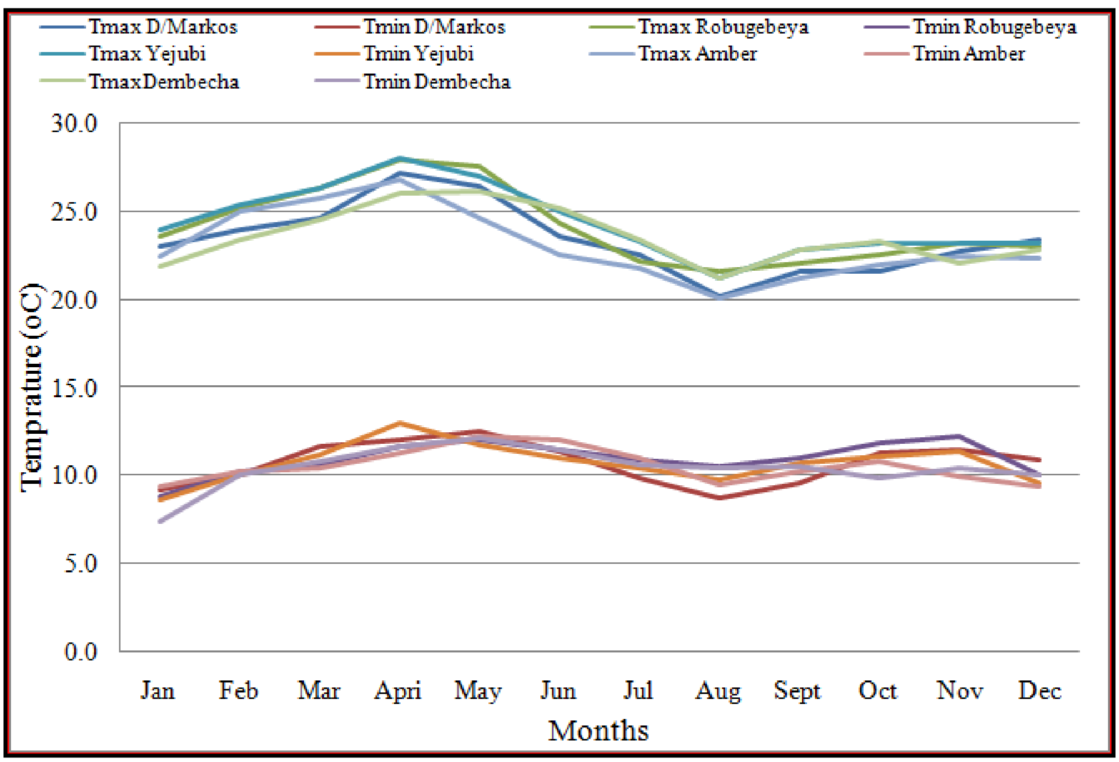
Appendix F: Mean monthly discharge flow data of Chemoga River

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	0.14	1.01	0.25	0.37	1.58	0.41	70.6	39.6	17.1	25	0.95	1.35
1995	0.1	0.08	25.3	13.7	1.43	23.8	4.11	83.5	11.3	10.4	22.2	3.03
1996	0.15	0.01	0.28	0.51	1.24	0.9	7.55	34.6	12	8.64	0.86	1.16
1997	1.16	9.18	0.27	0.55	1	0.84	4.81	37.2	10.8	7.47	15.6	0.59
1998	0.06	2.01	13.7	0.47	29	1.29	8.8	41.6	8.93	10.4	0.74	1.09
1999	0.09	0.03	11.3	0.58	0.83	1.1	14.3	43.9	22.2	12.6	0.8	19.9
2000	5.13	0.09	0.28	0.05	0.79	1.54	34.1	39.7	17.4	14.5	1.32	0.95
2001	0.1	1.06	18.1	0.03	1.09	1.35	39.9	36.1	15.4	10.9	2.23	5.66
2002	2.18	2.01	17	0.08	1.86	0.59	44.3	32	15	10.9	0.59	22.4
2003	0.07	0.03	14.3	0.52	2.32	0.55	15.6	77.7	20.9	7.47	11.3	0.82
2004	22.7	0.05	11.9	4.14	2.89	3.15	59.3	53.1	24.5	25.3	9.18	0.71
2005	0.15	3.05	12.8	1.25	0.31	3.4	51.6	25.3	14.9	7.85	0.54	20.9
2006	0.12	0.18	31.8	0.23	0.31	3.83	25.5	30.3	21.7	6.24	0.54	0.75
2007	1.14	0	18.9	0.11	5.15	4.78	42.7	34.1	34.9	4.19	1.47	6.86
2008	0.13	0.02	22.1	17	6.28	4.42	41.2	37.2	14.3	7.1	1.46	8.97
2009	19.8	4.16	25.2	21.1	7.46	6.78	30.8	37.1	10.7	15.6	0.46	0.79
2010	15.5	0.12	29.1	21.1	9.14	4.72	10.5	97.2	10.5	2.55	0.42	10.6
2011	12.9	0.08	0.33	12.9	12.6	5.14	9.44	38.4	5.9	19.7	1.49	19.9
2012	0.15	0.16	26.7	11.8	10.9	6.21	24.9	38	5.68	0.33	1.56	1.78
2013	2.1	6.21	30.2	20.4	9.46	7.58	51.1	34.2	6.51	2.2	1.46	0.64
2014	20.5	0.35	10.2	26.7	8.41	21	46.1	31.1	6	2.11	0.82	2.59
Average	4.97	1.42	15.2	7.31	5.43	4.92	30.3	43.9	14.6	10.1	3.62	6.26

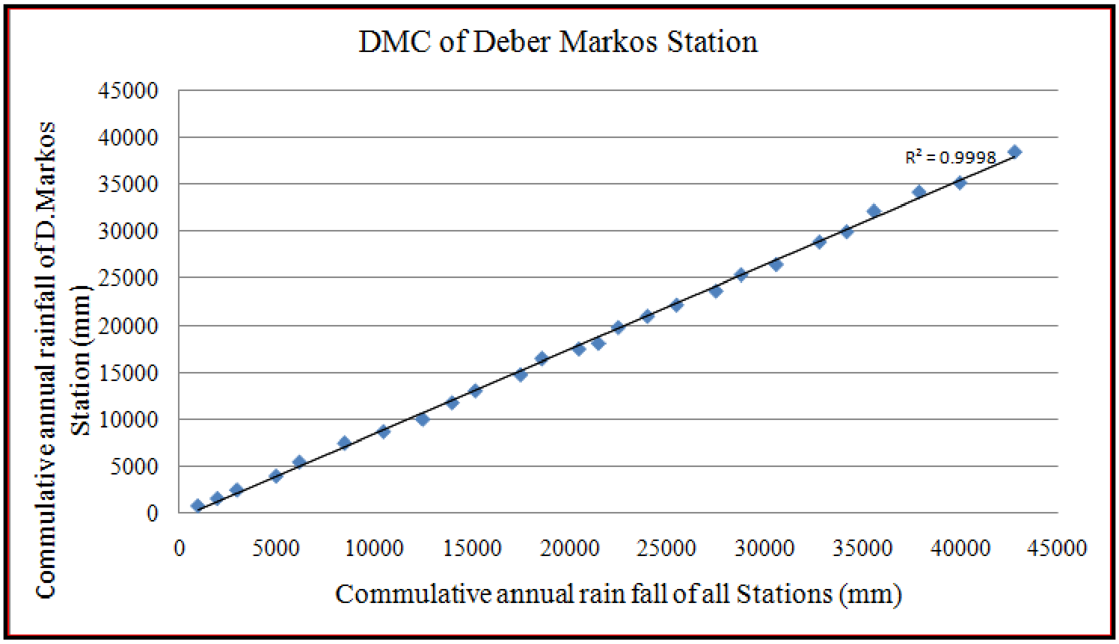
Appendix G: Monthly average minimum and maximum temperatures, wind speed, relative humidity and sunshine hours of Deber Markos station

Month	Min Temp(°C)	Max Temp(°C)	Humidity (%)	Wind (km/day)	Sun hours
January	8.0	20.2	44	66	5.1
February	11.4	20.6	55	47	7.4
March	12	28.8	79	52	10.4
April	12	22.6	61	61	7.8
May	15	22.8	49	76	9.2
June	11.4	24	56	67	10.8
July	11.8	25.4	71	43	10.2
August	11.6	24.4	83	41	8.4
September	11.6	23	82	42	6
October	11.5	20.4	66	69	3.2
November	10.2	21.2	42	63	5.6
December	6.8	20	46	46	5.7
Average	11.1	22.8	61	56	7.5

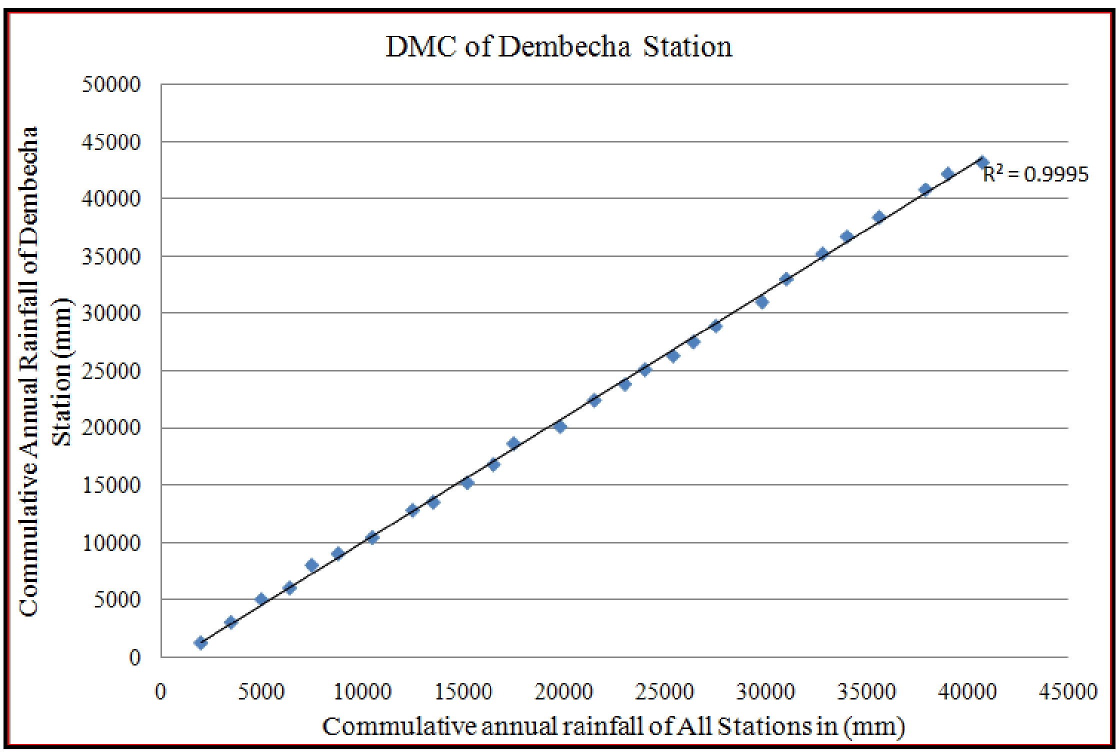
Appendix H: All Average monthly maximum and minimum temperature



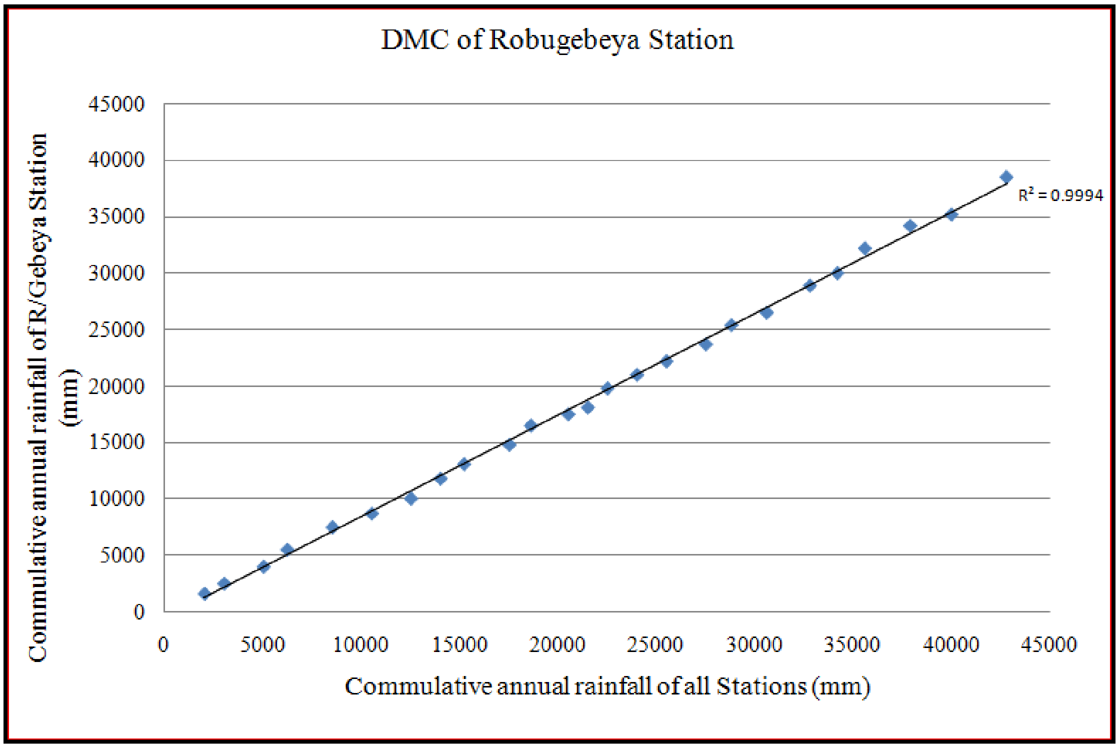
Appendix I: Double mass curve for Deber Markos rain gage station



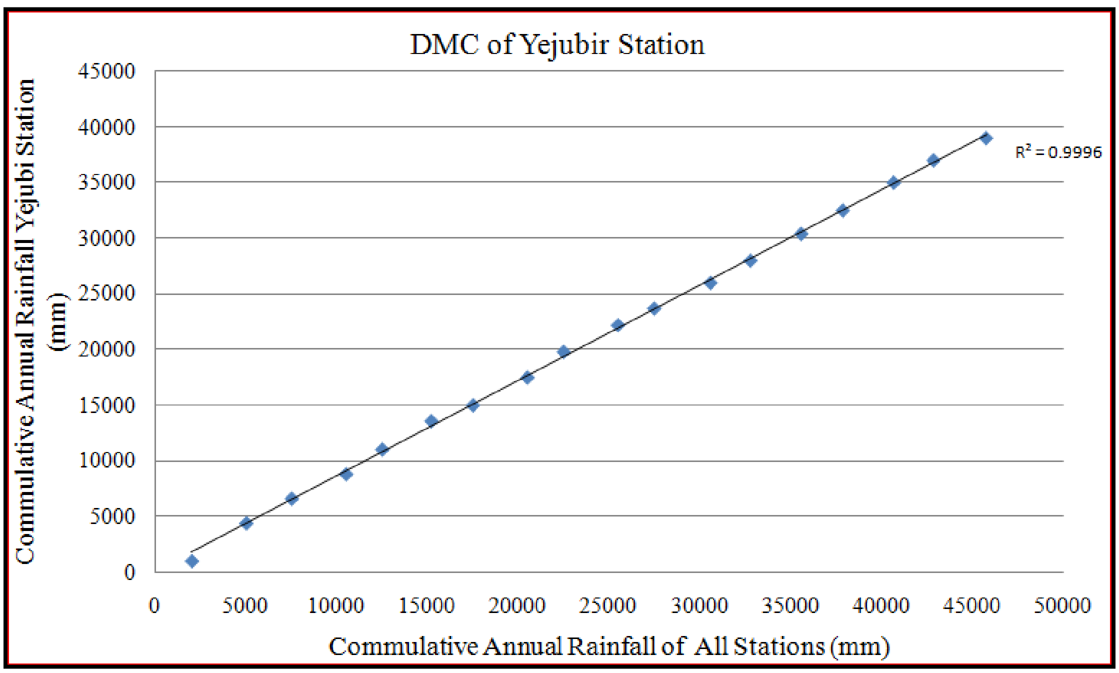
Appendix J: Double mass curve for Dembecha rain gage station



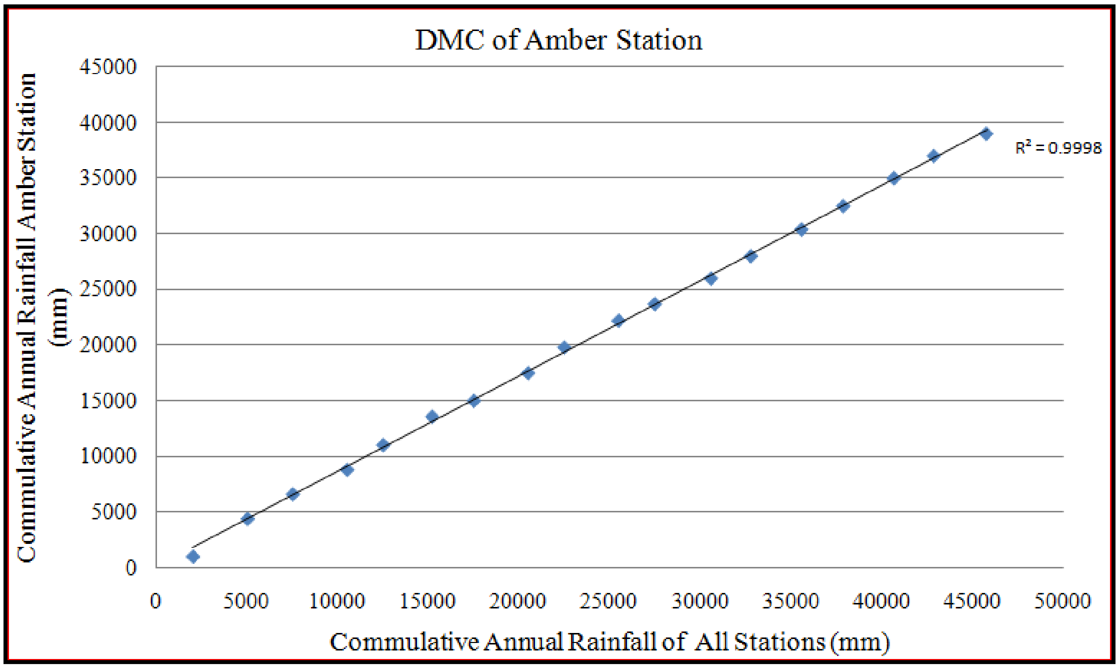
Appendix K: Double mass curve for Robugebeya rain gage station



Appendix L: Double mass curve for Yejubi rain gage station



Appendix M: Double mass curve for Amber rain gage station



Appendix N: ETo and climatic data D/Markos Meteorological data for CropWat 8.0.

Month	Min Temp°C	Max Temp°C	Humidity %	Wind km/day	Sun hours	Rad MJ/m/day	mm/day
January	8	20.2	44	66	5.1	15.1	2.69
February	11.4	20.6	55	47	7.4	19.5	3.13
March	11.6	23	79	52	10.4	25.2	4.08
April	12	22.6	61	61	7.8	21.5	3.74
May	15	22.8	49	76	9.2	23.2	4.21
June	11.4	24	56	67	10.8	25.1	4.28
July	11.8	25.4	71	43	10.2	24.4	4.16
August	12	24.4	83	41	8.4	22.1	3.78
September	11.6	28.8	82	42	6	18.4	3.57
October	11.5	20.4	66	69	3.2	13.5	2.66
November	10.2	21.2	42	63	5.6	16	2.96
December	6.8	20	46	46	5.7	15.5	2.55
Average	11.1	22.8	61	56	7.5	20	3.48

Appendix O: Rain fall and effective rain fall

Months	Rain mm	Eff rain mm
January	16.2	8.1
February	18.5	9.3
March	55.3	27.6
April	68.4	34.2
May	94.4	47.2
June	139.8	69.9
July	295.3	147.7
August	274.1	137.1
September	133.7	66.8
October	65.6	32.8
November	31.2	15.6
December	22.1	11.1
Total	1214.6	607.3

Appendix P: CWR and IWR estimation for Tomato crop

Month	Decade	Stage	Kc coeff	ETc mm/day	Etc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec	Each month Total
Nov	3	Init	0.4	1.67	2.01	0.2	1.4	2.0
Dec	1	Init	0.6	1.61	1.6	0.2	1.6	
Dec	2	Init	0.6	1.53	15.3	1	14.2	34
Dec	3	Init	0.6	1.56	17.1	0.7	16.4	
Jan	1	Deve	0.6	1.6	16	0.1	15.9	
Jan	2	Deve	0.69	1.87	18.7	0	18.7	55.5
Jan	3	Deve	0.83	2.34	20.8	0	25.8	
Feb	1	Deve	0.96	2.86	24.6	0	28.6	
Feb	2	Mid	1.08	3.37	28.7	0	33.7	83.7
Feb	3	Mid	1.1	3.8	30.4	1.2	29.2	
Mar	1	Mid	1.1	4.22	35.2	5.7	36.5	
Mar	2	Mid	1.1	4.6	39	8.4	37.7	118.1
Mar	3	Mid	1.1	4.44	43.9	9	39.8	
Apr	1	Late	1.07	4.12	32.2	9.1	32.1	
Apr	2	Late	0.96	3.57	25.7	9.8	25.9	80.5
Apr	3	Late	0.84	3.26	22.6	12.3	20.4	
May	1	Late	0.76	3.09	9.3	4.3	2	
								9.3
					443	61.9	378.4	

Appendix Q: CWR and IWR estimation for Potatot crop

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec	Each month Total
Nov	3	Init	0.46	1.24	1.1	0.1	1.5	1.1
Dec	1	Init	0.5	1.34	1.3	0.2	1.3	28.3
Dec	2	Init	0.5	1.27	12.7	1	11.7	
Dec	3	Init	0.5	1.3	14.3	0.7	13.6	
Jan	1	Deve	0.56	1.47	14.7	0.1	14.6	64.7
Jan	2	Deve	0.75	2.01	20.1	0	20.1	
Jan	3	Deve	0.96	2.72	29.9	0	29.8	
Feb	1	Mid	1.09	3.27	32.7	0	32.6	97.2
Feb	2	Mid	1.1	3.43	34.3	0	34.3	
Feb	3	Mid	1.1	3.78	30.2	1.2	29	
Mar	1	Mid	1.1	4.2	42	5.7	36.3	132.2
Mar	2	Late	1.09	4.57	45.7	8.4	37.4	
Mar	3	Late	1	4.05	44.5	9	35.5	
Apr	1	Late	0.87	3.34	33.4	9.1	24.3	55.8
Apr	2	Late	0.75	2.8	22.4	7.8	12.6	
					378.3	43.3	333.2	

Appendix R: CWR and IWR estimation for Cabbage crop

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr.Req. mm/dec	Each month Total
Dec	1	Init	0.7	1.88	1.9	0.2	1.9	26.7
Dec	2	Init	0.7	1.78	10.8	1	16.8	
Dec	3	Init	0.7	1.82	14	0.7	19.3	
Jan	1	Init	0.7	1.85	18.5	0.1	18.4	60.5
Jan	2	Deve	0.7	1.89	18.9	0	18.9	
Jan	3	Deve	0.74	2.1	23.1	0	23.1	
Feb	1	Deve	0.79	2.37	23.7	0	23.7	74.8
Feb	2	Deve	0.85	2.65	26.5	0	26.5	
Feb	3	Deve	0.89	3.07	24.6	1.2	23.3	
Mar	1	Deve	0.94	3.59	25.9	5.7	30.2	91.8
Mar	2	Mid	0.99	4.13	31.3	8.4	32.9	
Mar	3	Mid	1.01	4.06	34.6	9	35.6	
Apr	1	Mid	1.01	3.87	31.7	9.1	29.6	88.5
Apr	2	Mid	1.01	3.76	27.6	9.8	27.8	
Apr	3	Mid	1.01	3.92	29.2	12.3	26.9	
May	1	Late	1	4.06	30.6	14.4	26.2	61.9
May	2	Late	0.95	3.99	19.9	16.5	23.4	
May	3	Late	0.9	3.8	11.4	5.7	1	
					504.2	94.1	405.5	

Appendix S: CWR and IWR estimation for Onion crop

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec	Eachmonth Total
Nov	3	Init	0.5	1.32	2.2	0.1	1.6	2.2
Dec	1	Init	0.6	1.61	1.6	0.2	1.6	34
Dec	2	Init	0.6	1.53	15.3	1	14.2	
Dec	3	Init	0.6	1.56	17.1	0.7	16.4	
Jan	1	Deve	0.6	1.6	16	0.1	15.9	59.5
Jan	2	Deve	0.69	1.84	18.4	0	18.4	
Jan	3	Deve	0.8	2.28	25.1	0	25.1	
Feb	1	Deve	0.92	2.76	27.6	0	27.5	86.3
Feb	2	Mid	1	3.12	31.2	0	31.2	
Feb	3	Mid	1	3.44	27.5	1.2	26.3	
Mar	1	Mid	1	3.82	38.2	5.7	32.5	123.2
Mar	2	Mid	1	4.16	41.6	8.4	33.3	
Mar	3	Late	0.98	3.94	43.4	9	34.3	
Apr	1	Late	0.91	3.49	34.9	9.1	25.8	44.5
Apr	2	Late	0.86	3.21	9.6	2.9	4.7	
					347.5	38.4	307.3	

Appendix T. Effective irrigable area within minimum flow for each selected crops

Area(ha) Eff 50% **Tomato**		0.5	GIWR (M³/s)	Min flow m³/s	Irrigated Area(ha)	Un irrigated area (ha)
Month		Area	24027.93ha			
Dec		31	4.11	1.78	5203.13	18824.8
Jan		31	9.41	1.37	1749.11	22278.8
Feb		28	14.969	1.13	906.926	23121
Mar		31	16.638	1.06	648.478	23379.5
April		30	13.505	1.11	987.449	23040.5
Potato	Area		20023.3ha			
Dec		31	2.573	1.8	7003.87	13019.4
Jan		31	8.466	1.37	1620.12	18403.1
Feb		28	13.148	1.13	860.446	19162.8
Mar		31	15.633	1.06	678.842	19344.4
April		30	3.228	1.11	3442.66	16580.6
Cabbage	Area		16018.6ha			
Dec		31	3.422	1.78	4166.15	11852.5
Jan		31	6.27	1.37	1750.04	14268.6
Feb		28	7.838	1.13	1154.7	14863.9
Mar		31	11.263	1.06	753.784	15264.8
April		30	9.72	1.11	914.643	15104
May		30	5.349	4.63	6932.72	9085.9
Onion	Area		20023.3ha			
Dec		31	3.425	1.78	5203.13	14820.8
Jan		31	7.688	1.37	1784.07	18239.9
Feb		28	11.518	1.13	982.215	19041.7
Mar		31	14.288	1.06	742.744	19281.2
April		30	1.539	1.11	7220.87	12803.1