

**IRRIGATION WATER POTENTIAL AND LAND SUITABILITY  
ASSESSMENT IN KURFA CHELE-GIRAWA WATERSHED, WABE  
SHEBELLE RIVER BASIN, ETHIOPIA**

**MSC THESIS**

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## **DEDICATION**

I dedicate this thesis manuscript to my father Mideksa Egu, to my mother Shito Faranji, to my wife Adanach Bogala with our daughter and son (Hawi, Senahara and Simera Girma) for nursing me with affection, love and for their dedicated partnership in the success of my life.

## **STATEMENT OF THE AUTHOR**

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis, and compilation of this Thesis. Any scholarly matter that is included in the thesis has been given recognition through citation. This thesis has been submitted in partial fulfillment of the requirements for M.Sc degree at Haramaya University and is deposited at the University Library to be made available under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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## **BIOGRAPHICAL SKETCH**

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## ACRONYMS AND ABBREVIATIONS

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

# TABLE OF CONTENTS

<b>STATEMENT OF AUTHOR</b>	<b>v</b>
<b>BIOGRAPHICAL SKETCH</b>	<b>vi</b>
<b>ACKNOWLEDGMENTS</b>	<b>vii</b>
<b>ACRONYMS AND ABBREVIATIONS</b>	<b>viii</b>
<b>LIST OF TABLE</b>	<b>xiii</b>
<b>LIST OF FIGURE</b>	<b>xiv</b>
<b>LIST OF TABLE IN THE APPENDIX</b>	<b>xv</b>
<b>LIST OF FIGURE IN THE APPENDIX</b>	<b>xvi</b>
<b>ABSTRACT</b>	<b>xvii</b>
<b>1.INTRODUCTION</b>	<b>1</b>
<b>2. LITERATURE REVIEW</b>	<b>5</b>
2.1. Definition of Irrigation	5
2.2. Definition of Irrigation Potential	5
2.3. Irrigation Potential in Ethiopia	5
2.3.1. Surface irrigation water potential	6
2.3.2. Ground irrigation water wotential	7
2.3.3. Rain water harvesting (RWH) irrigation potential	8
2.4. Irrigation Land Suitability	9
2.4.1. Land suitability order	9
2.4.2. Land suitability classes	10
2.4.3. Slope	13
2.4.4. Soils	13
2.4.5. Land cover or land use	13
2.4.6. Water availability	14
2.5. Overview of GIS application	14

## TABLE OF CONTENTS(Continued)

2.5.1. Mapping	15
2.5.2. Weighted Overlay Analysis	15
2.5.3. Watershed Delineation	16
2.5.4. GIS as a tool for irrigation potential assessment	16
2.6. Application of Remote Sensing	18
2.7. Review of Commonly Used GIS and Remote Sensing Data.	18
2.7.1. Spatially interpolated climate data on grids	19
2.7.2. Satellite imagery	19
2.7.3. Digital elevation model (DEM)	20
2.8. Assessment of Water Resources	21
2.8.1. Determine the mean annual runoff (mm) at the gauged site	22
2.8.2. Determine the MAR at ungauged site	22
2.9. Description of the CROPWAT Model	223
<b>3.MATERIAL AND METHOD</b>	<b>24</b>
3.1.General Description of the Study Area	24
3.1.1. Location	24
3.1.2. Climate	25
3.2. Materials Used	26
3.3. Method	28
3.3.1. Selection of irrigation method	28
3.3.2. Selection of evaluation criteria	28
3.3.3. Data pre-processing and checking	29
3.3.4. Watershed delineation	30
3.3.5. Identification of potential irrigable site	33

## TABLE OF CONTENTS(Continued)\_Toc1803918

3.3.6. Computing irrigation water requirements	41
3.3.7. Estimating surface water resources potential of river catchments	43
<b>4. RESULTS AND DISCUSSIONS</b>	<b>46</b>
4.1. Testing Stream Flow and Rainfall Data for Consistency	46
4.2. Watershed Delineation	47
4.3. Irrigation Suitability Evaluation	48
4.3.1. Slope Suitability	48
4.3.2. Soil suitability	50
4.3.3. Land cover/use evaluation	55
4.3.4. Distance from water source suitability	58
4.4. Potential Suitable Land for Irrigation	60
4.5. Gross Irrigation Water Requirements of the Identified Command Areas	62
4.6. Water Resources Assessment	62
4.6.1. Gauged and un-gauged watersheds similarities	62
4.6.2. Mean areal rainfall of sub-watersheds	65
4.6.3. Stream flows at un-gauged sites	71
4.6.4. Transferring discharges to sites of interest	71
4.7. Irrigation Potential of River Catchments	72
4.8. Storage requirement	76
<b>5. RECOMMENDATION, SUMMARY AND CONCLUSION</b>	<b>77</b>
5.1. Summary and Conclusion	77
5.2. Recommendation	78
<b>6. REFERENCES</b>	<b>80</b>

## **TABLE OF CONTENTS(Continued)**

<b>7. APPENDICES</b>	<b>86</b>
7.1. Summary of Hydro Meteorological Data	86
7.1.1. Hydrological Data	86
7.2. Meteorological data	88
7.2.1 Rain fall data	88
7.2.2. ETO and climatic data tables	98
7.2.3. Cropwat requirements	106

## LIST OF TABLE

<b>Table</b>	<b>Page</b>
1. Surface irrigation potential in Ethiopia by river basin.	6
2. Ground water potential in the three Ethiopian zones	8
3. Slope suitability classification for surface irrigation	34
4. Soil suitability factor rating	35
5. Hydrometric stations inside the study area	43
6. Slope suitability range of the study area for surface irrigation	49
7. Soil suitability classification result for surface irrigation	53
8. Confusion matrix of SPOT 2016 LUC classification	56
9. Area coverage of land cover/use classes of the study are	57
10. Area coverage of Euclidean distance classes of the study are	59
11. Characteristics of watersheds above the gauged and un-gauged sites	64
12. Average monthly areal rainfall of the sub-watersheds.	69
13. Mean monthly stream flows of un-gauged river catchments estimated from gauged sites	71
14. Mean monthly discharges (m <sup>3</sup> /s) at the sites of interest	72
15. Critical command area of Maize	72
16. Critical command area of Potato	73
17. Comparing of irrigation demands and available flows of river catchments in the study area for Maize.	74
18. Comparing of irrigation demands and available flows of river catchments in the study area for Potato	75
19. The water storage requirement for potential command area of a maize crop	76
20. The water Storage requirement for potential command area of a Potato	76

## LIST OF FIGURE

<b>Figure</b>	<b>Page</b>
1. Hierarchical organization of criteria	12
2. Location map of the study area	25
3. Agro-climatic classification of the study area	26
4. Digital elevation model showing the drainage system of the study area map.	31
5. Flow direction and streams network map	32
6. Watershed outlets definition map.	33
7. SPOT2016 satellite image of the study area showing true color composite (321)	37
8. Irrigation suitability Flow Chart	40
10. Double mass curve of Hamaressa gauging station	46
11. Double mass curve of six rainfall stations	47
12. Shows the main and sub-watersheds in the study area.	48
13. Slope suitability map of the study area for surface irrigation	49
14. Soil classification of study area map	51
15. Soil suitability map of the study area	54
16. Land cover/use map of the study area	57
17. Euclidean distance map of the study area	59
18. Final irrigation suitability map of the study area	61
19. Potential irrigable land map of the study area	61
20. Soil map of Hamaressa and May guda Sub-watershed	63
21. Slope map of Hamaressa and Maya guda Sub-watershed	63
22. LULC map of Hamaressa and Maya kelo Sub-watershed	64
23. Theissen polygon map of Dawe sub-watershed gauge site near Gara	66
24. Theissen polygon map of Hamaressa sub-watershed gauge site near Harar	66
25. Theissen polygon map of Maya Guda sub-watershed	67
26. Theissen polygon map of Kersa guba sub-watershed	67
27. Theissen polygon map of Maya Kelo sub-watershed	68
28. Theissen polygon map of Bululo sub-watershed	68

## **LIST OF TABLE IN THE APPENDIX**

<b>Appendix Table</b>	<b>Page</b>
1. Hamaressa River monthly flow (m <sup>3</sup> /s)	86
2. Dawe River near garamulata'a monthly flow (m <sup>3</sup> /s)	87
3. Corrected monthly rainfall data at Haramaya (mm)	88
4. Corrected monthly rainfall data at Harar Indicative (mm)	90
5. Corrected monthly rainfall data at Kersa (mm)	91
6. Corrected monthly rainfall data at Girawa (mm)	92
7. Corrected monthly rainfall data at Kulubi (mm)	93
8. Corrected monthly rainfall data at Hakim gara (mm)	94
9. ETO and climatic data for Haramaya meteorological station	100
10. ETO and climatic data for Hara Indicative meteorological station	101
11. ETO and climatic data for Girawa meteorological station from climwat	102
12. ETO and climatic data for Kersa meteorological station from weather data	103
13. ETO and climatic data for Kulubi meteorological station from weather data	104
14. ETO and climatic data for Hakim gara meteorological station from weather data	105
15. Maize monthly irrigation water requirements at Haramaya stations	106
16. Maize monthly irrigation water requirements at Hara Indicative stations	107
17. Maize monthly irrigation water requirements at Girawa stations	108
18. Maize monthly irrigation water requirements at Kersa stations	109
19. Maize monthly irrigation water requirements at Hakim gara stations	110
20. Maize monthly irrigation water requirements at Kulubi stations	111
21. Potato monthly irrigation water requirements at Haramaya stations	112
22. Potato monthly irrigation water requirements at Harar Indicative stations	113
23. Potato monthly irrigation water requirements at Harar Indicative stations	114
24. Potato monthly irrigation water requirements at Hakim gara stations	115
25. Potato monthly irrigation water requirements at Kersa stations	116
26. Potato monthly irrigation water requirements at Kulubi stations	117
27. FAO Table value of crowpat for Maize and Potato	118

## LIST OF FIGURE IN THE APPENDIX

<b>Appendix Figure</b>	<b>Page</b>
1.Double mass curve for the consistency of Girawa meteorological stations rainfall data	95
2.Double mass curve for the consistency of Haramaya meteorological stations rainfall data	95
3.Double mass curve for the consistency of Haramaya meteorological stations rainfall data	96
4.Double mass curve for the consistency of Kulubi meteorological stations rainfall data	96
5.Double mass curve for the consistency of Hakim gara meteorological stations rainfall data.	97
6.Double mass curve for the consistency of Kersa meteorological stations rainfall data.	97

# **Irrigation Water Potential and Land Suitability Assessment in Kurfa Chele-Girawa Watershed, Wabe Shebelle River Basin, Ethiopia.**

## **ABSTRACT**

*Assessing available land and water resources for irrigation are important for planning their use. From a number of uncertainties, the watershed constrained that stream flows from some of the rivers are not known, potential irrigable areas in the watershed have not been identified and matched with the water requirements of some crops commonly grown in the watershed. It is therefore this study was initiated with the objective of assessing the water and land resources potential of river catchments in Kurfa Chele-Girawa watershed. Watershed delineation, identification of potentially irrigable land, and estimation of irrigation water requirement and surface water resources of river catchments were the steps followed to assess the irrigation potential of the study area. To identify potentially irrigable land, irrigation suitability factors such as soil type, slope, land cover/use, and distance from the water supply (sources) were taken into account. The irrigation suitability analysis of these factors indicates that 55.1 % of soil, 95.6 % slope and 93.7% of Euclidean distance in the study area are in the range of highly suitable to marginally suitable for a surface irrigation system and 88.6% of land cover/use are highly suitable. The weighted overlay analysis of these factors resulted that total surface irrigation potential of the study area are 128,429.6 ha, from this, the potential irrigable land was obtained as 58,995.15 ha. To grow crops on these identified irrigable areas, two crops such as Maize and Potato were selected and their gross irrigation demand were calculated by using nearby climatic stations. The result has shown that irrigation requirements of the identified command area varies according to nearby climatic station and type of crops selected. The discharges at un-gauged sites were estimated from gauged sites by applying runoff coefficient method and results were obtained on a monthly basis. By comparing gross irrigation demand of irrigable land with available flow in rivers, a gross irrigation demand of potentially irrigable land of 58,995.15ha are not fulfill with the present flow, so providing a means of water storage above the potential command area are necessary.*

**Keyword:** GIS, Remote sensing Land suitability, Surface Irrigation potential, weighted overlay.



## 1. INTRODUCTION

With declining productivity in rain-fed agriculture and with the need to double food production over the next two decades, water has been recognized as the most important factor for the transformation of low productive rain-fed agriculture into most effective and efficient irrigated agriculture (FAO, 1994). It is obvious that the utilization of water resources in irrigated agriculture provide supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. Hence, the solution for food insecurity could be provided by irrigation development that can lead to security by reducing variation in harvest, as well as an intensification of cropping by producing more than one crop per year.

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 smallholder agriculture and hence rainfall is the single most important determinant of food supply and the country's economy (Belete,2006). The major problem associated with rainfall-dependent agriculture in the country is the high degree of rainfall variability and unreliability. Due to this variability, crop failures due to dry spells and droughts are frequent. As a consequence, food insecurity often turns into famine with the slightest adverse climatic incident, particularly, affecting the livelihoods of the rural poor.

Ethiopia comprises 112 million hectares (Mha) of land. Cultivable land area estimates vary between 30 to 70 Mha. Currently, high estimates show that only 15 Mha of land is under cultivation. For the existing cultivated area, our estimate is that only about 4 to 5 percent is irrigated, with existing equipped irrigation schemes covering about 640,000 hectares. This means that a significant portion of cultivated land in Ethiopia is currently not irrigated. This section examines Ethiopia's water sources for irrigation, current irrigation schemes, and the potential to increase irrigated lands (Seleshi and Awlacheu,2010).

The concept of land sustainability implies the development and implementation of systems for land use, evaluation and management which will sustain individual and community benefits now and in the future. In Ethiopia, land resource degradation is a major threat that affects the existence and

livelihood of the community. The degradation of land resource, due to over-exploitation and misuse along with consequent economic, social and environmental impacts has intensified the pressure on the land resource of the country (Kebede,2010). The assessment of land suitability for agriculture is a complex, multidisciplinary and multi-criteria process which entails land topography, climate, water resources available for irrigation, soil capabilities and current management practices including land use and land cover (Malczewski, J., 2010; Elsheikh, R. *et al.*, 2013).

Sustainable food production that can be expected through an optimal development of water resources in conjunction with the development of land depends on the method of irrigation considered (FAO, 2003; Panigrahy *et al.*, 2006). These methods, however, can be broadly classified into three categories: surface (basin, border, and furrows), sprinkler, and drip/micro irrigation methods. Surface irrigation is the application of water by gravity flow to the surface of the field, either the entire field is flooded (basin irrigation) or the water is fed into a small channel (furrow) or strip of land (borders). It is the oldest and still the most widely used method of water application to agricultural lands.

Surface irrigation offers a number of benefits for the less skilled and poor farmers. Under such circumstances, more than 90% of the world uses surface irrigation, even if local irrigators have the least knowledge of how to operate and maintain the system (Saymen,2005). Furthermore, these systems can be developed at the farm level with minimal capital investment. The major capital investment on the surface system is mainly associated with land grading, but if the topography is not too undulating, these costs are not high. Hence, surface irrigation development requires favorable topography and information on land and water resources for proper planning (FAO, 1995). Therefore, the planning process for surface 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,1997). The suitability of the land must also be evaluated on condition that water can be supplied to it. The volume of water obtainable for irrigation will depend on the outcome of hydrological studies of surface water (FAO, 1985). The amount of runoff in river catchments with limited stream flow data can be determined from runoff coefficient of gauged river basin (Goldsmith, 2000; DFID, 2004; Sikka, 2005). After the amount of river discharges both gauged and un-gauged are quantified, an important part of the evaluation is the matching of water

supplies and water demand (requirement) (FAO, 1977b). Irrigation water supplies and their requirements are therefore, important physical factors in matching the available supply to the requirements.

Future increase in food production to supply a growing population must result from new irrigation projects that should be technically and environmentally well planned. However, new potential lands, suitable for irrigation with good quality of water were scarce resources. Modernization of the irrigation systems, efficient water management and reclamation of waterlogged and salt-affected lands are being thought to be an urgent need to achieve sustainable agriculture (Kebede,2010).

To achieve these goals, soil surveys, land irrigability and water resource potential are essential in the planning and design stages of irrigation projects, either for land evaluation to assess the suitability of new lands for irrigation or for land reclamation to achieve sustainability in rehabilitation projects.

Soil and topographic characteristics greatly affect the design and operation of the irrigation system. Soil survey provides a base for the decision about the kind and the intensity of land management needed for irrigated agriculture. It is useful in planning, designing and implementing an irrigation system for a farm. The kind of soil and its associated characteristics help in determining water application rate, the requirement of soil amendment and leaching and field practices to maintain optimum soil conditions for plant growth (Dagnenet,2008).

In Ethiopia, a limited number of reports and investigations were made to assess the irrigation potential based on physical land and water resources (Negash and Seleshi,2004). Small scale studies conducted on irrigation land suitability of the country seem to be inadequate in providing basic soil information that can help to make a decision on the proper utilization of resources.

In Kurfa Chele-Girawa watershed, there are one perennial river and eleven seasonal rivers. Despite this number of rivers, exploitation of their water resources for irrigated agriculture is low in the watershed. The efforts to establish small and large-scale irrigation schemes in the watershed are constrained by a number of uncertainties. Firstly, stream flows from some of the rivers are not

known. Secondly, potential irrigable areas in the watershed have not been identified and matched with the water requirements of some crops commonly grown in the watershed.

Therefore, to overcome these uncertainties, this study was carried out by using GIS as a tool for assessing irrigation potential in the watershed using input data from soil, digital elevation model (DEM), and satellite image (SPOT5.4.3) and geo-referencing and mapping of the assessment result in the context of surface irrigation development in the study area. Because with an adequate database, geographic information systems (GIS) can serve as a powerful analytic and decision-making tool for irrigation development (Aguilar-Manjarrez and Ross, 1995; FAO 1987, 1995, 1997, Melaku,2003; Hailegebriel,2007; Meron,2007). Furthermore, the study attempted to estimate water resource potential of the river catchments in the watershed and the irrigation water requirements of the identified irrigable areas for cultivating some selected crops in the area.

The main objective of this study was to assess the irrigation water potential and land suitability of Kurfa Chele-Grawa watershed in Wabe Shebelle basin and to provide a map of potential irrigable land of the catchments for future planning and development possibilities.

The specific objectives of the study include:

- To evaluate irrigation water potential for surface irrigation in Kurfa Chele-Girwa watershed.
- To evaluate irrigation land suitability for surface irrigation in Kurfa chele\_Girwa watershed using GIS approach.
- To develop irrigability potential map of the study area for future planning and development possibilities.

## **2. LITERATURE REVIEW**

### **2.1. Definition of Irrigation**

Irrigation can be defined as an artificial application of water to soil for the purpose of supplying the moisture essential in the plant root-zone to prevent stress that may cause reduced yield and/or poor quality of harvest of crops (Reddy, 2010; Gebremedhin and Asfaw,2015).

Irrigation can be referred as the process by which water is diverted from a river or pumped from a well and used for the purpose of agricultural production (FAO, 1986). The area, which can potentially be irrigated, depends on the physical resources, soil and water, combined with the irrigation water requirements as determined by the cropping patterns and climate.

Irrigation is an agricultural operation supplying the soil moisture deficit with water. To the agriculturalist, it is a component of successful crop husbandry, particularly in a dry climate. A reliable and suitable irrigation water supply can result in improvements in agricultural production and assure the economic vitality (FAO, 1989).

### **2.2. Definition of Irrigation Potential**

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

### **2.3. Irrigation Potential in Ethiopia**

Ethiopia has vast cultivable land (30 to 70 Mha), 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. However, the study estimates that total irrigable land potential in Ethiopia is 5.3 Mha assuming use of existing technologies, including 1.6 Mha through RWH and groundwater. The country has surface water, groundwater, and rainwater sources that can be developed for at least 5.3 million hectares of irrigation potential. This means that up to one-sixth of the country's cultivable land can be irrigated through existing water sources a significant increase from current levels. This includes 3.7 Mha from gravity-fed surface water and an additional 1.1 and 0.5 Mha from groundwater and rainwater harvesting, respectively (Seleshi and Awulachew,2010).

### 2.3.1. Surface irrigation water potential

While there is significant potential to increase irrigation through various surface water schemes, there are many challenges to realize this potential. Most of the surface water potential is located in pastoralist areas due to land availability and flow concentration in these low land areas. But realizing irrigation potential in pastoralist areas requires innovations, as it poses significant changes related to pastoralists' traditional lifestyles such as sedentary farming, the voluntary settlement from degraded highlands, and small to large scale commercial agriculture (Seleshi and Awlachew, 2010).

Table 1: Surface irrigation potential in Ethiopia by river basin.

Basin	Catchment Area(km <sup>2</sup> )	Irrigation Potential(ha) (Respective recent master plan studies)			
		Small Scale	Medium Scale	Large Scale	Total
Abbay	198,890.70	45,856	130,395	639,330	815,581
Tekeze	83,475.94	N/A	N/A	83,368	83,368
Baro-Akobo	76,203.12	N/A	N/A	1,019,523	1,019,523
Omo-Ghibe	79,000.00	N/A	10,028	57,900	67,928
Rift Valley	52,739.00	N/A	4,000	45,700	139,300
Awash	110,439.30	30,556	24,500	79,065	134,121
Genale-Dawa	172,133.00	1,805	28,415	1,044,500	1,074,720
Wabe-Shebelle	202,219.50	10,755	55,950	171,200	237,905
Danakil	63,852.97	2,309	45,656	110,811	158,776
Ogaden	77,121.00	-	-	-	-

Ayisha	2,000.00	-	-	-	-
Total	1,118,074.53				3,731,222

Source: Seleshi and Awlacheu, (2010). Irrigation Potential in Ethiopia (IWMI).

### 2.3.2. Ground irrigation water potential

Seleshi and Awlacheu, (2010) discuss groundwater in Ethiopia can be used for irrigation in multiple ways, such as deep and shallow wells from underground aquifers. Compared with other sources of irrigation, groundwater as a resource for agricultural development offers a number of advantages, including:

- ✓ Reliability of the water source, since it has a naturally renewable capacity if water is not extracted above certain thresholds
- ✓ On-demand water supply through natural water storage.
- ✓ Domestic water source, with no trans-boundary considerations.
- ✓ Availability in many places, e.g. in highlands, steep terrains, inland valleys, and plain areas
- ✓ Relative constancy of supply, which can help to buffer the high variability of surface water resources.

Despite these advantages of groundwater, it is not widely exploited in agriculture in Ethiopia due to the following constraints:

- Costly development and operations. The depth of access can increase investment requirements, since the average cost of per hectare of groundwater development, including operation, is two to four times higher than for surface water irrigation (e.g., stream diversion). This is especially true for deep wells, which are expensive to develop and operate.
- Lack of a comprehensive understanding of Ethiopia's groundwater resources. Information regarding aquifer characteristics, delineation, available water, sustainable recharge amount, etc., is limited and not well understood due to complex Ethiopian geology and lack of studies.
- Difficulties and costs related to the need for specialized equipment (e.g., deep drilling rigs) and specialized and well-trained staff (e.g., well drillers).
- The estimation of groundwater irrigation potential is 1.1 Mha. Irrigable potential by zone is summarized in the following Table (2).

Table 2: Groundwater potential in the three Ethiopian zones

Zone and ground potential	Available water (BMC)	Irrigation potential (ha)
o Zone 1 high potential	1.06	211,386.00
o Zone 1 medium potential	0.83	137,636.00
o Zone 1 low potential	0.23	32,317.00
o Zone 2 high potential	0.63	126,806.00
o Zone 2 medium potential	0.49	81,542.00
o Zone 2 low potential	0.23	32,317.00
o Zone 3 high potential	1.56	311,808.00
o Zone 3 medium potential	0.85	141,989.00
o Zone 3 low potential	0.63	90,081.00
	6.51	1,165,882.00

Source: Seleshi and Awlacheu, (2010), Irrigation Potential in Ethiopia (IWMI). Three Zone (High rainfall zone, Moisture deficit zone, and Pastoralist zone).

### 2.3.3. Rain water harvesting (RWH) irrigation potential

Currently, rainwater use in Ethiopian agriculture involves both unmanaged and managed rainwater use in rain-fed agriculture. In terms of increasing irrigation potential incrementally to the formal irrigation component, through RWH and better water management, it can provide an additional 0.5 Mha in irrigation. The assessment shows that rainwater harvesting potential measures are most important in zone 2 due to its low and highly variable rainfall, leading to a need for supplementary irrigation. In zone 1, capturing RWH potential could be through spate and shallow hand-dug wells, while for zone 3, the irrigation potential from RWH is minimal due to low rainfall (Seleshi and Awlacheu,2010).

Ethiopia, indeed, has significant irrigation potential assessed both from available land and water resources potential, irrespective of the lack of accurate estimates of potentially irrigable land and developed area under irrigation (Kebede,2010).

## 2.4. Irrigation Land Suitability

Land suitability is the fitness of a given type of land for a defined use. The land may be classified in its present condition or after improvements for its specified use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976; Kabede,2010).

The land suitability classes show degrees of suitability within each order. The degree of suitability indicates whether the land unit can be grouped into prime (or best) or lower (or poorest) levels of land suitability class for a land utilization type(OWWDSE,2010).

Land evaluation is primarily the analysis of data about the land: - its soils, climate, vegetation, and etc. in terms of realistic alternatives for improving the use of that land. For irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, to the distance from available water sources and to the terrain conditions in relation to methods of irrigation considered (FAO, 2007). In addition to these factors, land cover/land use types are considered as limiting factors in evaluating the suitability of land for irrigation (Haile, 2007; Meron,2007). As extensively discussed in FAO land evaluation guidelines (FAO,1976, 1983, 1985), the suitability of these factors for surface irrigation method and for the given land utilization types can be expressed corresponding to the following suitability classes.

### 2.4.1. Land suitability order.

Land suitability Orders indicate whether the land is assessed as suitable or not suitable for use under consideration. There are two orders represented in maps, tables, etc. by the symbols S and N for suitable and not suitable, respectively.

**Order S (Suitable):** Land on which sustained the 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 prevent sustained use of the kind under consideration. Land may be classed as “Not suitable” for a given use for a number of reasons. It may be that the proposed use is technically impracticable, such as the irrigation of rocky

steep land, or that it would cause severe environmental degradation, such as the cultivation of steep slopes. Frequently, however, the reason is economic that the value of the expected benefits does not justify the expected costs of the inputs that would be required.

#### **2.4.2. Land suitability classes**

Land Suitability Classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic numbers, in sequence of decreasing degrees of suitability within the Order. Within the “Order Suitable” the number of classes is not specified. There might, for example, be only two, S1 and S2. The number of classes recognized should be kept to the minimum necessary to meet interpretative aims; five should probably be the most ever used. If three Classes are recognized within the “Order Suitable”, as can often be recommended, the following names and definitions may be appropriate in a qualitative classification:

- **Class S1 (Highly Suitable):** Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
- **Class S2 (Moderately Suitable):** Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land.
- **Class S3 (Marginally Suitable):** Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

Within the Order Not suitable, there are normally two Classes:

- **Class N1 (Currently Not suitable):** Land having limitations which may be manageable in time but which cannot be corrected with existing knowledge at a currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.

- **Class N2 (Permanently Not suitable):** Land having limitations which appear so severe as to prevent any possibilities of successful sustained use of the land in the given manner. The quantitative definition of these classes is normally unnecessary since by definition both are uneconomic for the given use. The upper limit of Class N1 is already defined by the lower limit of the last suitable class in Order S.

The boundary of class N2, permanently Not Suitable, is normally physical and permanent. In contrast, the boundary between the orders, Suitable and Not Suitable is likely to be variable over time through changes in the economic and social context.

The factors considered for surface irrigation land suitability evaluation are described separately in the following sub-sections:

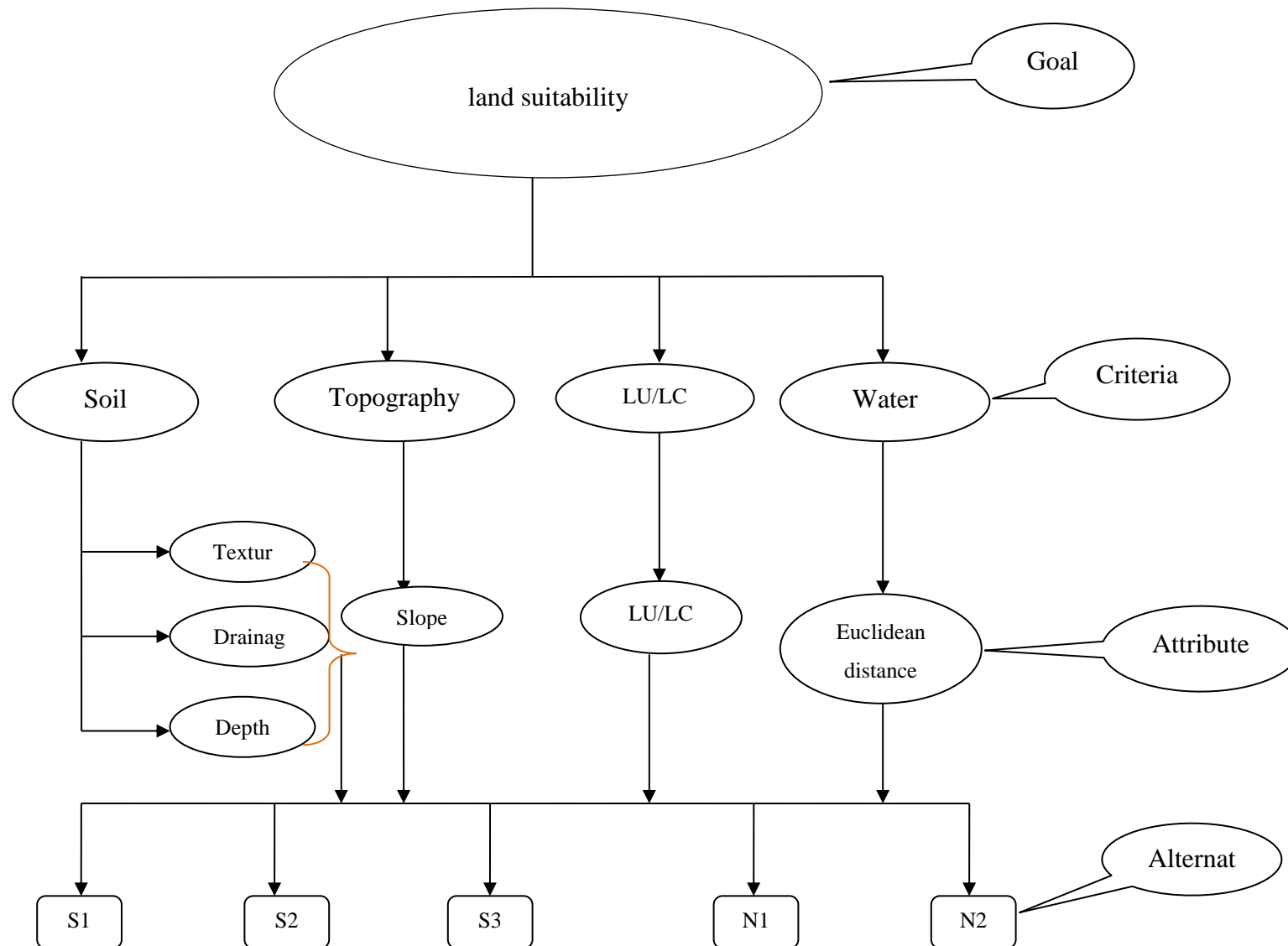


Figure 1. Hierarchical organization of criteria

### **2.4.3. Slope**

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

### **2.4.4. Soils**

The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such properties include drainage, texture, depth, salinity, and alkalinity (Fasina *et al*, 2008). Even though salinity and alkalinity hazards possibly improved by soil amendments or management practices, they could be considered as limiting factors in evaluating the soils for irrigation (FAO, 1997). Accordingly, some soils consider not suitable for surface irrigation could be suitable for sprinkler irrigation or micro-irrigation and selected land utilization types (Kebede,2010).

### **2.4.5. Land cover or land use**

Land cover and land use are often used interchangeably. However, they are actually quite different. GLCN (2006) defines land cover as the observed (bio) physical cover, as seen from the ground or through remote sensing, including vegetation (natural or planted) and human construction (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock or sand surfaces also count as land cover. However, the definition of land use establishes a direct link between land cover and the actions of people in their environment. Thus, land use can be defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one, or more than one, pieces of land and several land uses may occur on the same piece of land. Definitions of land cover or land use in this way provide a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation. Therefore, matching of existing land cover/use with topographic and soil characteristics

to evaluate land suitability for irrigation with land suitability classes, present possible lands for new agricultural production (Jaruntorn *et al.*,2004; Kebede,2010).

#### **2.4.6. Water availability**

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

Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source is near to 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 (Selesh,2000; Kebede,2010).

### **2.5. Overview of GIS Application**

Many definitions of GIS have been proposed in the literature depending on the discipline of application. However, a common theme in all definitions is that a GIS is a set of tools for collecting, storing, retrieving, reporting, analyzing, and displaying spatial information in order to improve the efficiency and effectiveness of a project (Hatibu *et al.*, 2000).

A Geographic Information System (GIS) is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data (Goodchild, 2000). Geographically referenced data are data that describe both the locations and characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface. The ability of a GIS to handle and process geographically referenced data distinguishes GIS from other information systems which are the other information system. It also establishes GIS as a

technology important to a wide variety of applications. Clearly, the increased availability of large, geographically referenced data sets and improved capabilities for visualization, rapid retrieval, and manipulation inside and outside of GIS will demand new methods of exploratory spatial data analysis that are specifically tailored to this data-rich environment (Wilkinson,1996; Gahegan,1999).

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. The most common geographic analyses that can be done with a GIS are narrated separately in the subsequent sub-sections (kebede,2010).

### **2.5.1. Mapping**

The main application in GIS is mapping where things are and editing tasks as well as for map-based query and analysis (Campbell,1984). A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. The map represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend (Kebede,2010).

### **2.5.2. Weighted overlay analysis**

The 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 the optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from the water supply (Yang Yi D.H.G., 2003). To prioritize the influence of these factor values, weighted overlay analysis uses an evaluation scale from 1 to 9 by 1. For example, a value of 1 represents the least suitable factor in evaluation while; a value of 9 represents the most suitable factor in the evaluation. Weighted overlay only accepts integer raster's as input, such as a raster of land cover/use, soil types, slope, and Euclidean distance output to find suitable land for irrigation

(Janssen and Rietveld, 1990). Euclidean distance is the straight line from the center of the source cell to the center of each of the surrounding cells.

### **2.5.3. Watershed delineation**

A watershed can be defined as the catchment area or a drainage basin that drains into a common outlet. Simply, the watershed of a particular outlet is defined as an area, which collects the rainwater and drains through gullies, to a single outlet. Delineation of a watershed means determining the boundary of the watershed i.e. ridgeline. GIS uses DEMs data as input to delineate watersheds with an integration of Arc-SWAT or by hydrology tool in Arc-GIS spatial analysis (Winchell *et al.*, 2008; Kebede,2010).

### **2.5.4. GIS as a tool for irrigation potential assessment**

In the past, several studies have been made to assess the irrigation potential and water resources by using GIS tool (FAO, 1987; FAO, 1995; FAO, 1997; Melaku,2003; Negash,2004; Hailegebriel,2007; Meron,2007). FAO (1987) conducted a study to assess land and water resources potential for irrigation in Africa on the basis of river basins of countries. It was one of the first GIS-based studies of its kind at a continental level. It proposed a natural resource-based approach to assess irrigation potential. Its main limitations were in the sensitivity of criteria for defining land suitability for irrigation and in water allocation scenarios needed for computation of irrigation potential.

Another study was conducted by FAO (1995), as part of the AQUASTAT programme, which is a program for the country wise collection of secondary information on water resources and irrigation. A survey was carried out in all African countries, where information on irrigation potential was systematically collected from master plans and sectoral studies. Such an approach integrates many more considerations than a simple physical approach to assessing irrigation potential. However, it cannot account for the possible double counting of water resources shared by several countries.

FAO (1997) has studied the irrigation potential of Africa taking into consideration the above limitations. It concentrated mainly on quantitative assessment based on physical criteria (land and water), but relied heavily on information collected from the countries. A river basin approach had

been used to ensure consistency at river and basin level. Geographic Information System (GIS) facilities were extensively used for this purpose. In this study, a physical approach to irrigation potential was understood as setting the global limit for irrigation development.

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

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

Hailegebriel (2007) conducted a study on Irrigation potential evaluation and crop suitability analysis using GIS and Remote sensing techniques in Beles sub-basin, Beneshangul Gumuz Region. The study considered slope, soil, land cover/use, water resources and climate factors in evaluating surface irrigation suitability.

Meron (2007) carried out similar work on surface irrigation suitability analysis of southern Abay basin by implementing GIS techniques. This study considered soil, slope and land cover /use factors to find suitable land for irrigation with respect to a 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.

Kabede (2010) conducted a study on Surface Irrigation Potential Assessment of River Catchments for Irrigation Development in Dale Woreda, Sidama Zone, SNNP based GIS. The study considered a slope, soil, land cover/use and water resources factors in evaluating surface irrigation suitability.

Tesfay Hailu (2017) conducted a study on Surface Irrigation Suitability Assessment and Development of Map for the Low Land Gilo Sub-Basin of Gambella, Ethiopia. The study considered factors that could be used to identify the existing and potential irrigable land were slope, soil texture, depth, drainage characteristics, soil type, and land use/cover.

## **2.6. Application of Remote Sensing**

Remote Sensing refers to the technique of obtaining information about an object or feature through the analysis of data acquired by a device that is not in contact with the object or feature under investigation (Lillesand and Kiefer, 1994). This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest.

Remote Sensing technology produces an authentic source of information for surveying, identifying, classifying, mapping, monitoring, and planning of natural resources and disasters mitigation, preparedness and management as a whole. Remote sensing is a technology that has a close tie to GIS. Remote sensing can provide timely data at scales appropriate to a variety of applications. As such many researchers feel that the use of GIS and RS can lead to important advances in research and operational applications. Merging these two technologies can result in a tremendous increase in information for many kinds of users. Land cover/use mapping is one of the most important and typical applications of remote sensing (Lillesand,2000). Land cover corresponds to the physical condition of the ground surface, for example, forest, grassland, concrete pavement etc. Land use reflects human activities such as the use of the land, for example, industrial zones, residential zones, agricultural fields etc.

## **2.7. Review of Commonly Used GIS and Remote Sensing Data.**

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

### **2.7.1. Spatially interpolated climate data on grids**

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

### **2.7.2. Satellite imagery**

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

The use of satellite images in any of fields mentioned above, demands the knowledge of the different bands that each sensor system onboard satellites use to take the imagery and how these bands of the electromagnetic spectrum interact with land surface features and with that of the atmosphere (Lemlem,2007; Kebede,2010). All types of satellites vary with their sensors, flight height, bands, and spatial resolution, spectral resolution, etc. The spatial resolution of a satellite image relates to the ground pixel size. For example, a spatial resolution of 30 meters means that each pixel in the satellite image corresponds to a ground pixel of 900 square meters. The pixel value, also called the brightness value, represents light energy reflected or emitted from the Earth's surface (Jensen 1996; Lillesand and Kiefer, 2000; Kebede,2010). The measurement of light energy is based on spectral bands from a continuum of wavelengths known as the electromagnetic spectrum. Panchromatic images are comprised of a single spectral band, whereas multispectral images are comprised of multiple bands.

As there are many satellites in the space providing remote sensing data, their application will vary with their way of data acquisition. The most popular satellites are the land sat and SPOT. The land

sat operated by the National Aeronautics and Space Administration (NASA) with the cooperation of the U.S. Geological Survey (USGS) since the early 1970s till 2003, has produced the most widely used imagery worldwide with 60,30 and 15m spatial resolutions (Blundell and Opitz, 2006).

SPOT (Système Pour l'Observation de la Terre) is a series of Earth observation imaging satellites designed and launched by CNES (Centre National d'Études Spatiales) of France, with support from Sweden and Belgium. SPOT-1 was launched in 1986, with successors following every three or four years. SPOT was designed to be a commercial provider of Earth observation data, and it is available with different resolutions such as 10m, 5m 2.5m and 1.5m on the market. SPOT has a number of benefits over other space-borne optical sensors. Its fine spatial resolution and pointable sensors are the primary reasons for its popularity (Zhang, 2002). The three band multispectral data are well suited to displaying as false-color images and the panchromatic band can also be used to "sharpen" the spatial detail in the multispectral data. SPOT allows applications requiring fine spatial detail (such as urban mapping) to be addressed while retaining the cost and timeliness advantage of satellite data. The potential applications of SPOT5 data are numerous. Applications requiring frequent monitoring (agriculture, forestry) are well served by the SPOT5 sensors. The acquisition of stereoscopic imagery from SPOT5 has played an important role in mapping applications and in the derivation of topographic information (Digital Elevation Models - DEMs) from satellite data (Kakiuchi *et al.*, 2003; Kebede,2010).

### **2.7.3. Digital elevation model (DEM)**

DEMs are point elevation data stored in digital computer files. These data consist of x, y grid locations, and point elevation or z variables. They are generated in a variety of ways for 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 on board a space shuttle. For most parts of the world, these data set provides a dramatic improvement in the availability of high-quality and high-resolution elevation data (Jarvis *et al.*, 2004). Digital Elevation Models (DEM)

is a commonly used digital elevation source and an important part of using for watershed characterization. Many agencies provide DEM data with 90-m, 30-m, and 10-m resolutions. The point elevation data are very useful as an input to the GIS. This data is used to yield important derivative products such as slope, aspect, flow accumulation, flow direction and curvature in the process of watershed delineation.

## **2.8. Assessment of Water Resources**

Assessment of water resources can only be done at the basin level (FAO, 1997; Seleshi *et al.*, 2007). According to the CA (2007), “river basins are the geographic area contained within the watershed limits of a system of streams and rivers converging toward the same terminus, generally the sea or sometimes an inland water body. Tributary sub-basins or basins more limited in size (typically from tens of square kilometers to 1,000 square kilometers) are often called watersheds (in American English), while catchment is frequently used in British English as a synonym for river basins, watershed being more narrowly defined as the line separating two river basins. An important consideration in water resource assessment is to estimate how much flow is available at the outlet of river catchment. The volume of water reliably available on an annual or seasonal basis can be determined from the available data in case of gauged rivers and for completely ungauged rivers the runoff coefficient method can be employed (Goldsmith, 2000).

According to DFID (2004), when this is the case, then data from the gauging site should be used to estimate mean annual runoff (MAR) at an ungauged site, provided that the requirements set out below are met:

- i. Catchment characteristics should be similar,
- ii. The distance between the centroids of the catchments should be less than 5km,
- iii. At least ten years of mean monthly flows should be available.

Otherwise, the simplest method of estimating mean annual runoff in the un-gauged site was established in applying a runoff coefficient to the mean annual rainfall as shown below in the following steps.

### 2.8.1. Determine the mean annual runoff (mm) at the gauged site

$$MAR_g = K * MAP \quad (2.1)$$

where:

$MAR_g$  = Mean annual runoff at gauged site (mm)

$MAP$  = Mean annual precipitation at gauged site (mm)

$$K = \frac{MAR_g}{MAP} \quad (2.2)$$

$K$  = Runoff coefficient at gauged site

### 2.8.2. Determine the MAR at an ungauged site

$$MAR_u = K * MAP_g \quad (2.3)$$

$MAR_u$  = Mean annual runoff at the un-gauged site (mm)

The mean annual or monthly runoff depth obtained from equation (2.3) at the un-gauged site can be converted to mean monthly runoff considering, average areal monthly rainfall and catchment area of both gauged and ungauged sites (Jamshid,2003; Kabede,2010). Estimation of areal rainfall over a given catchment is therefore, useful for estimating the total runoff generated from the entire catchment. There are several methods of determining the spatial distribution of rainfall, and all of them yield slightly different variations of rainfall patterns across an area.

The Thiessen method is a widely recognized scheme proven to be reasonably accurate for estimating areal precipitation distributions. The primary assumption in the Thiessen method is that areas closest to a precipitation station are most likely to experience similar rainfall conditions to those measured at the station location (Chow *et al.*, 1988). Thiessen polygons can be constructed using the GIS to determine the spatial distribution of storms for computation of spatially variable excess rainfall. Grids of rainfall can also be computed and mapped for selected storm events (Melesse,2002; Kebede,2010).

## 2.9. Description of the CROPWAT model

CROPWAT is a computer program to calculate crop water requirements, reference evapotranspiration and irrigation requirements from climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying cropping patterns. The program will run on any IBM-PC type of computer with a minimum of 360 Kb(FAO,1992).

CROPWAT is one of the models that are being extensively used in the field of water management throughout the world which is designed by Smith (1991) of the Food and Agricultural Organization (FAO). CROPWAT facilitates the estimation of the crop evapotranspiration, crop water requirements and irrigation schedule with different cropping patterns for irrigation planning (Kuo *et al.*, 2006; Gowda *et al.*, 2013; George *et al.*, 2000; Gouranga and Verma,2005; Martyniak *et al.*, 2006; Dechmi *et al.*, 2003; Zhiming *et al.*, 2007).

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (FAO 1992). Water use requirement for same crop varies under different weather conditions. To achieve effective planning on water resources, accurate information is needed for crop water requirements, irrigation withdrawal as a function of crop, soil type and weather conditions. CROPWAT is a FAO model for irrigation management designed by (Smith,1991) which integrates data on climate, crop and soil to assess reference evapotranspiration (ET<sub>o</sub>), crop evapotranspiration (ET<sub>c</sub>) and irrigation water requirements.

The climatic input data required are reference evapotranspiration (monthly/decade) and rainfall (monthly/decade/daily). Reference evapotranspiration can be calculated from actual temperature, humidity, sunshine/radiation and wind-speed data, according to the FAO Penman-Monteith method (FAO, 1998). The CLIMWAT database provides monthly climatic data for CROPWAT on 144 countries (FAO, 1993)

### **3. MATERIAL AND METHOD**

#### **3.1. General Description of the Study Area**

##### **3.1.1. Location**

The study area is found in the Kurfa Chele-Girawa watershed of Wabe Shebelle basin which is located in East Oromia National Regional state covering the full areas of Kurfa Chele, 90% of Haramaya, the half parts of Girawa, Kersa and Fedis districts which is located between 41° 42' 3.46" to 42° 3' 12.84" East longitude and 8° 43' 3.10" to 9° 25' 59.1" North latitude. The areal extent of the Kurfa Chele-Girawa Sub-watershed is 2373.6km<sup>2</sup> with the altitude range of 996 masl to 3173 masl.

The Kurfa Chele-Girawa watershed is made up of two main broad geographic types. The flat to undulating high plateau including steep side slopes and the low land plains. The flat to undulating high lands steep side slopes include the level lands such as plains, depressions, valley floors and the medium gradient hills, the medium gradient mountains, and the high gradient mountains. This situation gives rise to widely varying agro-ecological zones and agricultural practices in the watershed and mixed farming practices. The low land plains are mostly those areas of Fedis, Districts that is not enclosed between higher lying lands.

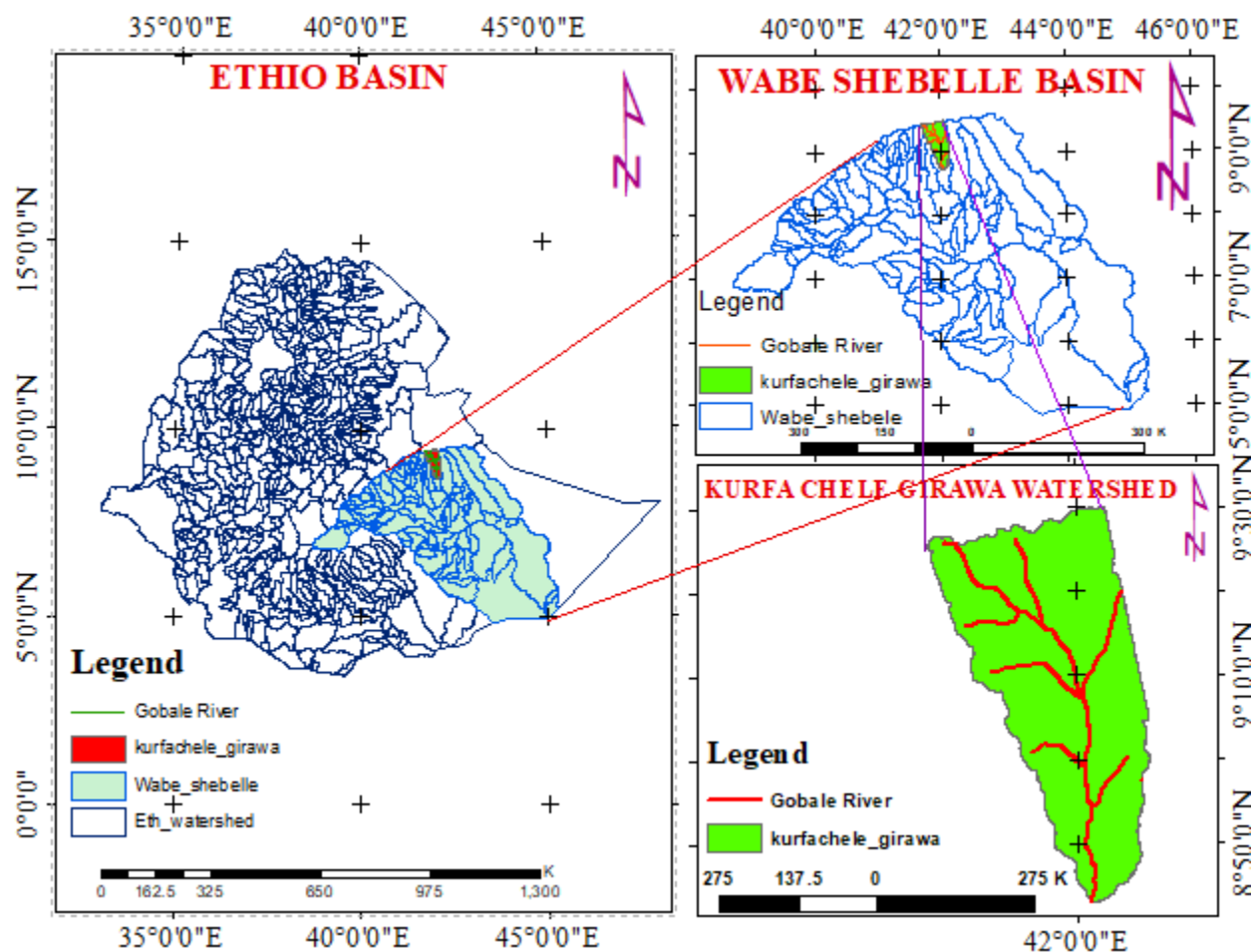


Figure 2. Location map of the study area

### 3.1.2. Climate

According to MoA (2000) agro-ecology classification, Ethiopia is classified as Wurch, Dega, Weina-dega, Kolla, and Bereha.

Agro-climatically, the economy of the watershed is based on agriculture, mainly mixed agriculture in the highland/Dega and Weyna-Dega traditional climatic zone and mainly extensive form of livestock rearing in the low land /kola traditional climatic zone. The mean annual precipitation range of the watershed varies from 400mm to 1300mm. The temperature ranges of the watershed are 18 to 31.7°C (OWWDSE, 2010). The monthly rainfall data from meteorological stations of Haramaya, Girawa, Kersa, Kulubi, Hakim gara and Harar Indicative was used.

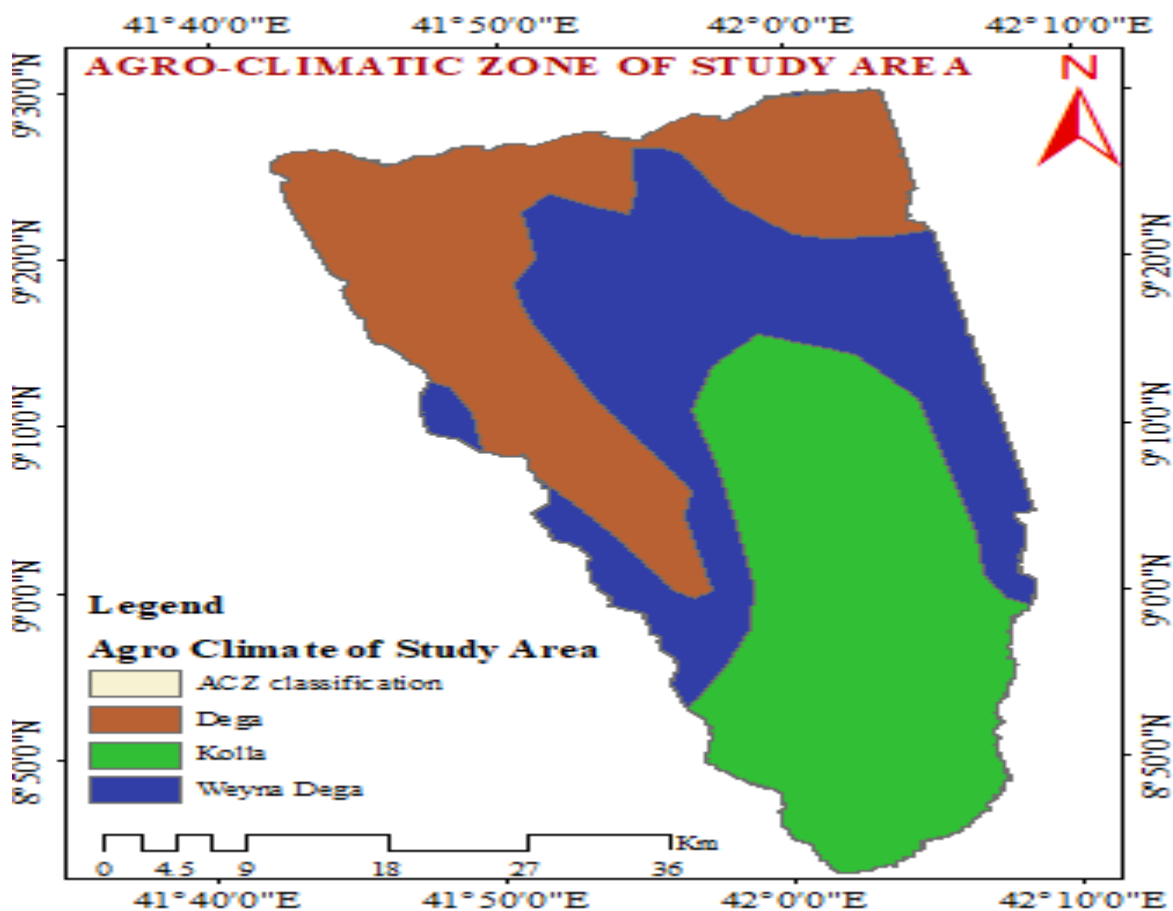


Figure 3. Agro-climatic classification of the study area

### 3.2. Materials Used

The materials and data used to assess the irrigation water potential and land suitability of this study was:

#### GPS and Digital Camera

GPS and digital camera were used to collect geographic coordinate values in (UTM, Latitude and Longitude) and field photographs, respectively. The geographic coordinate values were used as ground control points to locate field photographs on SPOT5.4.3 image for supervised classification. The field photographs were used as the signature of a land cover class which helped as region of interest in supervised image classification.

### **Satellite images**

SPOT5.4.3 satellite images, with acquisition dates between January 2016 and February 2016 that included three bands (1, 2 and 3) and with a spatial resolution of 1.5m to 5m, were obtained from Ethiopian Mapping Agency. They were used to classify land cover of the study area.

### **Topographic maps**

Topographic maps of the study area, with a scale of 1: 50,000 and with a scale of 1: 250,000 and map sheet number of NB 37-6 obtained from the Ethiopian Mapping Agency, were used as a background for the GPS to locate the samples of ground truth data and to use the data during the satellite image classification.

### **Streamflow data**

Discharges of two gauging stations such as Dawe and Hamaresa rivers both on upper part of Gobebe river were obtained from the Hydrology Department of the Ministry of Water, Irrigation and energy. The streamflow data were used to assess both water resources potential of the gauged and un-gauged sites for irrigation purpose.

### **Meteorological data**

Meteorological data of Haramaya, Kersa, Harar Indicative, Kulubi, Hakim gara, and Girawa stations were collected from NMA and grid interpolated rainfall data of kulubi and Haramaya stations were obtained from ILRI GIS database. These data were used to estimate irrigation water requirements of some selected crops using CROPWAT8.0. In addition, the rainfall data were used to calculate average areal rainfall using the Thiessen polygon extension in ArcGIS. The areal rainfall was used in the estimation of stream flow at un-gauged sites from gauged sites.

### **Soil data**

Soil Map in the form of FAO/UNESCO- Soil Map of East Africa (1997) and soil physical and chemical properties were collected from the OWWDSE Integrated land use planning of Wabe-

Shebelle basin available in Arc/Info format with scale of 1:1000000, and soil laboratory results of Rift valley lakes river basin were obtained from OWWDSE Potential Assessment Department. These data were used for soil suitability analysis for surface irrigation.

### **DEM (Digital Elevation Model)**

DEM data were obtained from ILRI GIS database and were used as input data in ArcGIS to delineate watersheds and to derive slope maps of the study area for irrigation suitability analysis.

### **Soft wares**

The soft wares used to prepare and analyze data were ArcGIS10.1, ArcSWAT10.1, ENVI 4.5, CROPWAT 8.0, and SPOT 5.4.3.

## **3.3. Method**

### **3.3.1. Selection of irrigation method**

Irrigation has contributed significantly to poverty alleviation, food security, and improving the quality of life for rural populations. While selecting the irrigation method for the study area, the current land cover/use and cropping system, topography, properties of soils, water sources, etc. were taken into consideration. Experts in the fields of agriculture, soil science, and land-use planners were consulted to decide upon the potential irrigation types. The selection was also based on data available on the irrigation environment requirement. For this study area, the method for irrigation development that has been considered is surface irrigation. It is considered as current and potential surface irrigation to be applied in the study area.

### **3.3.2. Selection of evaluation criteria**

The evaluation of soil qualities and terrain conditions to predict the performance for surface irrigation is an essential part of a land evaluation and land-use planning exercise applied to agriculture. In the framework of the study, an emphasis was placed on the suitability of soils and terrains for irrigation development.

### 3.3.3. Data pre-processing and checking

Before using the collected data for this study, the hydrological and meteorological data were checked and errors were removed. The collected data may contain errors due to failures of measuring device or the recorder. The analysis was extended to hydrological and meteorological data to prepare input data for water resources assessment and irrigation water requirement estimation using the CROPWAT model.

#### 3.3.3.1. Filling missing rainfall data

Missing records of the rainfall data were estimated by using normal annual precipitation method where annual rainfall variation of different stations within 10% of the normal annual precipitation at station X, then a simple arithmetic average procedure has to be used to estimate missed precipitation and normal ratio method which was recommended to estimate missing data in regions where annual rainfall among stations differ by more than 10% (Dingman,2002). This approach enables estimation of missing rainfall data by weighting the observation at m gauges by their respective annual average rainfall values as expressed by equation 3.1 (Yemane,2004).

$$P_X = \frac{N_x}{M} \left[ \frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \dots + \frac{P_m}{N_m} \right] \quad (3.1)$$

where:

$P_X$  = missing annual precipitation data,

$N_1, N_2 \dots N_m$  = the annual average precipitation at the gauge with the missing data,

$P_1, P_2 \dots P_m$  = annual average values of neighboring stations

$N_x$  = monthly rainfall data in the station for the same month of missing station

$M$  = the total number of the station under consideration.

#### 3.3.3.2. Consistency of stream flow and rainfall data

To prepare the streamflow and rainfall data for a further application, the consistency was checked using double mass curve analysis. A double mass curve is a plot of cumulative values of one variable against the accumulation of another quantity during the same time period (Searcy and Hardison,1960; Jason M., 2004). The theory behind double-mass curves is that by plotting the accumulation of two quantities, the data would plot as a straight line, and the slope of this line

would represent the constant of proportionality between the two quantities. A break in slope indicates a change in the constant of proportionality (Searcy and Hardison,1960; Jason M., 2004). A plot of accumulative discharge/rainfall data of each rainfall/gauging stations against the accumulative average at the surrounding stations is generally the purpose of these curves is to check the consistency of streamflow and rainfall data over time and to identify changes in trends by changes in the slope used. To check the degree of consistency; Nemec (1973) provides the value of a coefficient of correlation as follows:

$r = 1$ : direct linear correlation

$0.6 \leq r < 1$ : good direct correlation

$-0.6 < r < 0$ : insufficient (reciprocal correlation)

$-1 < r < 0.6$ : good reciprocal correlation

$r = -1$ : reciprocal linear correlation

Rainfall data were analyzed using grid interpolation. If the streamflow and rainfall data are inconsistent, it can be adjusted by proportioning, using correlation coefficient, between the stations (Selesh,2000; Moutaz,2001; Yarahmad,2003).

### **3.3.4. Watershed delineation**

Following drainage boundaries on the DEM, masking the Digital Elevation Model (DEM) of Kuraf-Chele Girawa watershed coverage of Wabe-Shebelle basin. The delineation process requires a Digital Elevation Model (DEM) in ESRI grid format and the watershed was delineated using Arc SWAT. DEM data were obtained from ILRI GIS database and was used as input data in ArcGIS to delineate watersheds and to derive slope map of the study area for irrigation suitability analysis. The step was followed to delineate watershed:

#### **3.3.4.1. Importing DEM data**

The DEM of the watershed was projected to UTM Coordinate system using Arc Catalog in Arc GIS and imported to Arc SWAT to start automatic watershed delineation. Figure 4 shows imported DEM into SWAT session.

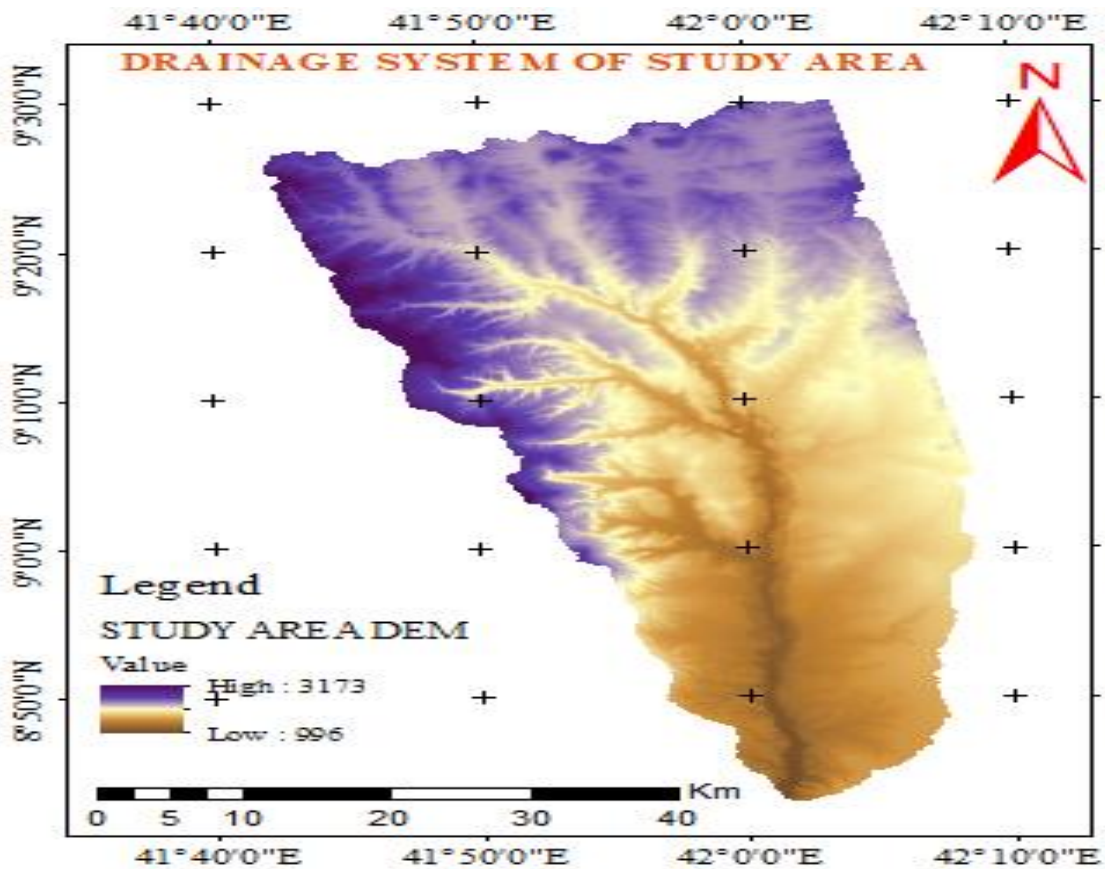


Figure 4. Digital elevation model showing the drainage system of the study area map.

### 3.3.4.2. Computing flow direction

Flow directions for individual DEM cells were created using flow direction and accumulation tool in Arc SWAT. SWAT computes flow direction for individual DEM cells and uses stream threshold area in hectares to create streams based on these directions. Figure 5 shows flow direction and the networks of streams on top of the DEM.

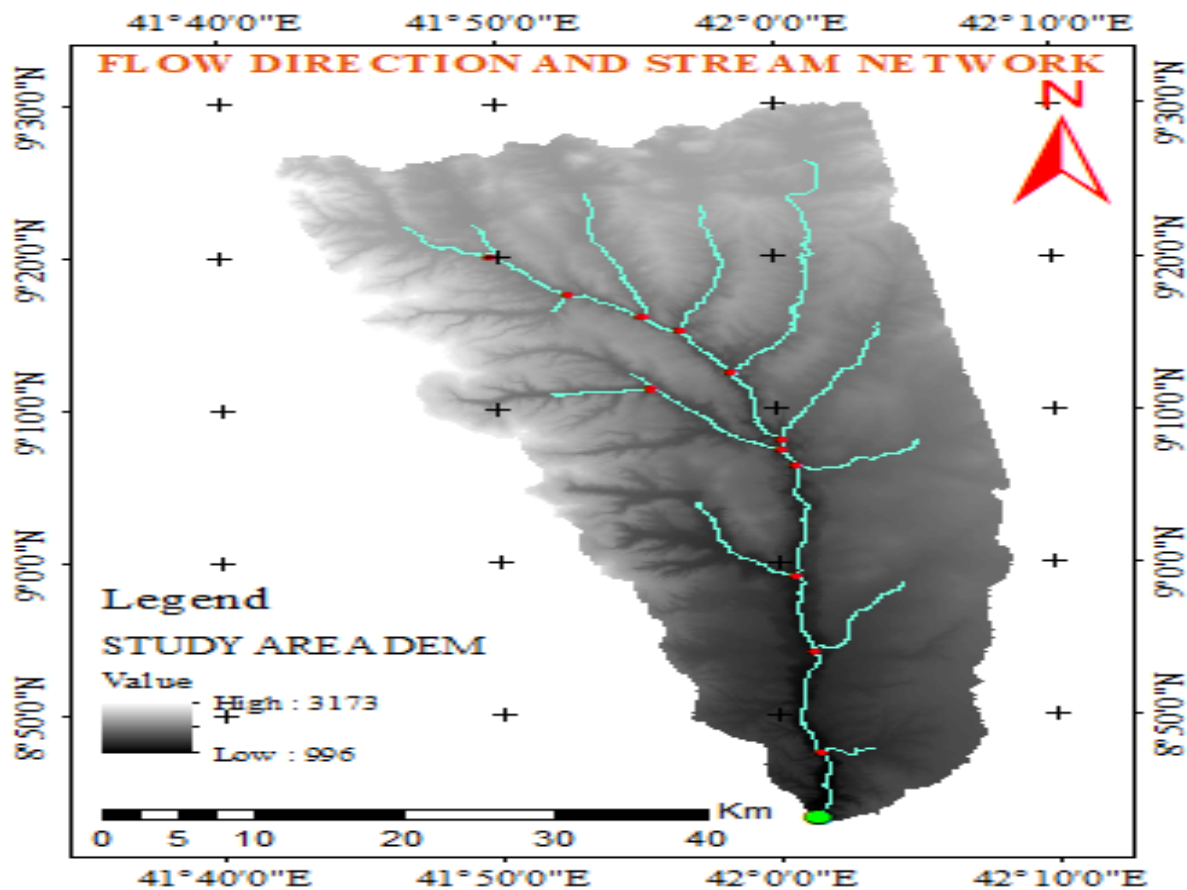


Figure 5. Flow direction and streams network map

### 3.3.4.3. Creating watershed outlets

An outlet, or pour point, is the point at which water flows out of an area. This is the lowest point along the boundary of the watershed. The cells in the source raster are used as pour points above which the contributing area is determined. By using the outlet selection tool in SWAT, the watershed outlets are defined as shown in Figure 6.

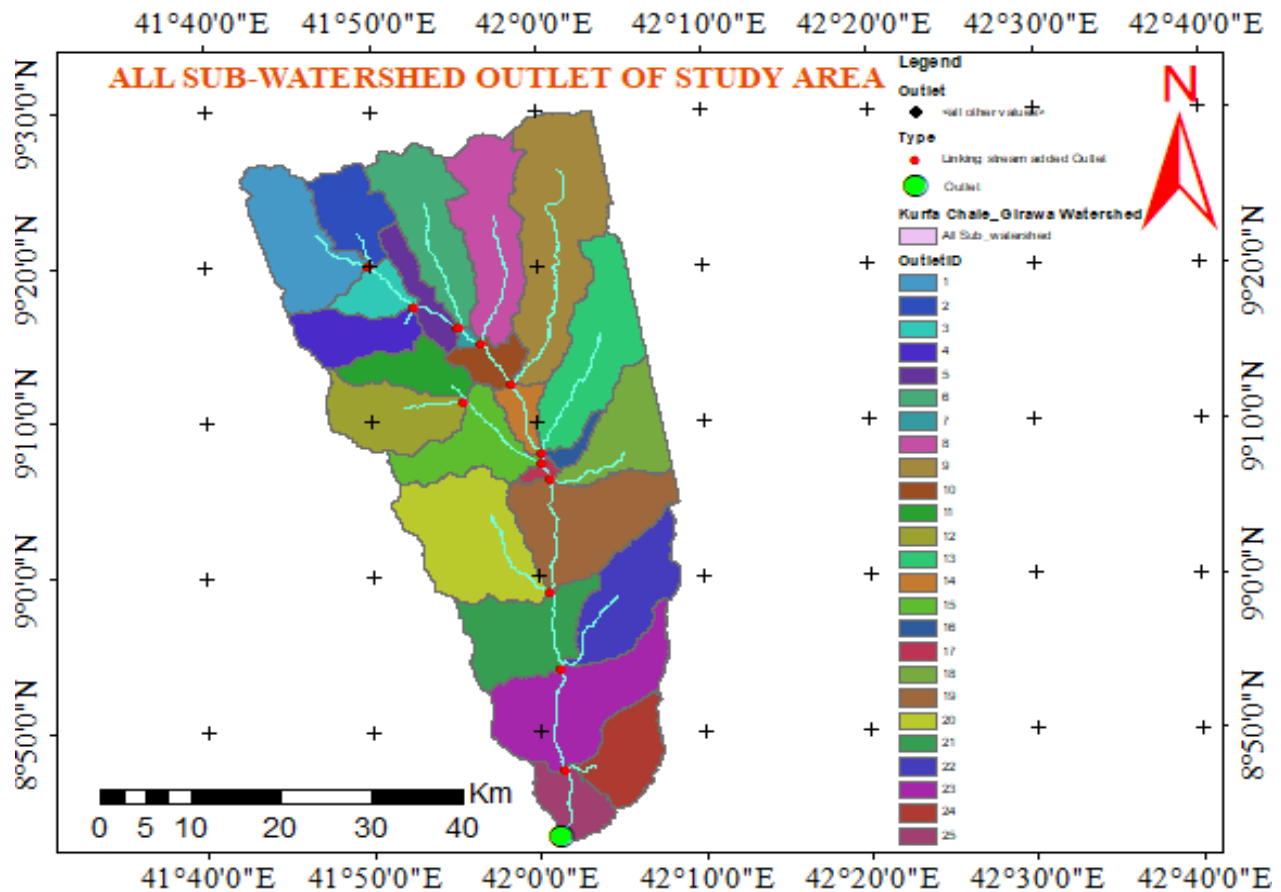


Figure 6. Watershed outlets definition map.

#### 3.3.4.4. Delineation of main and sub-watersheds

The main watershed was delineated by using watershed delineator tool in Arc SWAT based on an automatic procedure using the watershed outlets created in step three above and it covers an area of 237,363.1ha. In order to create sub-watersheds, additional drainage outlets need to be defined. After several nodes or vertices are defined into drainage outlets along the stream arcs there are 25 sub-watersheds and the same method defining watershed outlets in step three was used again to delineate every 25 sub-basins.

#### 3.3.5. Identification of potential irrigable sites

To find suitable land for surface irrigation, a suitability model was created using model builder. Once their individual suitability was assessed, the irrigation suitability factors such as slope, soil,

land cover/use and distance between water supply and the potential command area as factors. Finally, weighted to get potential irrigable sites. This procedure is presented as follows.

### 3.3.5.1. Slope suitability analysis

The land slope is the most important topographical factor influencing land suitability for irrigation. To derive slope suitability map of the study area, digital elevation model of the area was clipped from SRTM of NASA satellite of 30m by 30m' resolution from <https://earthexplorer.usgs.gov/> by masking layer of the watershed using Arc GIS software. Then the slope map of the watershed was derived using the "Spatial Analysis" tool in ArcGIS. The Slope derived from the DEM was classified based on the classification system of FAO (1996) using the "Reclassification" tool, which is an attribute generalization technique in ArcGIS. The four suitability ranges (S1, S2, S3, and N) will be used for classification irrigation land.

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

Table 3. Slope suitability classification for surface irrigation

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

Source: FAO (1996).

### 3.3.5.2. Soil suitability assessment

To assess soil suitability of the study area for irrigation was analyzed by taking soil physical and chemical properties from the OWWDSE Integrated land use planning of Wabe-Shebelle basin (2010) and FAO/UNESCO- soil map of East Africa (1997) was used. It is available in ARC/ INFO format with a scale of 1: 1000000. The major soil groups classified in the study area were: Luvisols, Vertisols, Cambisols, Fluvisols, and Leptosols. Chemical and physical properties of these soil

groups were used for irrigation suitability analysis. The following soil suitability rating was used based on the FAO guidelines for land evaluation (FAO, 1976, 1979, 1990, 1991) and FAO (1997) land and water bulletin.

The soil vector layer was converted into a raster layer using conversion tool “To Raster or Feature to Raster module”. The rasterized soil map of the study area was then reclassified based on their soil type name, texture, depth and drainage class. Using overlay tool in Arc GIS 10.1 Spatial analyst, weighted overlay analysis of these factors were performed to determine their suitability for surface irrigation. Then, the new values were reassigned for each soil factor in the order of their irrigation suitability rating based on common evaluation scale from 1-9 available in weighted overlay analysis. A value 1 represents the least suitable factor in the evaluation while, value 9 represents highly suitable factor in the evaluation. Soil factor that is highly suitable was given a value 9, for moderately suitable factor was given a value 6, for marginal suitable factor was given a value 3 and for least suitable factor was given a value 1. When scale values from 1-9 is not assigned for soil factors in evaluation, that cell value restricted for surface irrigation and it should be excluded from evaluation. For example, a soil factor with soil depth 10cm is restricted for surface irrigation development and the cell value representing this value is assigned as ‘restricted scale’ so that it will be excluded from the evaluation.

Table 4. Soil suitability factor rating

Factors	Factor Rating			
	S1	S2	S3	N
Drainage class	Well	Imperfect	Poor	Very Poor
Soil depth (cm)	>100	80-100	50-80	<50
Soil texture	L, SiCL, C	SL	-	-
Salinity	<8 mmhos/cm	8-16 mmhos/cm	-	-
Alkalinity	<15 ESP	15-30 ESP	-	-

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

### **3.3.5.3. Land cover/use**

Land cover/use of the study area is also another factor, which was used to evaluate the land suitability for irrigation. The land cover classification was done using SPOT5.4.3 (Système Pour l'Observation de la Terre) satellite image of 1.5m to 5m resolution for identifying land cover types to estimate potentially irrigable land. The classification was carried out using ENVI software. ENVI (Environment for Visualizing Images) is the ideal software for the visualization, analysis, and presentation of all types of digital imagery. ENVI's complete image-processing package includes advanced, yet easy-to-use, spectral tools, geometric correction, terrain analysis, radar analysis, raster and vector GIS capabilities, extensive support for images from a wide variety of sources, and much more. ENVI's unique approach to image processing combines file-based and band-based techniques with interactive functions. The following steps are ENVI software classification.

#### **I. Image pre-processing**

Successful identification of land cover usually requires multi-temporal images. The SPOT image for the study area was assessed. The SPOT images are geo-referenced by ancillary data such as topographic maps and geographic coordinates of the study area. Then true color composite images were created by combining the spectral bands that most closely resemble the range of vision of the human eye which in the SPOT images are normally used for land cover analysis. A true color composite uses the visible red (band 3), visible green (band 2), and visible blue (band 1) channels to create an image that is very close to what a person would expect to see in a photograph of the same scene as shown in Figure 7. The bands to color mapping for a 321 Composite are:

Band 3 (Visible red) = red

Band 2 (Visible green) = green

Band 1 (Visible blue-green) = blue

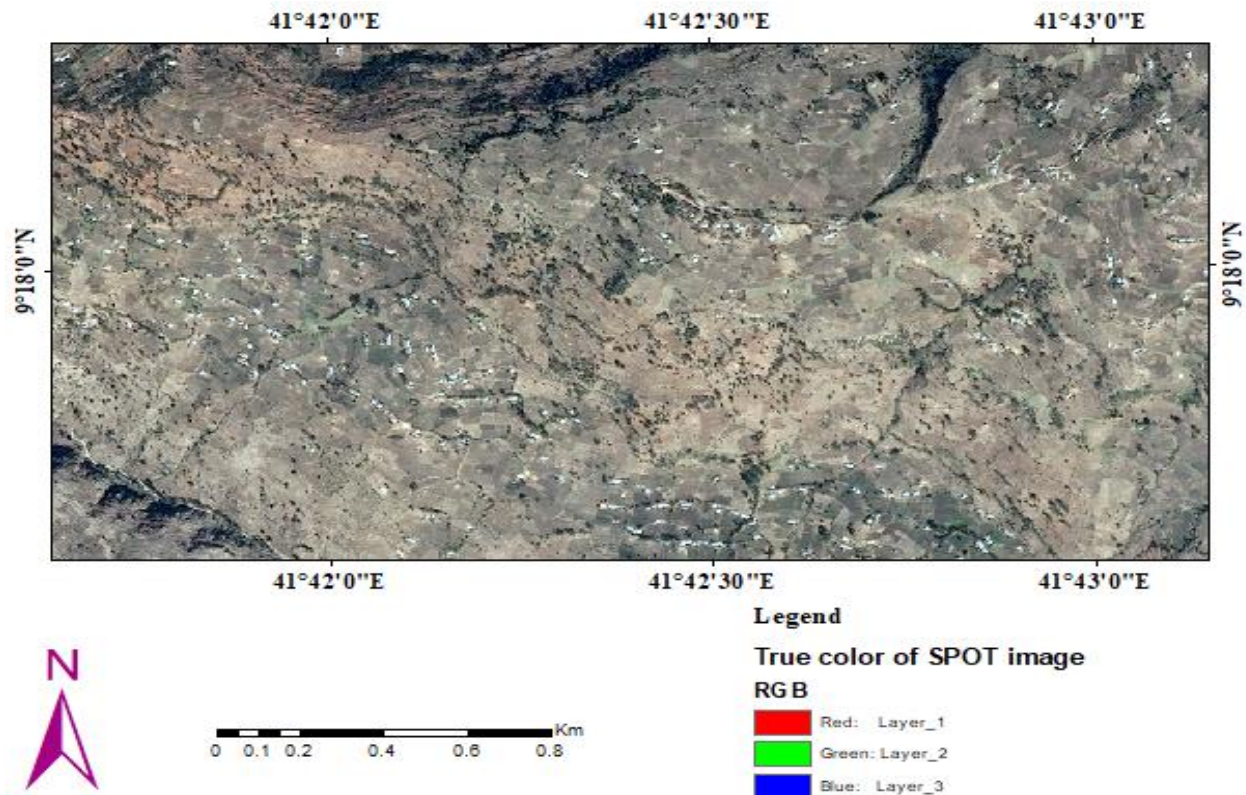


Figure 7.SPOT2016 satellite image of the study area showing true color composite (321)

The other image pre-processing steps, such as image rectification and restoration and image enhancement, were also performed.

## II. Image classification

There are two approaches to extract spectral information: the supervised and unsupervised classification (Richards, 1986). Unsupervised classification is the method in which image pixels are assigned to spectral classes without the user having previous knowledge about the study area whereas, supervised classification is a method that involves selection of areas in the image, which statistically characterize the categories of interest. Prior to the fieldwork, unsupervised classification from the SPOT image was conducted to understand the general land cover classes of the study area. Based on results from unsupervised classification and information from a topographic map of the study area, sample training sites were selected to collect geographic coordinates and field photographs data. The geographic coordinate values of field observation were added to the SPOT image as Ground Control Points Selection dialog box in ENVI. This

process, therefore, establishes the framework of the GCPs positions of the pixels for the output image. The problem then is to decide how best to examine the different land cover signatures at pixels in the image and comparing field photographs of the same GCPs locations with the unclassified image. This information was then used in the selected region of interest for the supervised classification.

### III. Accuracy assessment

To validate and crosscheck the result of the SPOT classification with known ground truth data, accuracy assessment was checked for the signature values of the classified images by calculating the confusion matrix in ENVI software. The confusion matrix is a table with the columns representing the reference (observed) classes and the row the classified (mapped) classes (Rossiter,2001). The ground truth data were used in the maximum likelihood report as the independent data set from which the classification accuracy was compared. The accuracy is essentially a measure of how many pixels in the ground truth region of interests (ROIs) were classified correctly. Items calculated include; overall accuracy, kappa coefficient, and confusion matrix. The overall accuracy was calculated by summing the number of pixels classified correctly and dividing by the total number of pixels.

Kappa coefficient represents a strong agreement between classified land cover classes and observes land cover/use (Ephrem,2007). It lies between 0 and 1, where 0 represents weak agreement and 1 represents strong agreement. According to Rahman *et.al* (2006), kappa values can be classified into three: the value greater than 0.8 represents strong agreement, between 0.4 and 0.8 represents moderate agreement and a value below 0.4 represents poor agreement. Equation 2 gives a mathematical relationship for calculating kappa coefficient in ENVI software.

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

where,

$P_o$  = is the proportion of correctly classified classes

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

#### **IV. Compilation of final land cover/use map**

Classified images require post-processing to generalize classes for export to image-maps and vector GIS. In ENVI post classification tool, majority analysis was applied to generalize image classification. Then classification to vector tool was used to convert classification results to ENVI polygon vector layers (. evf files) and then exported to shape files, Arc-GIS compatible file set. The classification images will have a vector layer for each selected class. Due to the higher spatial resolution of SPOT image, a countless of very small polygons were created in the classified image. To produce land cover map by 1:250,000 scale (a common rule of thumb for thematic mapping), it was, therefore, necessary to filter these polygons so that no polygons were smaller than 50 ha. This processing was performing within Arc-Map software using Select by attribute tool and Generalization tool in the Arc Toolbox.

The aim of this processing is to generalize the classification by removing small polygons. In this case, polygons were removed if they are less than 50 ha. The final clearer map with a scale of 1:250,000 was produced.

##### **3.3.3.4. Distance from the water supply (source)**

To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from watershed outlets was calculated using DEM of 30m \* 30m cell size and reclassified. Then, the reclassified distance was used for weighted overlay analysis together with other factors.

##### **3.3.3.5. Weighing of irrigation suitability factors to find potential irrigable sites**

To find a suitable site for irrigation, a suitability model will be created using model builder in Arc Toolbox and tools from spatial analysis toolsets. Then, after their individual suitability is assessed, the irrigation suitability factors, such as slope factor, soil factor, land cover /use factor and distance factor is used as the input for irrigation suitability model to find the most suitable land for irrigation.

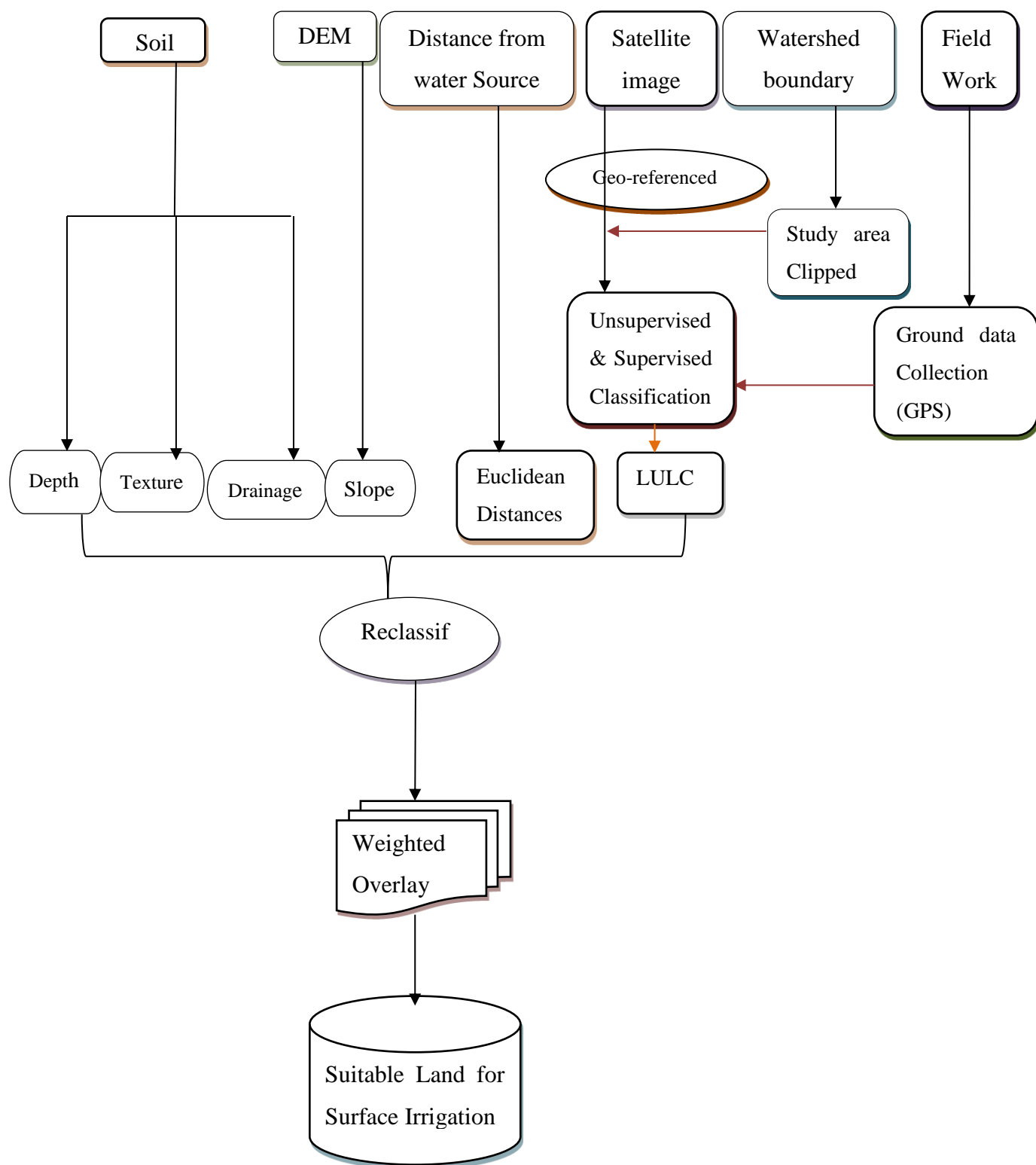


Figure 8. Irrigation suitability Flow Chart

### 3.3.6. Computing irrigation water requirements

In order to estimate irrigation water requirements of some selected crops in the potential irrigable sites, the definition of area of influence of the climatic stations using Arc GIS inside and around the watershed was assessed. To obtain a spatial coverage of climate data over the study area, each station was assigned to an area of influence using the Thiessen polygons method (FAO, 1997). This method assigns an area of 'nearest vicinity' to each climate station.

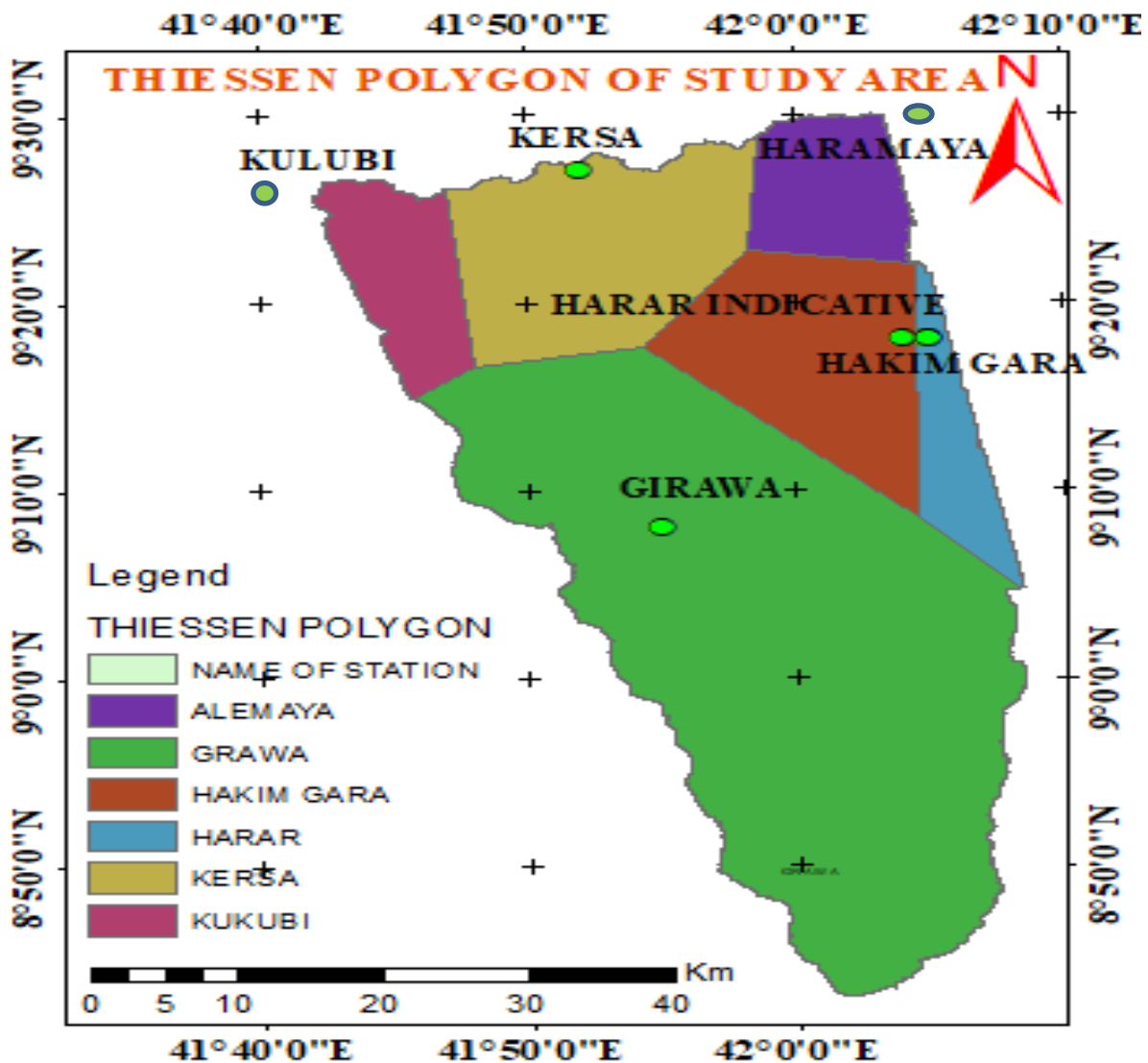


Figure 9: Thiessen polygons showing an area of influence of climatic stations in the study area

The climatic stations Girawa, Hakim gara, Harar Indicative, Haramaya, Kersa, and Kulubi were taken to calculate irrigation water requirement of the identified irrigable area. Therefore, recorded data of the stations identified to use for this study from the FAOCLIM has taken for creation of the database. Then based on the cropping pattern of the study area, obtained from East Hararge agricultural office, two crops such as Potato and maize, were selected to estimate the water demand on a monthly basis. Planting dates for potato and maize were chosen in such a way that the planting dates coincided with the local cropping calendar at the nearby meteorological stations.  $ET_0$  and other climatic data were derived from the computation for crop water requirement estimation. The respective crop coefficients for the crops were selected based on FAO (1998).

Then, gross irrigation water requirements of the crops at the identified potential irrigable sites were estimated by considering application efficiency of 65% for surface irrigation according to FAO (2001) and assuming 75% of water conveyance efficiency from the source to identified command area as follows:

$$ET_c = ET_0 * K_c \quad (3.3)$$

where

$ET_c$  = crop evapotranspiration (mm/day)

$ET_0$  = Reference crop evapotranspiration (mm/day)

$K_c$  = crop coefficient [a function of plant type, growing period, relative humidity and Wind] (dimensionless)

$$IWR = ET_c - P_{ef} \quad (3.4)$$

where:

$IWR$  = Irrigation water requirement (mm)

$P_{ef}$  = effect rainfall (mm)

$$GIWR = \frac{1}{E} (FWS * A_{crop}) \quad (3.5)$$

where:

E = water conveyance efficiency

GIWR = Gross irrigation requirements ( $m^3/month$ )

FWS = Field Water Supply (l/s/ha)

$A_{Crop}$  = the potential irrigable area to be cultivated with a selected crop (ha)

### 3.3.7. Estimating surface water resources potential of river catchments

The available surface water of the catchments was estimated using stream flow discharges of the gauging stations (obtained from the Ministry of Water, Irrigation and Electricity) and rainfall data (obtained from NMA and ILRI GIS database). The stream flows that were used as input to determine discharges at ungauged sites were measured at the gauging stations inside the study area.

Table 5. Hydrometric stations inside the study area

No	River	Site	Start date	End date	Latitude	Longitude	Drainage area(km <sup>2</sup> )
1	Hamaressa	NearHarar	1988	1997	9°19'48"	43°4'48"	63.71
2	Dawe	Near gara	1999	2008	9°19'48"	41°48'0"	150.4

#### 3.3.7.1. Estimating discharges at un-gauged sites from gauged sites

The rainfall data analysis results and discharges from gauged sites were used to estimate the streamflow at the ungauged sites in the study area. Since irrigation potential of perennial rivers was considered in this study, a long term average of stream-flow at gauged sites and mean monthly areal rainfall of the sites were used to estimate the discharges at ungauged sites. This is performed by applying the runoff coefficient of the gauged sites to ungauged sites (FAO, 1997; Goldsmith, 2000; DFID, 2004).

According to Goldsmith (2000) and DFID (2004), to estimate mean monthly runoff volume of ungauged sites from gauged sites, catchment characteristics such as land cover, soil type, and catchment slope ranges should be similar, and distances between the gauged and ungauged river catchments should not be more than 50km and minimum 10 years mean monthly river flow at the gauged sites should be available. Based on these criteria, the gauged and ungauged river catchments soil, slope, and land cover maps were derived using FAO (1997) digital soil map of

East Africa, DEM and SPOT5.4.3 satellite image, respectively. Then runoff volume per month at the ungauged site was estimated using the following steps:

1. Both gauged and un-gauged catchment areas were calculated
2. Point rainfall data of stations both in and around gauged and un-gauged catchments were converted to areal or average rainfall over an area of river catchments using Thiessen polygon method in ArcGIS.
3. Both un-gauged and gauged river catchments in terms of their land cover/use, soil type and slope range were compared to determine their similarities.
4. Runoff coefficient from the ratio of mean monthly discharge to mean monthly areal rainfall of gauged catchments were determined.
5. Above steps were followed to estimate monthly average runoff of the un-gauged river catchments from gauged river catchments using the following equation (Jamshid,2003).

$$Q_{\text{ungauged}} = \left( \frac{A_{\text{ungauged}}}{A_{\text{gauged}}} \right) * Q_{\text{gauged}} \quad (3.6)$$

where,

$Q_{\text{ungauged}}$  = discharge at an ungauged site ( $\text{m}^3/\text{s}$ )

$A_{\text{ungauged}}$  = drainage area of the ungauged site ( $\text{km}^2$ )

$Q_{\text{gauged}}$  = discharge at the gauged site ( $\text{m}^3/\text{s}$ )

$A_{\text{gauged}}$  = drainage area at the gauged site ( $\text{km}^2$ )

The streamflow calculated using the above procedure for ungauged sites are used to estimate their adequacy for the potential irrigable sites.

### 3.3.7.2. Transferring discharges of gauged rivers to the site of interest

For ungauged rivers, the discharges from gauge sites were transferred to the site of interest using the following formula.

$$Q_{\text{site}} = \left( \frac{DA_{\text{site}}}{DA_{\text{gauge}}} \right)^n * Q_{\text{gauge}} \quad (3.7)$$

where:

$Q_{\text{site}}$  = discharge at the site of interest

$Q_{\text{gauge}}$  = discharge at gauge site

$DA_{\text{gauge}}$  = drainage area at gauge site

$DA_{\text{site}}$  = drainage area at the site of interest

The exponent  $n$  varies between 0.6 and 1.2. If the  $DA_{\text{site}}$  is within 20% of the  $DA_{\text{gauge}}$  ( $0.6 \leq DA_{\text{site}} / DA_{\text{gauge}} \leq 1.2$ ),  $n$  value equal to 1 is used, otherwise, the value 0.6 is used (Kebede, 2010).

## 4. RESULTS AND DISCUSSIONS

### 4.1. Testing Stream Flow and Rainfall Data for Consistency

The double-mass curve analysis shown that there is a good direct correlation between the cumulative stream flow records at Hamaressa gauging station with the cumulative average streamflow's at the two stations ( $r = 0.996$ ). This indicates that the stream flow data at Hamaressa gauging station is consistent. For Dawe gauging station, the consistencies of their streamflow records were checked using similar procedure and it was found that no significant shift of slope was observed on their respective plots. As presented in Appendix Figure 1, the correlation coefficients of the two stations indicated that there is a good direct correlation between the stations' records and their corresponding base stations. Therefore, it was concluded that the stream flow data from two stations can be used for a further application.

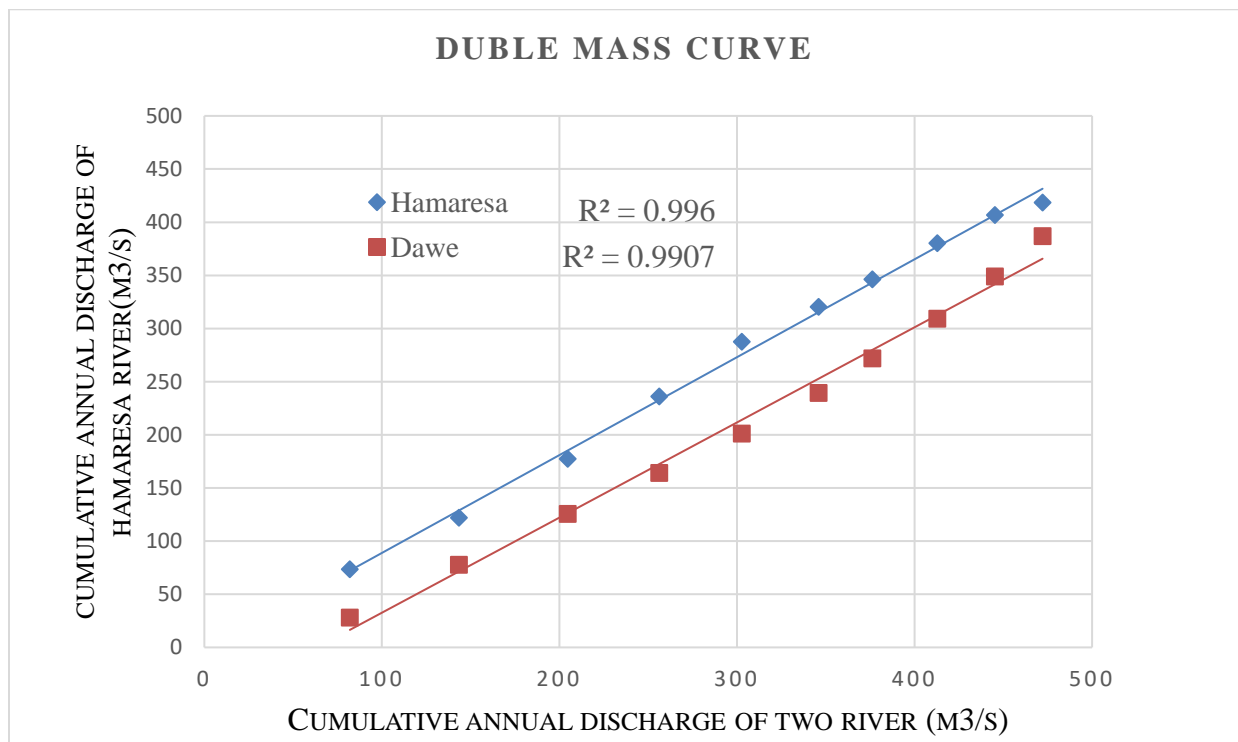


Figure 10. Double mass curve of Hamaressa gauging station

The rainfall data showed that there were missing rainfall records at all stations. Therefore, to use these data for a further application, missing values were filled and results summarized in Appendix Tables 3-8. The results of the double-mass curve analysis of the rainfall stations revealed that the

rainfall recorded at the six gauging stations (Haramaya, Harar Indicative, Girawa, Kulubi, Hakim gara, and Kersa) of 30 years (1985-2014) are consistent with no significant change of slope on their respective plots as presented in Figures 11. Hakim gara rain fall station has no full record and the weather data be used and presented in Appendix Figures (8). This also suggests that the rainfall data at these six stations can be used directly for further analysis.

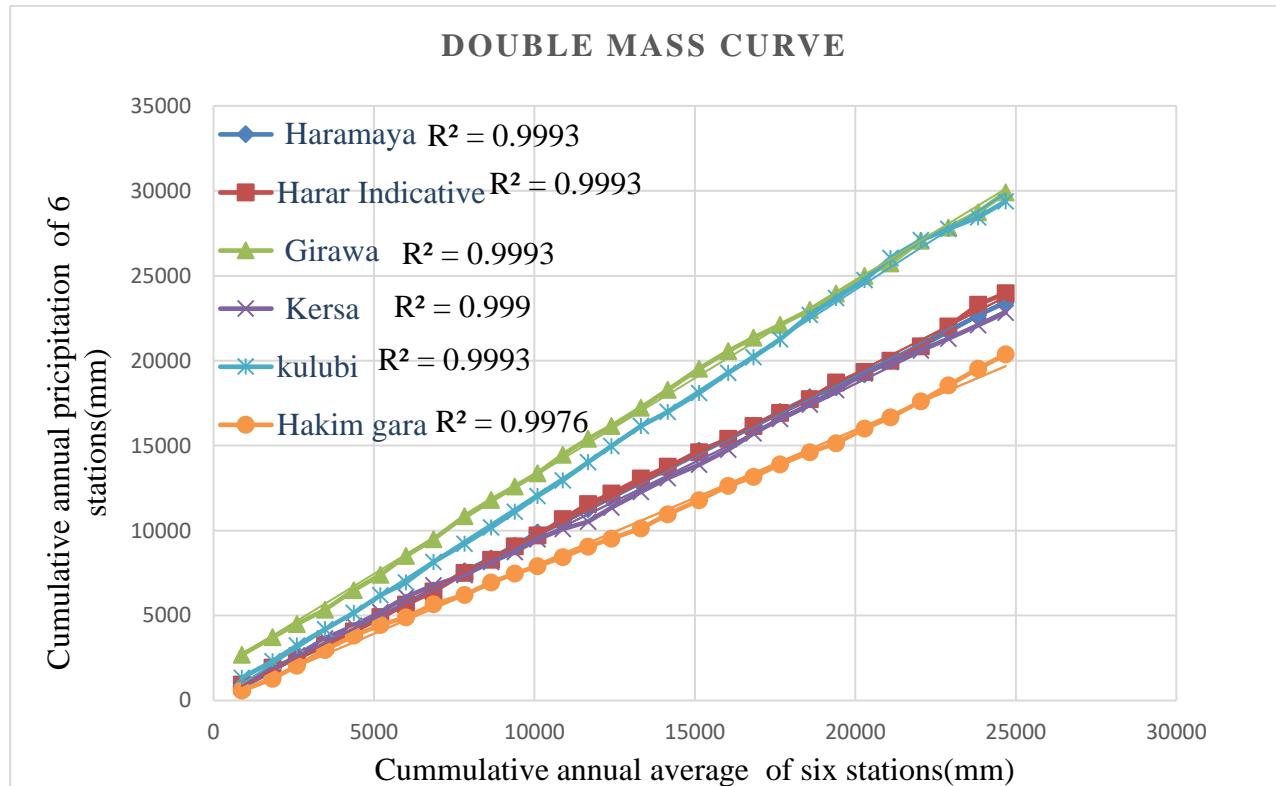


Figure 11. Double mass curve of six rainfall stations

## 4.2. Watershed Delineation

The watershed delineation showed that there were one main watershed and twenty-five sub-watersheds in the study area. Maya guda sub watersheds are the major ones. The others sub-watershed such as Hamaressa, Dawe, Kersa guba, Maya kelo, and Bululo each covering an area of 15,781.20 ha, 13,147.69 ha, 13,078.98 ha, 14,535.06 ha and 7,022.32 ha, respectively. Maya guda is the largest sub-watershed in the study area covering a total area of 24,539.61 ha and comprising of the above five sub-watersheds, Hamaressa sub-watershed is the second largest watershed in the study area. It covers a total area of 15,781.20 ha.

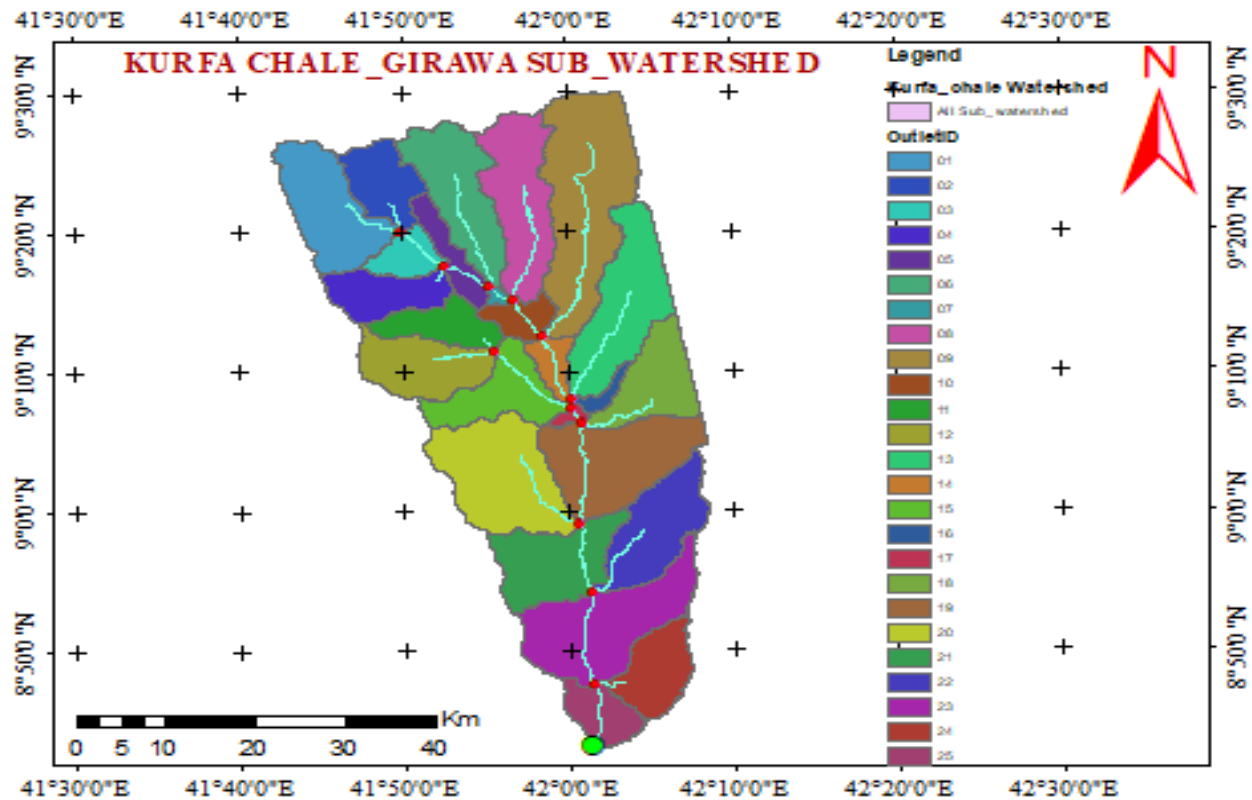


Figure 12. Shows map of the main and sub-watersheds in the study area.

### 4.3. Irrigation Suitability Evaluation

Based on the suitability criteria assigned, the layer of the criteria was developed, an overlay was done to generate one suitability map which has the attribute of all land qualities with their theme attribute table. The analysis results of surface irrigation suitability evaluation factors are presented as follows:

#### 4.3.1. Slope suitability

The slope has been considered as one of the evaluation parameters in irrigation suitability analysis. Based on the four slope classes (S1, S2, S3, and N), the slope suitability of the study area for the development of surface irrigation system is shown in Figure 13 and the area coverage of the suitability classes are presented in Table 6.

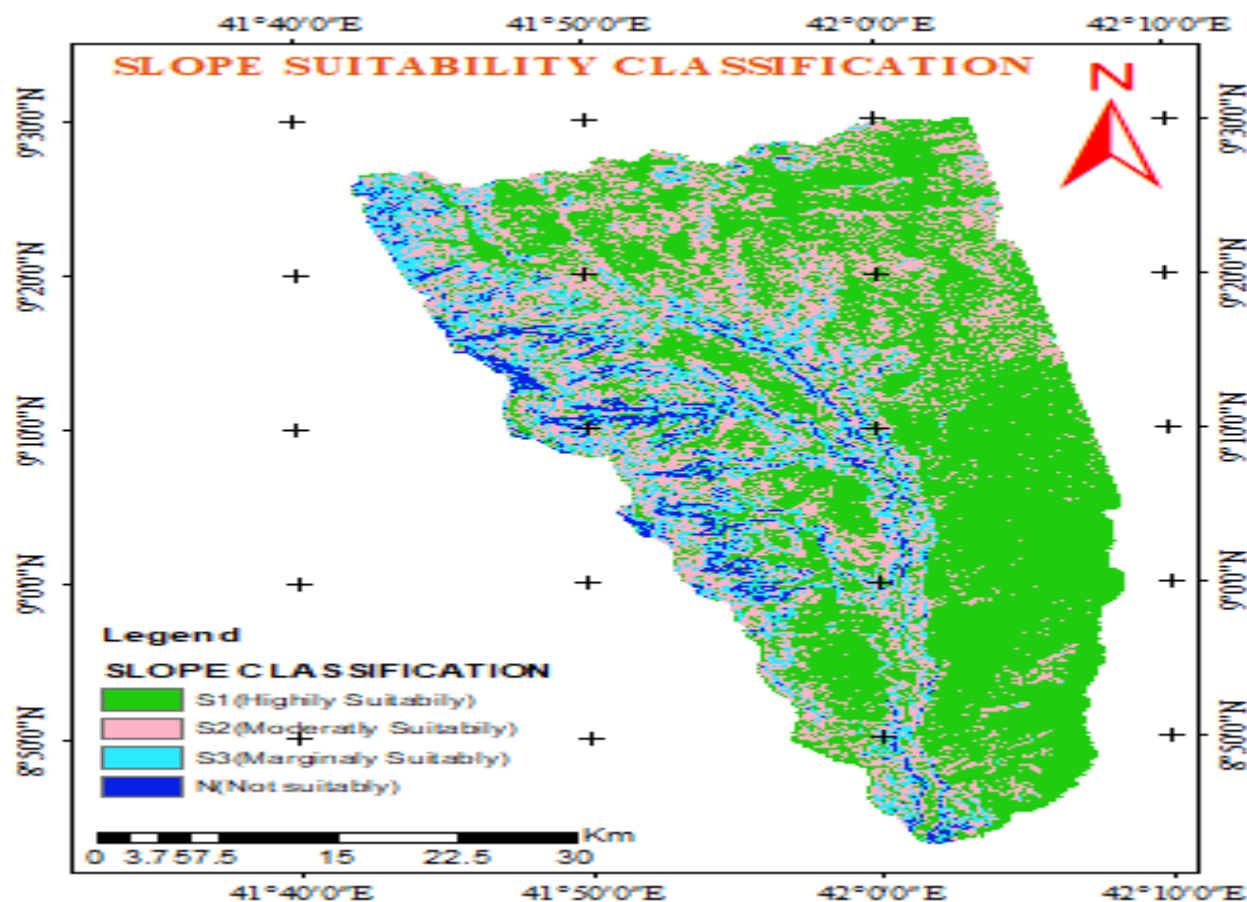


Figure 13. Slope suitability map of the study area for surface irrigation

Table 6. Slope suitability range of the study area for surface irrigation

Slope range (%)	Area coverage(ha)	% of the total area(ha)	Suitability Classes
0-2	129,456.9	54.5	S1
2-5	69,407.0	29.2	S2
5-8	28,030.1	11.8	S3
>8	10,469.1	4.4	N
	237,363.1	100.0	

The results in slope suitability show that 54.5%(129,456.9 ha) of the total area of the watershed is highly suitable,29.2%(69,407.0 ha) of the total area of the watershed is moderately suitable and 11.8%(28,030.1 ha) of the total area of the watershed is marginally suitable for surface irrigation system with respect to slope whereas the remaining 4.4%(10,469.10 ha) of the area of watershed is not suitable for surface irrigation. Hence, the majority of the study area is highly to marginally

suitable for surface irrigation in terms of slope suitability. According to FAO (1976) suitability classification for surface irrigation, most of the area of the watershed was falls below 8%, which is suitable range of slop classification for surface irrigation with miner modification to negotiate the natural slop.

#### **4.3.2. Soil suitability**

The major soil groups identified in the study area are Luvisols, Vertisols, Cambisols, Fluvisols, and Leptosols as shown in Figure 18. Summary of soil suitability classification results is given in Table 7.

Results of this analysis indicate that the study area can be generally classified into three irrigation suitability classes based on soil suitability as a factor: S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable). Fluvisols which was highly suitable covering an area of 37,16.62 ha which accounts 1.58% of the total area, Cambisol, luvisol, and Vertisols(haplic), covering an area of 69,761.95 ha which accounts 29.65% of the total area, was classified as moderately suitable (S2) for surface irrigation and Vertisols (calcic and rock, chromic) which was marginally suitable covering an area of 56,112.36 ha which accounts for 23.85% of the total area. Leptosols and Cambisols(leptic) which was not suitable covering an area of 26,598.66 ha which accounts for 44.91% of the total area.

According to FAO (1979) soil permeability evaluation techniques the soil drainage of the flat and alluvial flooded plains of watershed was falls under Excessively/ well, moderately well, poorly and very poorly drained conditions. The lower part of the study area was dominated by poorly to very poorly drained soil drainage condition. In relation to agricultural crop production this soil drainage condition is the most limiting factors in most soil types of the study area, which further need special attention to address such problems through improvement of soil drainage.

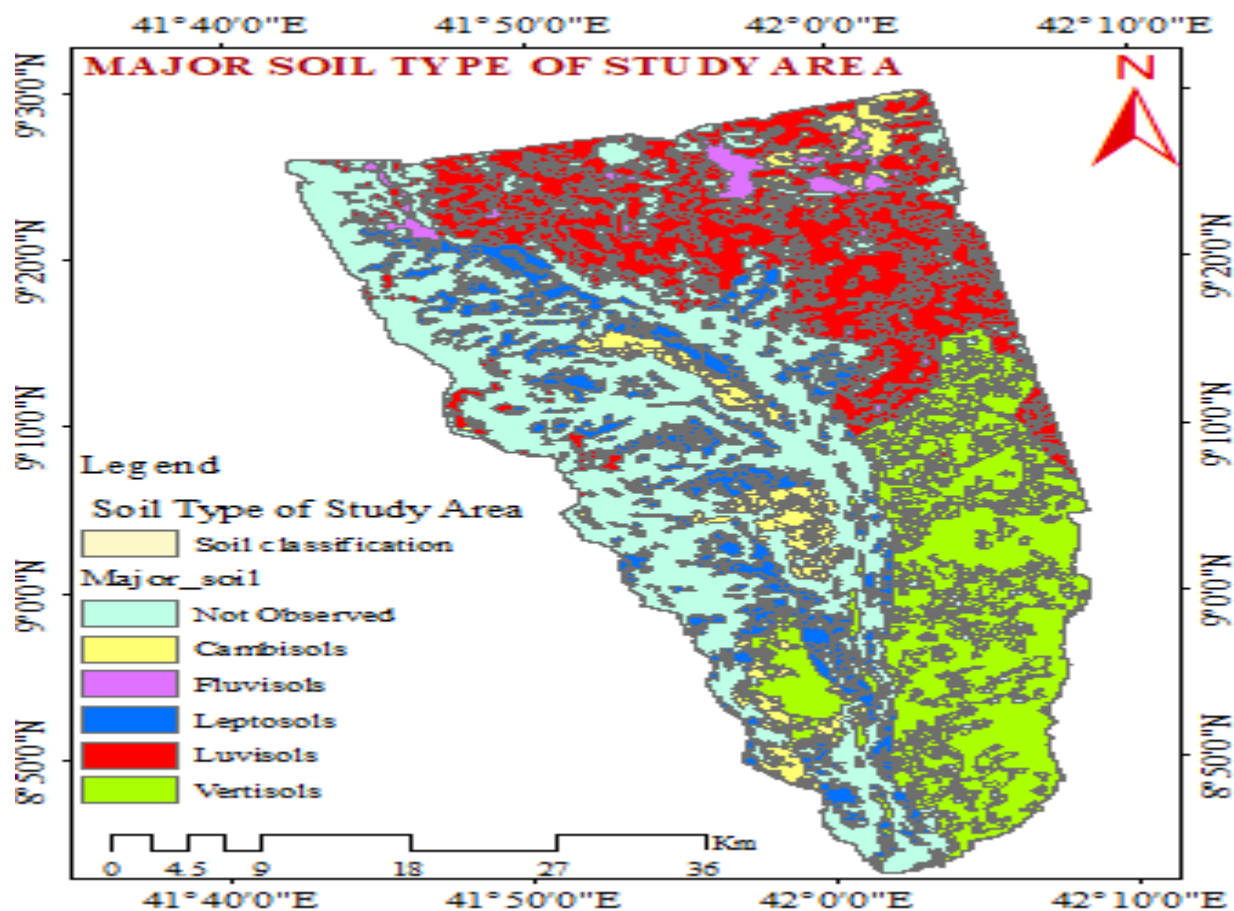


Figure 14. Soil classification of study area map

Cambisols represents soils in which soil formation is characterized by certain development of structure, or by color indicating moderately pronounced alteration and development. Cambisols are well, moderately well to somewhat excessively drained, shallow to deep soils. They have a moderately developed subsoil horizon, which is only in an initial stage of development. The structure is weak to strongly developed angular, occasionally granular in the topsoil over moderate sub-angular blocky in the subsoil. Consistency is hard when dry, friable to a firm when moist and slightly sticky and slightly plastic when wet. The color of the soils varies from red, reddish brown to dark reddish. Cambisols are formed on a wide range of parent materials and colluvial /alluvial materials derived from these rocks. The textures of Cambisols of the highlands are sandy clay loam, clay loam to clay, whereas loam to sandy loam textures is typical in the lowlands. They are classified as Chromic, Calcic, Leptic, and Vertic-calcic Cambisols occurring in the lowlands(OWWDSE,2010).

Luvisols and vertisols were classified as S3 (marginally suitable class). Luvisols are soils having an Argic horizon, which has base saturation of 50% or more at least in the lower part of B horizon. These soils are derived from different parent materials. They are found in areas where climate condition permits clay movement. They are occurring on flat to gently undulating surfaces. Luvisols are generally well drained deep to very deep, and fine to medium textured clay to clay loam soils. The Structure of Luvisols is moderately developed medium sub angular blocky over moderately to strongly developed medium to coarse sub angular blocky. Consistency is hard (dry), friable to firm (moist), sticky and slightly plastic. Color of top soils is dark brown and dark reddish brown in the sub-soils. Luvisols are characterized by optimum conditions for surface irrigation system in terms of all factors except that both are limited by sandy loam texture.

Vertisols are soils having a high content of clay mineral that shrinks and swell as they change water content. When wet they shrink, as they dry, forming deep cracks in horizons to a depth of at least 50cm from the surface downward. The color of vertisols is dark grayish/very dark grayish brown to dark black. They are deep to very deep and imperfectly to poorly drained soils. They occur on flat to gently undulating surfaces of high volcanic plateaus, low plateaus (middle altitude). Vertisols in the watershed are derived from volcanic materials, limestone and colluviums/alluvium parent material. Classified as *chromic, haplic, and calcic*. Vertisols are limited by their imperfect drainage condition while the other factors are optimum for surface irrigation. In general, about 55.1% of the land in the study area (129,590.9ha) can be categorized as moderately suitable (S2 class) to marginally suitable(S3) for surface irrigation.

Fluvisols are major soil groups which are found adjacent to the main rivers and streams that are subject to annual flooding receiving fresh sediments from each flood. Therefore, the soils show very little or no profile development. The soils are moderately deep to deep, poorly to imperfectly drained, medium to light textured and are stratified. Their color is variable differing from yellowish brown to dark reddish brown. The extents of fluvisols in the watershed are narrow covering only about 1.58% and are classified as *eutric*

These soils are classified as S2 and S3 because of the presence of the factors limiting the land for the specified use (FAO, 1979). However, S2 can be transferred to S1 using the most appropriate irrigation methods such as sprinkler and drip irrigation on these soils(OWWDSE,2010).

Table 7. Soil suitability classification result for surface irrigation

Soil Type	Soil Map Unit	Depth	Texture	Drainage	Salinity (EC)	Alkalinity (ESP)	Irrigation Suitability	Area (ha)	% of coverage
Cambisols leptic	IV CMlp_2	40	L	Well	0.1	0.92	N	40.7	0.02
Cambisols calcareic	IV CMca_2	150	SCL	Well	0.1	0.61	S2	1320.1	0.56
Cambisols chromic	III LVcr_2	200	SCL	Well	0.1	0.259	S2	8169.7	3.46
Cambisols vertic_calcic	III CMvr_2	200	SCL	Well	0.1	1.02	S2	4034.8	1.71
Fluvisols eutric	III FLeu_1	150	SL	Moderately well	0	0.32	S1	3716.6	1.57
Leptosols dystic	IV LPdu_3	20	L	Moderately Well	0.2	0.46	N	1752.5	0.74
Leptosols lithic	V LPli_3	15	C	Moderately Well	0.1	0.58	N	19529.5	8.26
Leptosols lithic rendzic	V LPli_2	10	L	Excessively/well	0.1	1.41	N	5652.0	2.39
Luvisols chromic	IV LVcr_2	140	SCL	Excessively/well	0.1	0.64	S2	43790.8	18.53
Luvisols vertic	III LVvr_2	200	C	Moderately/Well	0	0.24	S2	12903.2	5.46
Vertisols calcic &rock.	V VRcc_1	165	C	Poor	3.1	6.36	S3	1202.0	0.51
Vertisols chromic	IV VRcr_2	140	C	Poor/poor	0.1	0.1	S3	54910.4	23.23
Vertisols haplic	IV VRha_1	180	C	Moderately Well	0.1	0.28	S2	297.3	0.13
Not observed		0			0	0	N	79065.9	33.45
								236385.4	100.00

SCL=Sandy clay loam, SL=Sandy Loam, C=Clay, L=Loam,

The result shows land in the study area with soil types that can be categorized as S1 (highly suitable), S2 (moderately suitable) and S3 (marginally suitable) classes cover an area of 37,16.62 ha, 69,761.9 ha and 56,112.30ha respectively. Lithic Leptosol (lithic, dystric, & lithic rendzic) and Cambisols leptic are limited by shallow soil depth (<50 cm) which is unfavorable for crop growth and surface irrigation method, the areas covered by soils were classified as N (not suitable class) are 105,664.0 ha including the unobserved soil(OWWDSE,2010). land classified under N class accounts for 44.86%(105,664.6 ha) of the total study area. Vertisols has poor drainage that limits the workability of soil in general. Figure 19 shows soil suitability map of the study area

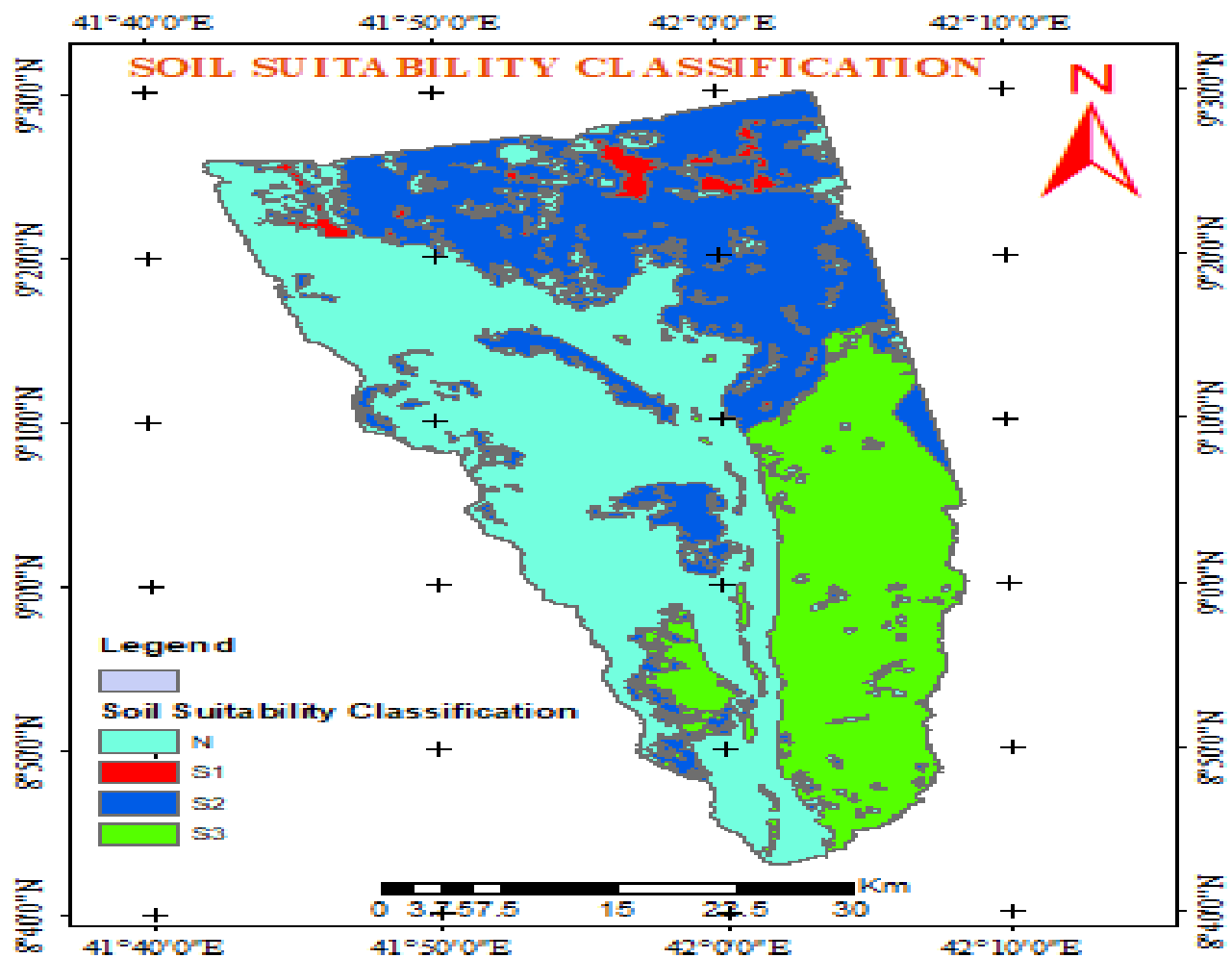


Figure 15. Soil suitability map of the study area

### **4.3.3. Land cover/use evaluation**

Land use/cover supervised classification using SPOT5.4.3 satellite image shows that ten land cover/use classes (Figure 16). Table 9 shows all land cover/use classes were classified with high accuracy except open shrub land, open grassland and bush land. From all land cover classification, marsh area and settlement were classified with 100% accuracy level. The land cover/use of the study area was classified with overall accuracy of 90.39% and Kappa coefficient of 0.8936. The Kappa coefficient of 0.89 of the land cover classification in the study area represents a strong agreement according to Rahman et.al (2006).

Table 8. Confusion matrix of SPOT 2016 LUC classification

	Ground True(Percent)										Total
	Marsh Area	Water Body	Built Up Area	Cultivated Land	Dense shrub land	Forest	Exposed Rock Surface	Open Shrub Land	Open Grass Land	Settlements	
Unclassified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marsh Area	100	0.00	0.00	2.17	0.00	0.00	0.00	0.00	0.00	0.00	0.80
Water Body	0.00	97.9	2.50	0.00	0.91	0.12	0.00	2.24	21.6	0.00	39.65
Built Up	0.00	0.00	91.85	0.00	2.76	0.01	10.15	0.08	0.75	0.00	32.05
Cultivated Land	0.00	0.00	0.00	92.11	4.30	0.00	0.00	0.00	0.00	0.00	13.50
Dense shrub	0.00	0.00	0.50	0.00	78.21	0.00	0.00	3.00	0.00	0.00	2.05
Forest	0.00	0.00	4.00	0.00	0.00	89.82	0.00	0.00	0.00	0.00	1.25
Exposed Rock S.	0.00	0.00	0.00	0.00	0.00	9.01	90.25	0.00	0.00	0.00	1.70
Open Shrub Land	0	2.1	0.95	5.72	3.38	1.04	0.00	75.65	0.00	0.00	6.80
Open Grass Land	0.00	0.00	0.20	0.00	0.00	0.00	0.00	19.13	77.65	0.00	1.20
Settlements	0.00	0.00	0.00	0.00	10.44	0.00	0.00	0.00	0.00	100	1.00
Total	100	100	100	100	100	100	100	100	100	100	100

Overall Accuracy = (5000688/4520054) =90.39%

Kappa Coefficient = 0.8936

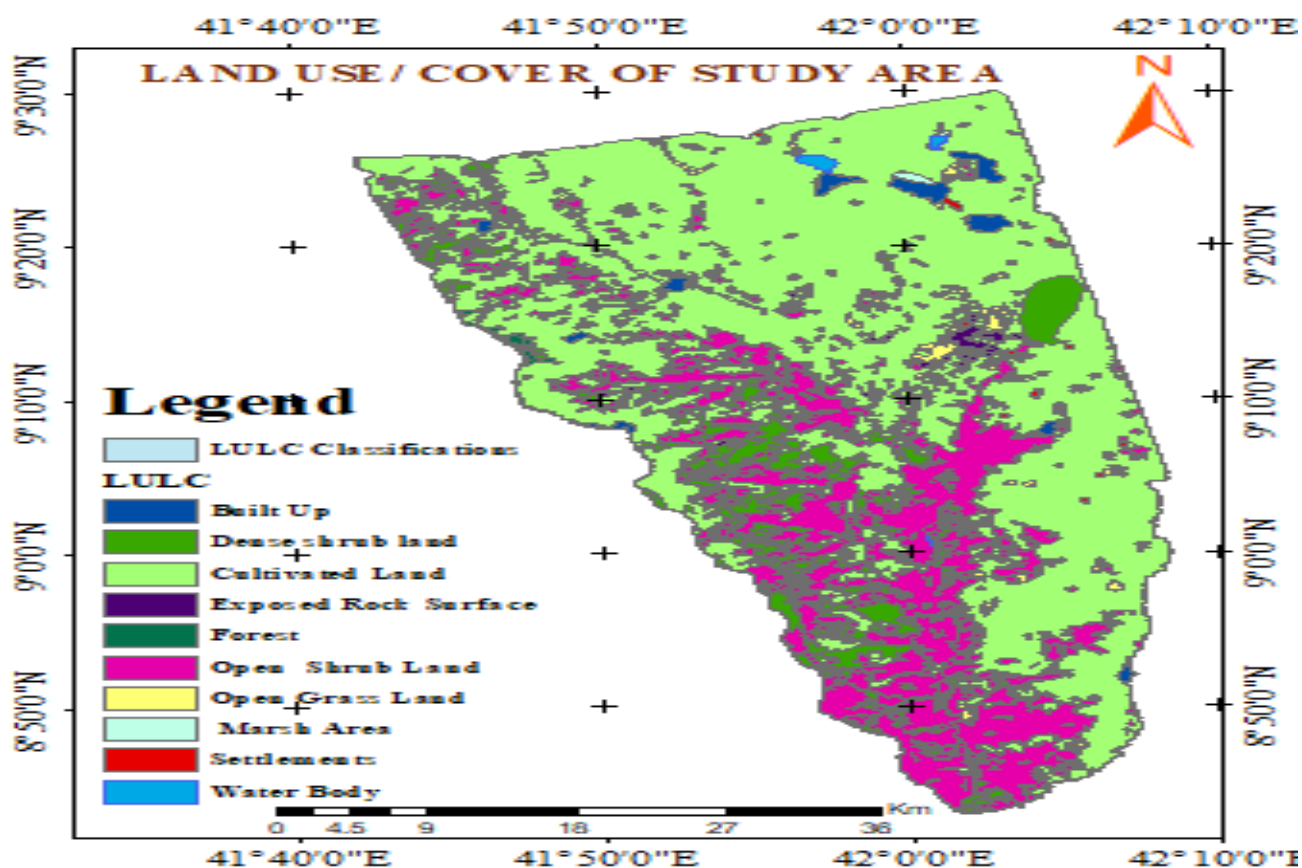


Figure 16. Land cover/use map of the study area

Table 9. Area coverage of land cover/use classes of the study area

S.No	LULC	Area(ha)	Percentage(%)
1	Cultivated Land	146709.4	62.36
2	Exposed Rock Surface with scattered shrubs	2541.5	1.08
3	Built Up	2685.1	1.14
4	Dense shrub land	19633.9	8.35
5	Forest	531.4	0.23
6	Open Shrub Land	15510.3	6.59
7	Open Grass Land	46045.4	19.57
8	Marsh Area	395.4	0.17
9	Settlements	802.8	0.34
10	Water Body	400.7	0.17
		235,255.9	100

The total land use/cover area was less than the area coverage of the catchment of the study area because the polygon less than 50 ha was ignored. Land cover/use classes such as cultivated land, open grassland, and open shrub land were classified as highly suitable for irrigation with the assumption that these land cover classes can be irrigated without limitations. They cover 88.6% of the study area. Other land units such as dense shrub land and forest lands were classified as lands not suitable for irrigation. This is because according to the local culture land use reserved for these purposes can't be put under cultivation and it covers 8.5% of the study area. It is obvious that land cover classes such as Exposed rock surface with scattered shrubs, water body, settlement, buildup area, and marsh area land cover classes are restricted to use for irrigation and it covers 2.9% of the study area. Therefore, the land cover that was not suitable for surface irrigation accounts for 11.4%. It is in line with Wabe-Shebelle integrated land use plan done by OWWDSE,2010.

#### **4.3.4. Distance from water source suitability**

Distance from water source has been considered as one of the evaluation parameters in irrigation suitability analysis. Based on the four classes (S1, S2, S3, and N), 93.7% the distance from the watershed outlet are from highly to marginally suitable of the study area for the development of surface irrigation system. The area coverage of the suitability classes is presented in Table 10.

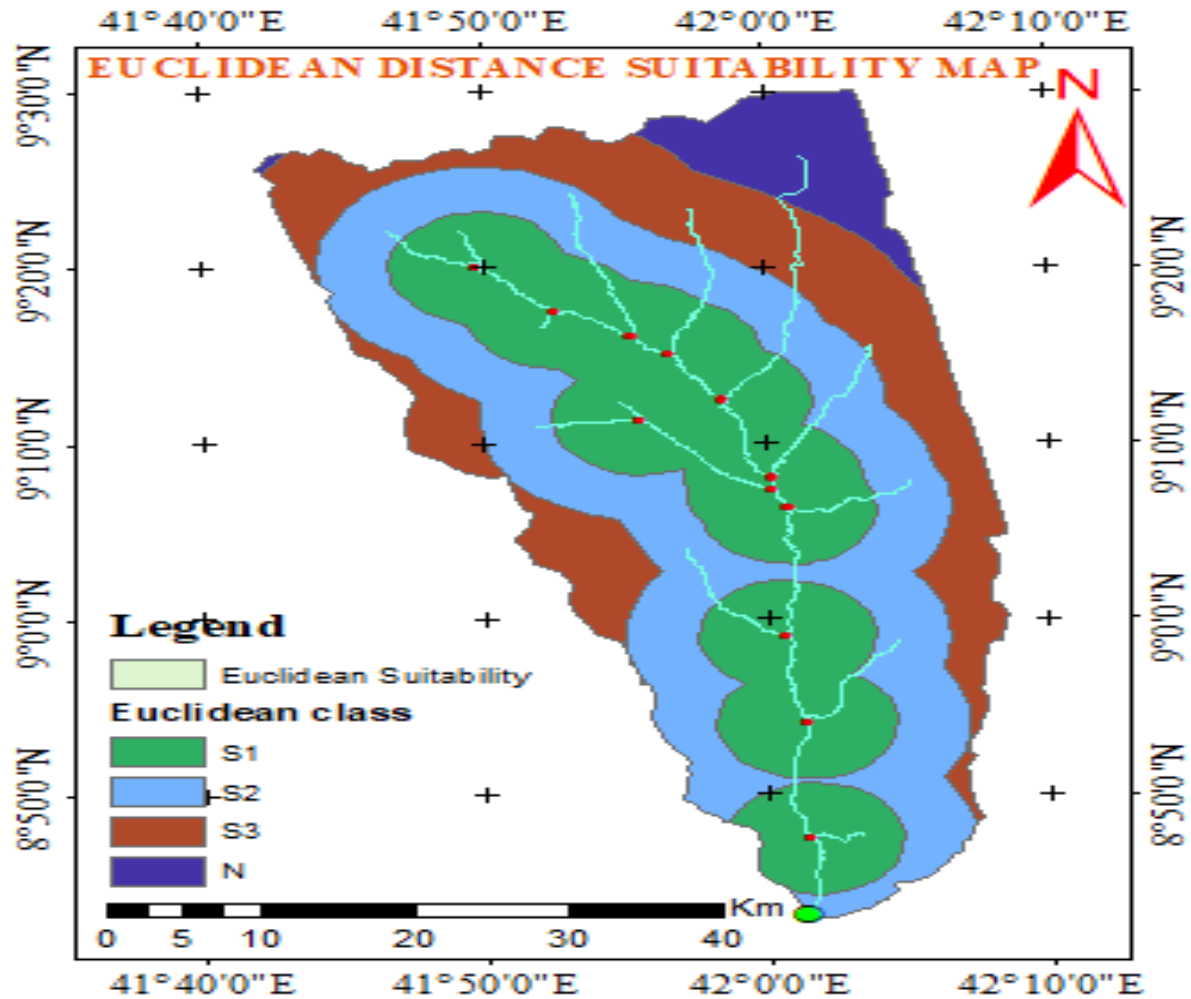


Figure 17. Euclidean distance map of the study area

Table 10. Area coverage of Euclidean distance classes of the study area

S. No	Euclidean distance suitability classes	Area(ha)	Percentage(%)
1	S1	82220.43	34.65
2	S2	84628.82	35.66
3	S3	54966.66	23.16
4	N	15498.52	6.53
	Total	237,314.43	100.0

#### **4.4. potential Suitable Land for Irrigation**

Potentially irrigable land was obtained by creating irrigation suitability model analysis which involved weighting of values of all data sets such as soil, slope, land cover and distance from the water supply. Figure 18 shows the identified potential irrigable lands below the reservoir or diversion sites among the main and tributary perennial rivers. The main and tributary rivers are referring to the main and sub-watersheds obtained by watershed delineation in section 4.2. Attempts were made to identify potential reservoir or diversion sites above the identified irrigable areas since the suitability was assessed for surface irrigation methods.

Based on the interpretation of physical and chemical characteristics of the parameters, the qualitative land evaluation for irrigation suitability implies that majority of the lower part of the study area identified as moderately to marginally suitable for surface irrigation in respect to soil, slope, land cover and distance from the water supply.

The final result of irrigation suitability model analysis of kurfa Chele-Girawa watershed was classified under moderately to marginally suitable for the application of surface irrigation which covers about 10.02% (23,567.7 ha) and 44.6%(104,861.9 ha) of the total area covered in the study area respectively, from these total surface Irrigation suitability area, the potential irrigable surface area identified was 45.9%(58,995.15ha) for future development of surface irrigation of the study area . The rest 45.4%(106,825.7 ha) of the area coverage classified as permanently not suitable for surface irrigation.

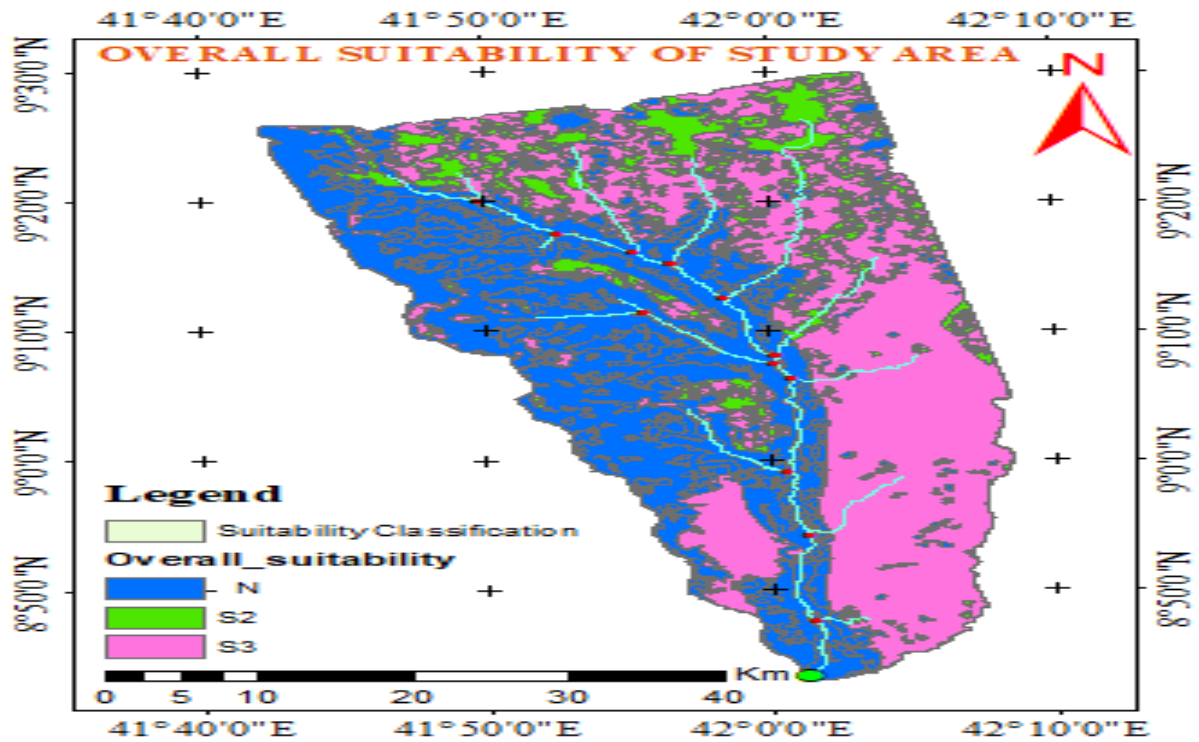


Figure 18. Final irrigation suitability map of the study area

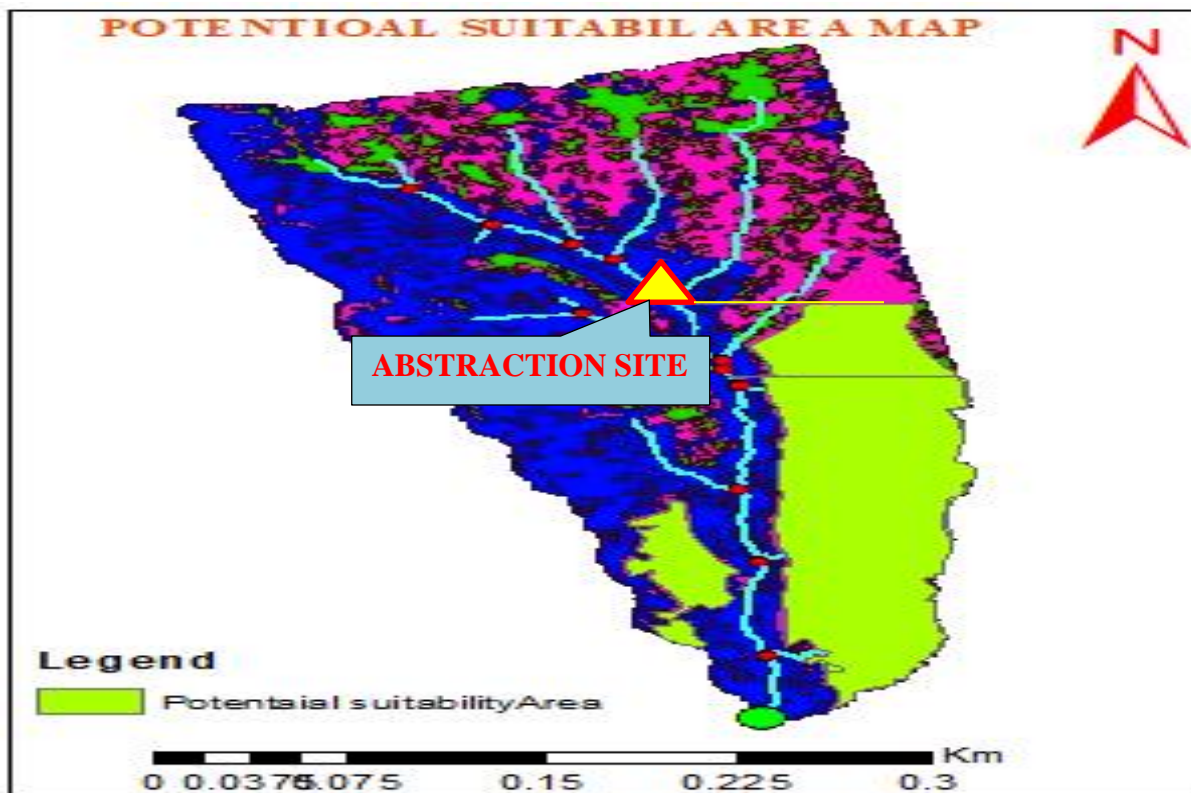


Figure 19. Potential irrigable land map of the study area

#### **4.5. Gross Irrigation Water Requirements of the Identified Command Areas**

Gross irrigation water requirements of maize and potato at the identified potential irrigable sites under surface irrigation methods were estimated using ETo. These results depict a general overview of monthly water demands of the crops that should be abstracted from the rivers by assuming single cultivation in a year during the local cropping period (mono-cropping). These indicated that the gross irrigation requirements of the crops at the identified potential irrigable areas are affected by the type of crop selected and the nearby meteorological stations.

#### **4.6. Water Resources Assessment**

Water resources assessment relies on a full understanding of all the water flows and storages in the river basin or catchment under consideration. Prior to estimating stream-flows at the un-gauged sites from gauged sites, watersheds above both gauged and un-gauged sites were characterized. Taking the watershed similarities into account, stream flows at un-gauged sites were estimated from the gauged sites by applying the runoff coefficient method. These results are discussed under the following sub-sections:

##### **4.6.1. Gauged and un-gauged watersheds similarities**

Referring to Figures 19-21, the sub-watersheds in Hamaressa sub-watershed with similar land cover, soil type, and slope range are identified and the results are presented in Table 11 of Un-gauged sub-watersheds such as Maya kelo and Maya guda. Dawe sub-watershed are a similar land cover, soil type, and slope range with ungauged sub-watersheds such as Kersa guba, and Bululo

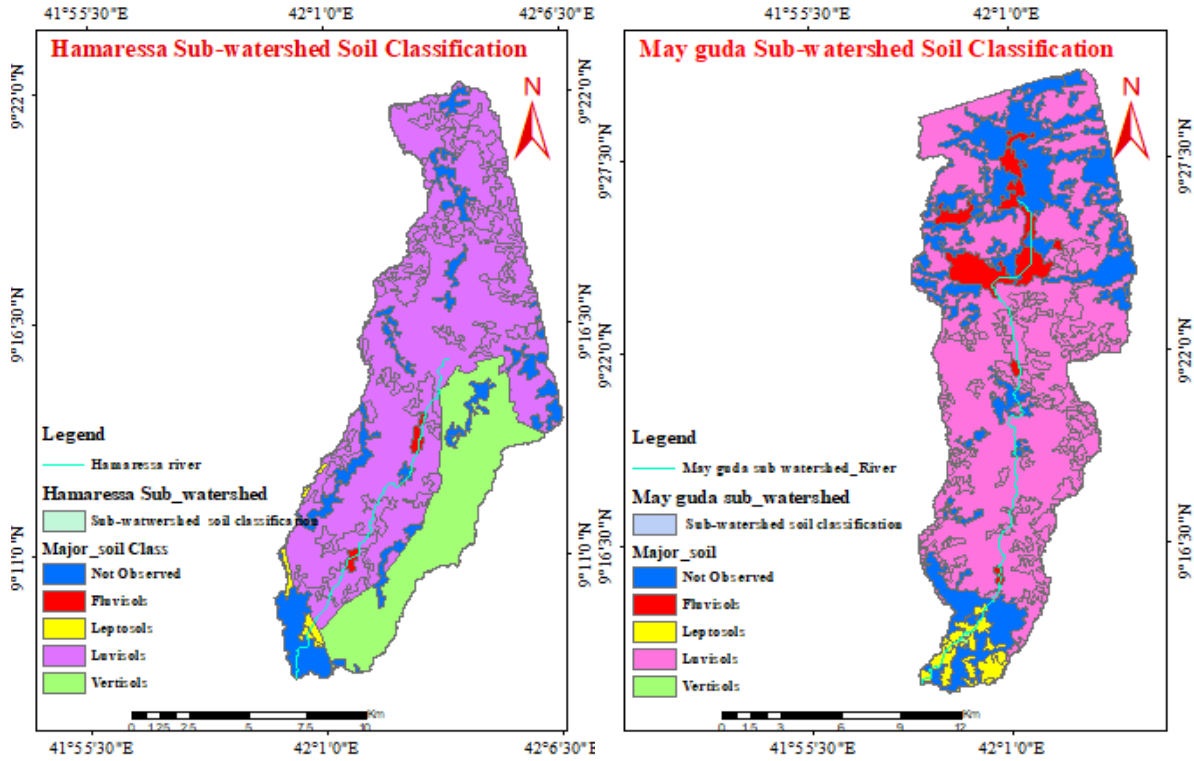


Figure 20. Soil map of Hamaressa and May guda Sub-watershed

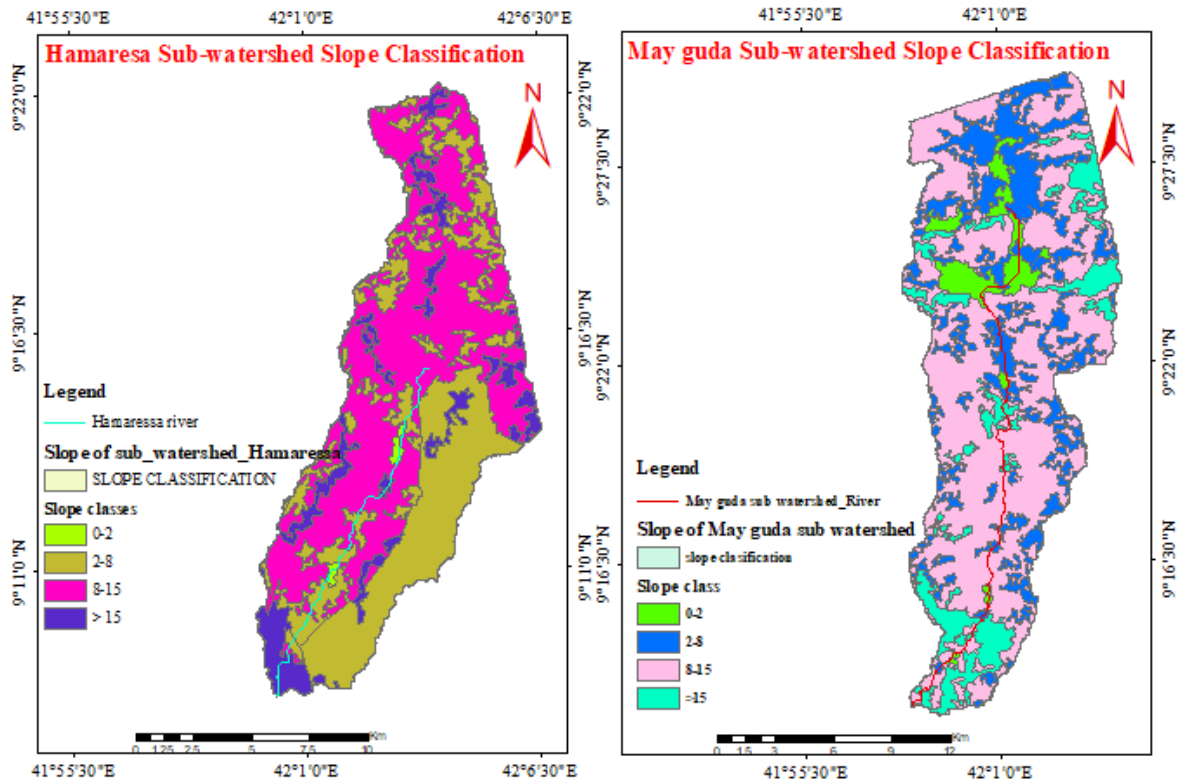


Figure 21 .Slope map of Hamaressa and Maya guda Sub-watershed

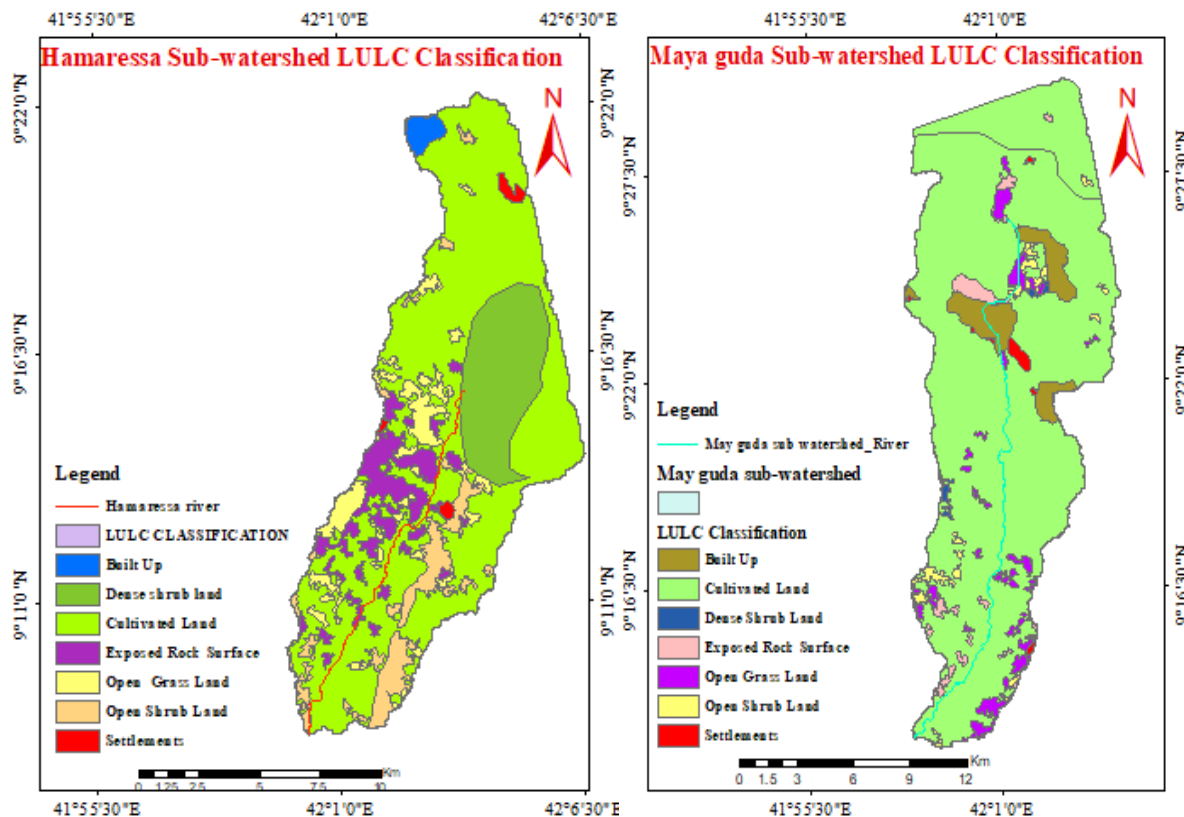


Figure 22.LULC map of Hamaressa and Maya kelo Sub-watershed

Table 11. Characteristics of watersheds above the gauged and un-gauged sites

Gauged sub-watershed	Ungauged sub-watershed
1 Hamaressa River near to Harar	Maya kelo and Maya guda
Soil Type	
Fluvisols	Fluvisols
Leptosols	Leptosols
Luvisols	Luvisols
Vertisols	Vertisols
Slope Range	
0-2	0-2
2.-8.	2.-8.
8.-15.	8.-15.
>15	>15
Land Use/cover	
Built Up	Built Up
Dense Shrub Land	Dense Shrub Land
Cultivated Land	Cultivated Land
Exposed Rock Surface with scattered shrubs	Exposed Rock Surface with scattered shrubs

Open Grass Land	Open Grass Land
Open Shrub Land	Open Shrub Land
Settlements	Settlements
<b>2</b> Dawe near to Gara	Kersa guba and Bululo
Soil Type	
Fluvisols	Fluvisols
Luvisols	Luvisols
Leptosols	Leptosols
Cambisols	Cambisols
Slope Range	
2.-8.	2.-8.
8.-15.	8.-15.
> 15(Dominant)	> 15(Dominant)
Land Use/cover	
Built Up	Built Up
Cultivated Land	Cultivated Land
Dense Shrub Land	Dense Shrub Land
Open Grass Land	Open Grass Land
Open Shrub Land	Open Shrub Land
Marsh area	Marsh area
Settlements	Settlements

#### 4.6.2. Mean areal rainfall of sub-watersheds

Mean areal rainfall of sub-watersheds, which were used as input data to estimate stream flows in un-gauged sites, were calculated by Thiessen polygon method using Arc GIS. Figures 22 to 28 show Thiessen polygon maps of each sub-watershed inside and around the study area. All sub-watersheds are influenced by more than one rain gauge station's. Table 14 presents the stations drainage areas within the watersheds, stations' area fraction, and stations mean monthly rainfall contribution (calculated by multiplying stations area fraction by long term mean monthly rainfall data from Appendix Tables 3-8).

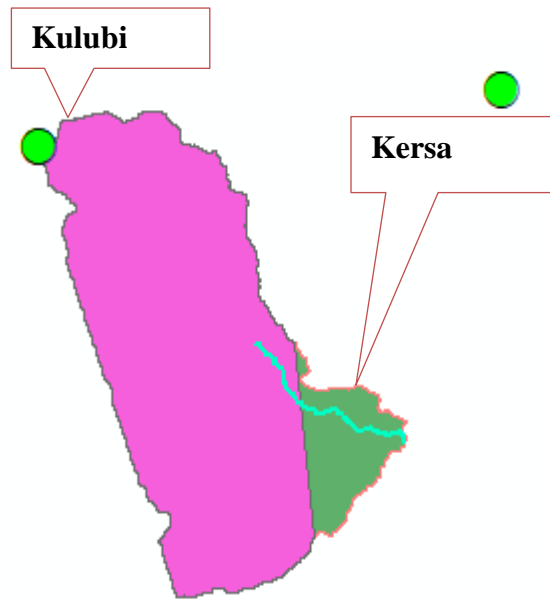


Figure 23 . Theissen polygon map of Dawe sub-watershed gauge site near Gara

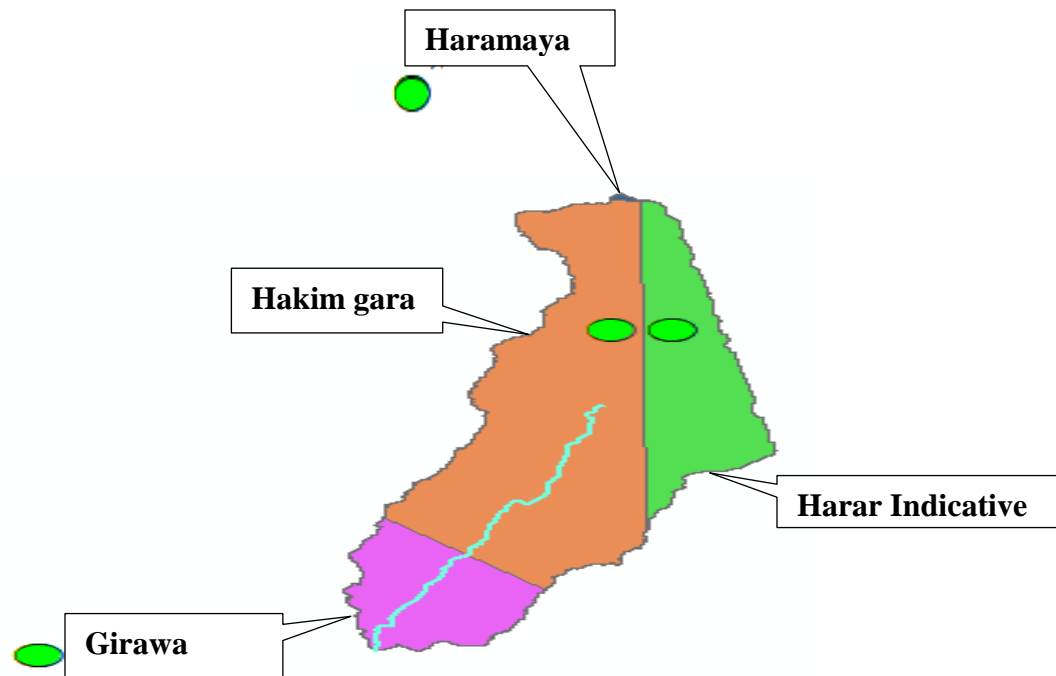


Figure 24. Theissen polygon map of Hamaressa sub-watershed gauge site near Harar

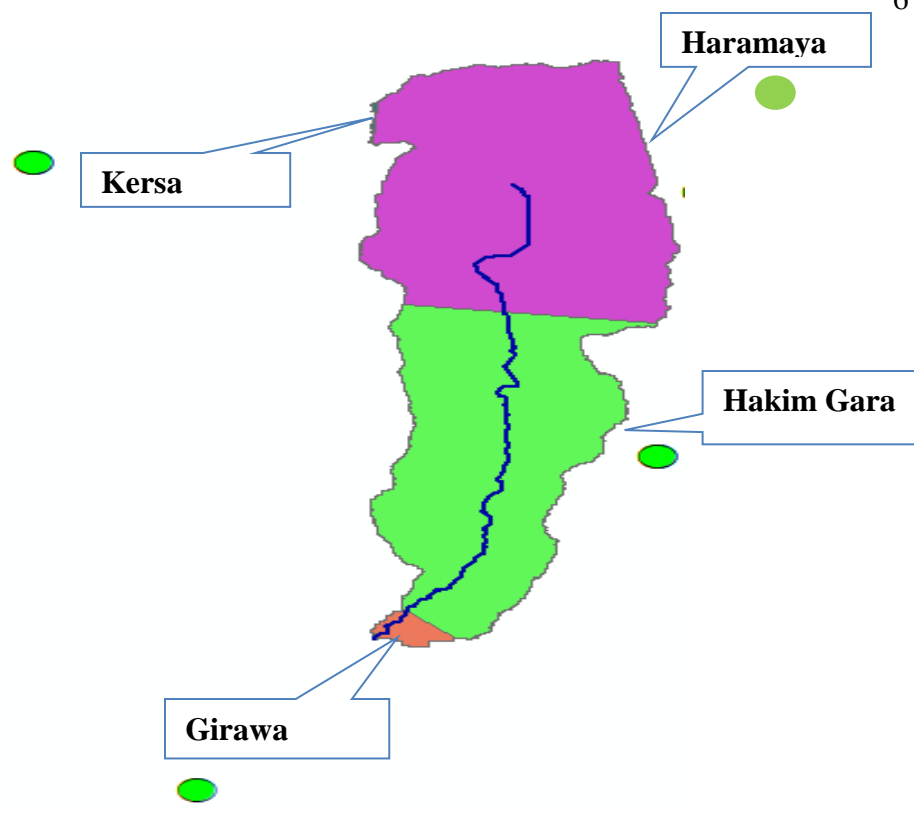


Figure 25. Theissen polygon map of Maya Guda sub-watershed

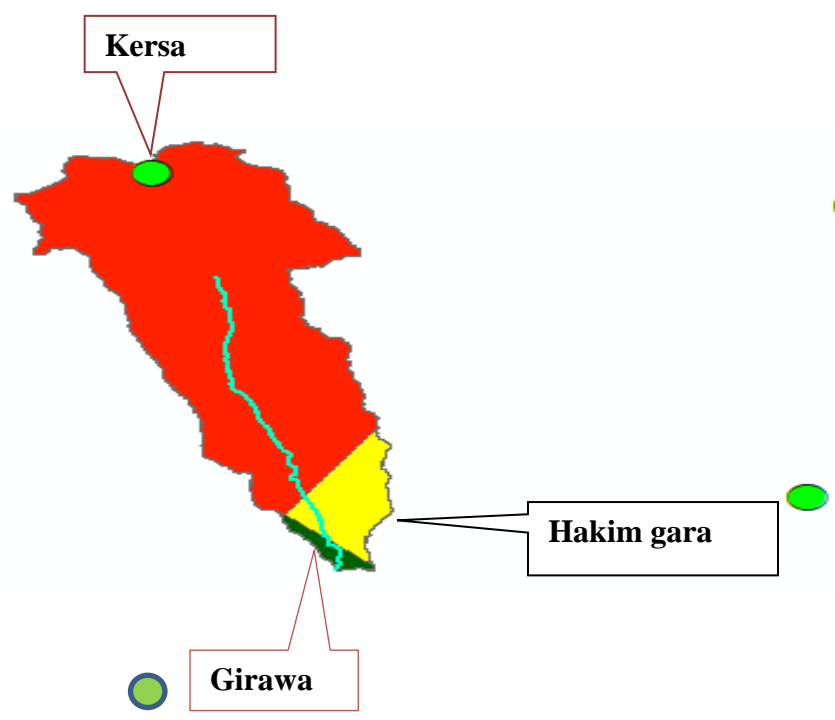


Figure 26. Theissen polygon map of Kersa guba sub-watershed

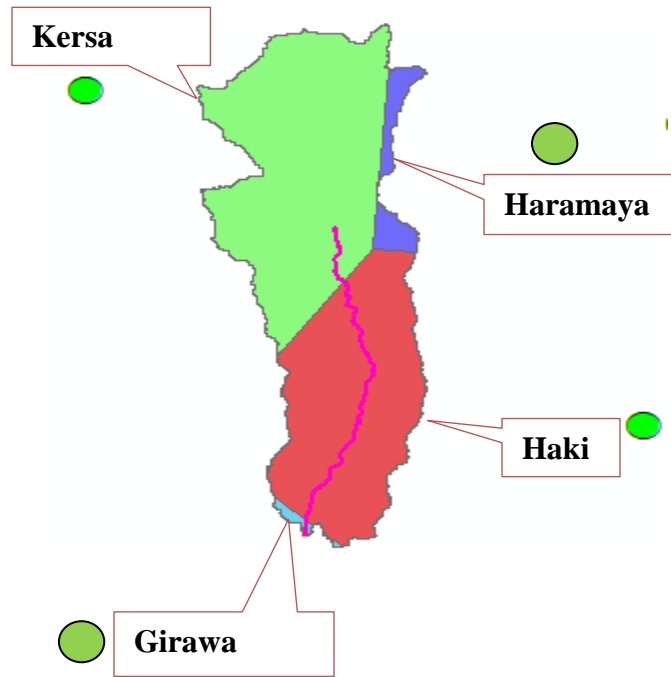


Figure 27. Thiessen polygon map of Maya Kelo sub-watershed

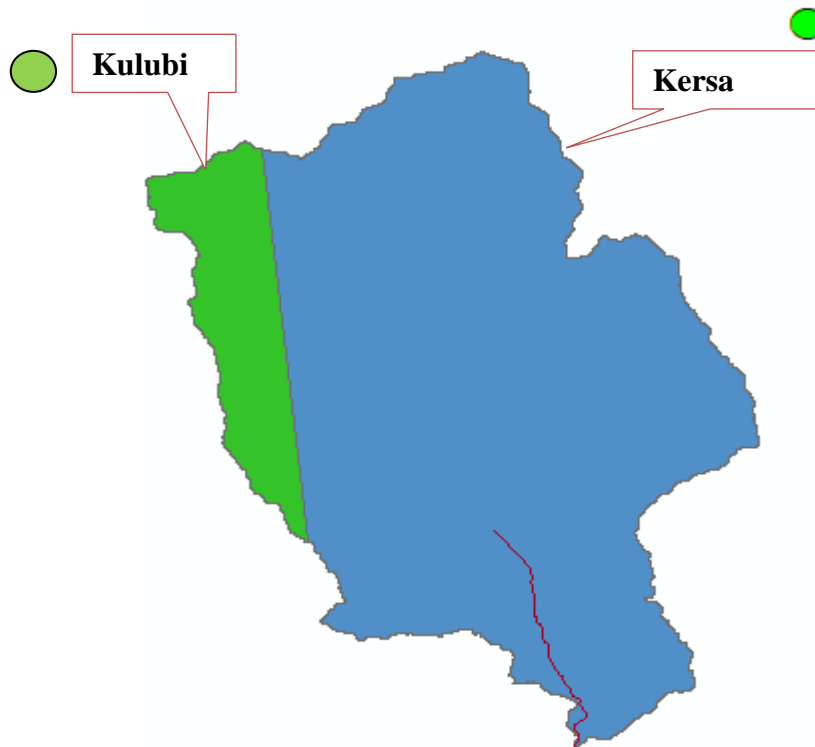


Figure 28. Thiessen polygon map of Bululo sub-watershed

Table 12. Average monthly areal rainfall of the sub-watersheds.

Stations	Stations drainage area in (km <sup>2</sup> )	Station area fraction(%)	Stations monthly rainfall contribution in (mm)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<b>1 Hamaressa Sub-watershed</b>														
Girawa	26.90	17.0	3.1	2.8	12.7	28.1	18.9	11.9	21.2	28.2	22.1	9.8	3.9	1.8
Harar	37.88	24.0	3.2	5.4	19.2	32.1	22.1	14.1	24.6	29.9	26.6	11.9	3.9	2.6
Haramaya	0.21	0.1	0.01	0.02	0.06	0.11	0.09	0.05	0.11	0.15	0.12	0.05	0.02	0.02
Hakim gar	92.81	58.8	4.6	17.1	44.5	99.9	67.9	50.5	71.7	66.8	59.7	21.5	13.6	1.5
Total	157.8	100.0	10.9	25.4	76.4	160.3	109.0	76.6	117.7	125.0	108.5	43.3	21.4	5.8
<b>2 Maya Guda Sub-watershed</b>														
Girawa	3.43	1.4	0.25	0.24	1.04	2.32	1.55	0.97	1.74	2.32	1.82	0.81	0.31	0.14
Haramaya	131.55	53.6	4.56	9.77	29.61	60.91	51.07	26.10	59.18	82.46	66.70	24.60	11.32	7.90
Kersa	0.30	0.1	0.017	0.014	0.069	0.100	0.084	0.067	0.107	0.142	0.107	0.070	0.022	0.011
Hakim gar	110.12	44.9	7.27	4.62	18.59	33.33	31.40	18.47	31.13	34.11	28.17	27.81	8.74	3.67
Total	245.40	100.0	12.10	14.64	49.31	96.66	84.10	45.61	92.17	119.04	96.80	53.29	20.40	11.73
<b>3 Kersa guuba Sub-watershed</b>														
Girawa	2.30	1.76	0.31	0.30	1.31	2.91	1.94	1.22	2.19	2.92	2.29	1.02	0.39	0.18
Kersa	116.52	89.09	15.57	12.90	61.12	89.52	74.62	59.75	95.50	126.13	95.39	62.43	19.46	9.41
Hakim gar	11.97	9.15	1.48	0.94	3.79	6.79	6.40	3.76	6.34	6.95	5.74	5.67	1.78	0.75
Total	130.79	100.00	17.36	14.15	66.22	99.22	82.96	64.73	104.04	136.00	103.42	69.11	21.63	10.34
<b>4 Maya kelo Sub-watershed</b>														

Girawa	0.96	0.66	0.12	0.11	0.49	1.09	0.73	0.46	0.82	1.09	0.86	0.38	0.15	0.07
Haramaya	6.01	4.14	0.35	0.75	2.29	4.70	3.94	2.02	4.57	6.37	5.15	1.90	0.87	0.61
Kersa	78.14	53.76	9.39	7.79	36.88	54.02	45.03	36.05	57.63	76.11	57.56	37.67	11.74	5.68
Hakim gar	60.24	41.45	6.71	4.27	17.16	30.77	28.98	17.05	28.74	31.49	26.00	25.67	8.07	3.39
Total	145.35	100.00	16.57	12.92	56.82	90.58	78.68	55.58	91.77	115.07	89.58	65.62	20.83	9.75
<b>5</b> Dawe Sub-watershed														
Kersa	15.22	11.58	2.02	1.68	7.94	11.64	9.70	7.77	12.41	16.39	12.40	8.11	2.53	1.22
Kulubi	116.26	88.42	22.73	32.18	87.72	144.30	86.91	60.31	126.20	176.47	118.99	36.59	15.96	19.47
Total	131.48	100.00	24.75	33.86	95.67	155.94	96.61	68.08	138.61	192.87	131.38	44.70	18.49	20.70
<b>6</b> Bululo Sub-watershed														
Kersa	61.78	87.99	15.37	12.75	60.37	88.41	73.69	59.01	94.32	124.57	94.21	61.66	19.22	9.30
Kulubi	8.43	12.01	2.17	3.07	8.36	13.76	8.29	5.75	12.03	16.82	11.34	3.49	1.52	1.86
Total	70.21	100.00	17.54	15.81	68.73	102.17	81.98	64.76	106.36	141.40	105.56	65.14	20.74	11.15

### 4.6.3. Stream flows at un-gauged sites

Table 13 shows that the characteristics of watershed above the un-gauged sites on Maya guda, Maya kelo, Kersa guba, and Bululo rivers are similar with the watersheds above the gauged sites on Dawe river (near Gara) and Hamaressa river (near Harar). Similarly, the distances between these gauged and un-gauged sites were found to be less than 50 kilometers and the length of records of streamflow data at Dawe and Hamaresa gauging sites were about 10 years, respectively, (Appendix Tables 1 and 2). Hence, the requirements suggested by Goldsmith (2000) and DFID (2004) to use the runoff coefficient method were met and thus estimated mean monthly discharges at the un-gauged sites from gauged sites are presented in Table 13.

Table 13. Mean monthly stream flows of un-gauged river catchments estimated from gauged sites

River Catchment Name		Mean Monthly flows in (m <sup>3</sup> /s)											
Gauged River	ungauged River	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dawe	Kersa gub.	1.9	2.0	2.1	4.0	4.0	4.4	4.5	4.3	4.5	3.1	2.6	2.1
	Bululo	4.1	4.4	4.6	8.7	8.7	9.6	9.8	9.4	10.0	6.8	5.7	4.6
Hamaresa	Maya gud.	3.8	3.3	5.8	6.6	6.8	6.5	6.4	5.8	5.4	4.8	5.2	4.7
	Maya kelo	2.2	2.0	3.4	3.9	4.0	3.8	3.8	3.4	3.2	2.8	3.1	2.8

### 4.6.4. Transferring discharges to sites of interest

The discharges at the site of the interest were obtained by transferring the river discharges at the gauged site to the site of interest on the same river. The site of interest, in this case, is referring to a site closer to and above the identified potential irrigable land (command area). All drainage areas of the sites of interest were found within 20% of the drainage areas of the gauged sites. Hence, the area ratio method suggested by Silesh (2000) was adopted and the results are presented in Table 14.

Table 14. Mean monthly discharges (m<sup>3</sup>/s) at the sites of interest

Site-of Interest	Mean monthly Discharge at site of interest in m <sup>3</sup> /s											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dawe-at Mudena	7.8	8.2	8.6	16.3	16.3	18.0	18.4	17.5	18.8	12.6	10.6	8.6
Hamaresa at Gobale	8.8	8.0	13.5	15.7	15.7	15.4	15.0	13.5	12.8	11.3	12.1	11.0

#### 4.7. Irrigation Potential of River Catchments

Irrigation potential of the river catchments in the study area was obtained by comparing irrigation requirements of the identified land suitable for surface irrigation and the available mean monthly flows in the river catchments based on the method suggested by FAO (1997). Tables 17 and 18 present gross irrigation demand of the two crops commonly grown in the study area (Potato and maize) and the available mean monthly flows of the corresponding river catchments. Results of these analyses showed that monthly irrigation requirements of both potato and maize are less than the available mean monthly flows for the month of February and March for the sub-watershed above abstraction/ diversion site with the potential command area. But in the mid and late stage of Maize crop growth (the month of April, May, and June) monthly irrigation water requirement of Maize is higher than the available flows. As a result, the critical command areas were calculated according to (Micheal,2008) to grow these crops as shown in table 17 that can be reliably irrigated using the available flows.

Table 15. Critical command area of Maize

Critical month	FWS(l/s/ha)	Potential command area(ha)	Critical command area(ha)
February	0.417		66745.6
April	0.757	58,995.15	73000.1
May	1.930		28793.7
June	1.931		29819.7

Similarly, irrigation requirement of Potato at all stage except late stage growth (June) higher than the available flow in the sub-watershed above the abstraction/diversion site. The critical command areas were calculated according to Micheal (2008) to grow these crops as shown in table 18 that can be reliably irrigated using the available flows.

Table 16. Critical command area of Potato

Critical month	FWS(l/s/ha)	Potential command area(ha)	Critical command area(ha)
February	0.682		40867.1
March	0.711	58,995.15	53408.8
April	0.882		62623.6
May	1.387		40065.5

Table 17. Comparing of irrigation demands and available flows of river catchments in the study area for Maize.

River Name	Potential command area(ha)	Mean monthly Discharge at the site of interest in m <sup>3</sup> /s											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dawe	58,995.15	7.8	8.2	8.6	16.3	16.3	18.0	18.4	17.5	18.8	12.6	10.6	8.6
Hamaresa		8.8	8.0	13.5	15.7	15.7	15.4	15.0	13.5	12.8	11.3	12.1	11.0
Kersa gub.		1.9	2	2.1	4	4	4.4	4.5	4.3	4.5	3.1	2.6	2.1
Bululo		4.1	4.4	4.6	8.7	8.7	9.6	9.8	9.4	10.0	6.8	5.7	4.6
Maya gud.		3.8	3.3	5.8	6.6	6.8	6.5	6.4	5.8	5.4	4.8	5.2	4.7
Maya kelo		2.2	2	3.4	3.9	4	3.8	3.8	3.4	3.2	2.8	3.1	2.8
<b>Total</b>			28.6	27.9	38.0	55.3	55.6	57.6	57.9	53.9	54.7	41.4	39.2
<b>FWS(l/s/ha)</b>													
<b>Stations</b>		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haramaya		0.000	0.085	0.102	0.149	0.270	0.288	0.028	0.000	0.000	0.000	0.000	0.000
Hara Indicative		0.000	0.076	0.073	0.086	0.218	0.227	0.000	0.000	0.000	0.000	0.000	0.000
Girawa		0.000	0.096	0.000	0.000	0.116	0.181	0.000	0.000	0.000	0.000	0.000	0.000
Kersa		0.000	0.086	0.102	0.385	0.569	0.470	0.079	0.000	0.000	0.000	0.000	0.000
Kulubi		0.000	0.060	0.045	0.136	0.482	0.454	0.000	0.000	0.000	0.000	0.000	0.000
Hakim gara		0.000	0.015	0.000	0.002	0.275	0.311	0.000	0.000	0.000	0.000	0.000	0.000
<b>Total</b>		0.000	0.417	0.321	0.757	1.930	1.931	0.108	0.000	0.000	0.000	0.000	0.000
<b>Crop wat requirement of Maize</b>													
Potential command area(58,995.15ha)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Available flow(m <sup>3</sup> /s)		28.6	27.9	38.0	55.3	55.6	57.6	57.9	53.9	54.7	41.4	39.2	33.7
Total _GIR(m <sup>3</sup> /s)		0	32.8	25.3	59.5	151.8	151.9	8.5	0	0	0	0	0

Table 18. Comparing of irrigation demands and available flows of river catchments in the study area for Potato

River Name	Mean monthly Discharge at the site of interest in m <sup>3</sup> /s												
	Potential command area(ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dawe		7.8	8.2	8.6	16.3	16.3	18.0	18.4	17.5	18.8	12.6	10.6	8.6
Hamaresa		8.8	8.0	13.5	15.7	15.7	15.4	15.0	13.5	12.8	11.3	12.1	11.0
Kersa gub.	58,995.15	1.9	2	2.1	4	4	4.4	4.5	4.3	4.5	3.1	2.6	2.1
Bululo		4.1	4.4	4.6	8.7	8.7	9.6	9.8	9.4	10.0	6.8	5.7	4.6
Maya gud.		3.8	3.3	5.8	6.6	6.8	6.5	6.4	5.8	5.4	4.8	5.2	4.7
Maya kelo		2.2	2	3.4	3.9	4	3.8	3.8	3.4	3.2	2.8	3.1	2.8
Total Available flow(m <sup>3</sup> /s)		28.6	27.9	38.0	55.3	55.6	57.6	57.9	53.9	54.7	41.4	39.2	33.7
FWS(l/s/ha)													
Stations		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haramaya		0.000	0.125	0.180	0.161	0.176	0.060	0.000	0.000	0.000	0.000	0.000	0.000
Hara Indicative		0.000	0.112	0.084	0.074	0.145	0.025	0.000	0.000	0.000	0.000	0.000	0.000
Girawa		0.000	0.130	0.093	0.031	0.112	0.051	0.000	0.000	0.000	0.000	0.000	0.000
Kersa		0.000	0.182	0.238	0.433	0.437	0.112	0.000	0.000	0.000	0.000	0.000	0.000
Kulubi		0.000	0.109	0.115	0.182	0.355	0.104	0.000	0.000	0.000	0.000	0.000	0.000
Hakim gara		0.000	0.025	0.000	0.000	0.160	0.035	0.000	0.000	0.000	0.000	0.000	0.000
Total		0.000	0.682	0.711	0.882	1.387	0.387	0.000	0.000	0.000	0.000	0.000	0.000
Crop wat requirement of Potato													
Potential command area(58,995.15ha)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Available flow(m <sup>3</sup> /s)		28.6	27.9	38.0	55.3	55.6	57.6	57.9	53.9	54.7	41.4	39.2	33.7
Total GIR(m <sup>3</sup> /s)		0.0	53.6	55.9	69.4	109.1	30.4	0.0	0.0	0.0	0.0	0.0	0.0

#### 4.8. Storage requirement

Storage requirement to meet the demand of crop water requirement at critical month is estimated at different exceedance available flow level for each sub-watershed without losing the potential command area. It is observed that much storage is required in the abstraction/diversion points for both maize and potato to fulfill the crop water requirement.

Table 19. The water storage requirement for potential command area of a maize crop

Critical Month	FWS (l/s/ha)	Potential command area(ha)	Available flow (m <sup>3</sup> /s)	Required flows (m <sup>3</sup> /s)	Difference (m <sup>3</sup> /s)	Water storage required (m <sup>3</sup> )
February	0.417		27.9	32.8	5.0	429,715.5
April	0.757	58,995.15	55.3	59.5	4.3	370,175.2
May	1.93		55.6	151.8	96.2	8,313,308.9
June	1.931		57.6	151.9	94.3	8,150,494.2
Total						17,263,693.7

Table 20. The water Storage requirement for potential command area of a Potato

Critical Months	FWS (l/s/ha)	Potential command area(ha)	Required flows (m <sup>3</sup> /s)	Available flows(m <sup>3</sup> /s)	Difference (m <sup>3</sup> /s)	Water storage required (m <sup>3</sup> )
February	0.682		53.6	27.9	25.8	2,226,192.0
March	0.711	58,995.15	55.9	38.0	18.0	1,551,156.1
April	0.882		69.4	55.3	14.2	1,222,599.4
May	1.387		109.1	55.6	53.5	4,624,016.7
Total						9,623,964.3

## 5. SUMMARY, CONCLUSION AND RECOMMENDATION

### 5.1. Summary and Conclusion

The irrigation suitability study was conducted for Kurfa Chele-Girawa watershed which located in the Wabe Shebelle basin Oromia regional state. The total area coverage of the watershed that obtained through watershed delineation is 237,363.1 ha. It had been carried out to evaluate and estimate suitable irrigable land and water resource in the study area and develop the final suitability map. By assessing available land and water resources for irrigation an important investment for improving rural income through increased agricultural production. Therefore, identified surface irrigation potential of river catchments in the study area can assist in policy decisions during the development of irrigation projects in Kurfa Chele-Girawa watershed.

The main irrigation suitability factors undertaken during the study were a slope, soil, land use/cover, and Euclidean distance. The result from the irrigation suitability analysis; a slope of 95.6%, a soil of 55.14%, Euclidean distance of 93.7% and land use/cover of 88.1% of the study area identified in the range of highly suitable to marginal suitable for surface irrigation. This indicates that most of the lowland of Kurfa Chele-Girawa watershed was potentially suitable for irrigation development.

The soil drainage classification implies that 23.85% of the study area was classified under poor drainage. In relation to the application of surface irrigation poor soil drainage condition was the most limiting factor which makes most of the soil to classify as S2 and S3. Other soil related irrigation suitability factors like salinity, alkalinity and stoniness are very low to the extent of no negative impact. In terms of land use/cover, 11.4% of the study area including; settlement, forest, bush land, marsh area, exposed rock surface with scatter, built-up area and water body are restricted from irrigation.

By weighting values of these constraint data sets using weighted overlay in Arc GIS, the irrigation suitability map was developed and potentially irrigable land for surface irrigation was as 10.02%, 44.6% and 45.4% for S2, S3, and N respectively.

From the results obtained the conclusion that could be drawn, 54.6% of the study area was suitable for surface irrigation development with respect to slope, soil, Euclidean distance and land use/cover and from this, the potential suitability for surface irrigation below the abstraction site was 45.9% of the study area suitability for surface Irrigation. Based on the finding of this study, it was clear that the most limiting factor for irrigation suitability in the study area is soil drainage limitation due to the soil in the suitability area almost vertisols.

Irrigation investment plays an important role in maintaining sustainable food security by improving the agricultural production which is the core foundation for Ethiopia's economy, growth, and long-term food security.

In all the sub-watershed the potentially irrigable land exceeds the available surface water capacity during the low flow periods. This does not mean that the total annual flow capacity is less than the irrigation water demand. There is a large amount of river flow as well as runoff during the peak flow periods, which is able to satisfy the demand of irrigated area. Due to the seasonal variation of streamflow, provision of storage reservoirs has to be implemented in the watershed. This is because the distribution of available water is not even both in space and time domain.

## **5.2. Recommendation**

Irrigation suitability constraints such as water quality, environmental, economic and social terms should be assessed to get a sound result in addition to those parameters (slope, soil, land use/cover, and Euclidean distance) considered in this study to evaluate land suitability for irrigation.

GIS is a powerful technology used for systematic land suitability assessment and develops clearly current land use and irrigation land suitability description for potential resource in the area. So for detail and accurate assessment GIS and remote sensing data inputs should be recent data layers with high spatial resolution.

The data generated such as, land cover/use, soil, and slope maps for the purpose of this research work to estimated discharges at ungauged sites, potential evapotranspiration data close to

identified potential irrigable sites of river catchments can assist local or regional planners to facilitate preliminary surveys and prepare irrigation projects in the study area.

The final suitability of the watershed shows that there was no highly suitable land for surface irrigation, the present land was in the standard of moderately and marginally suitability for surface irrigation, so addressing the specific constraint of land and management option for sustainable use. Marginally suitable land should be used under high level management.

The potentially irrigable land exceeds the available flows of water during the low flow periods but the mean total annual flow capacity is less than the irrigation water demand so, provision of storage reservoirs has to be implemented in the watershed to satisfy the crop water requirement during low flows.

Due to fine textured/clay soil of the study area, the area has poor drainage and workability problems under excessive moisture regimes. These soils could be made more suitable by adopting an improved drainage system, soil, and crop management practices. Hence an appropriate drainage system provision should be taken into consideration in further development.

For the area which have slope above 8%, land leveling operation or soil conservation work have to be incorporated to break surface slope and to make it suitable for surface irrigation.

Land use policy necessity take account of land suitability in relation to the expected future needs and the possibility of meeting demands. The critical importance of land for specified uses should be known either physical or economic suitability.

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## 7. APPENDICES

### 7.1. Summary of Hydro Meteorological Data

#### 7.1.1. Hydrological Data

Appendix Table 1. Hamaressa River monthly flow (m<sup>3</sup>/s)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997	3.376	3.197	9.767	8.585	8.019	5.396	4.624	5.409	6.635	5.141	7.211	6.104	73.463
1998	1.147	1.147	3.280	4.509	4.770	4.531	4.757	5.563	5.427	4.598	4.416	4.443	48.588
1999	3.591	3.263	8.166	6.549	4.775	4.614	4.494	4.744	4.221	3.678	3.304	3.909	55.307
2000	3.606	4.043	4.898	6.352	4.425	4.435	4.406	5.553	4.448	4.775	6.234	5.555	58.731
2001	2.950	2.883	3.848	4.879	4.695	4.253	4.622	5.219	4.422	4.267	4.450	4.862	51.349
2002	4.098	3.458	3.365	3.776	4.891	4.908	4.400	1.919	1.104	0.914	0.000	0.000	32.833
2003	0.000	0.000	0.047	1.041	3.904	4.464	3.995	3.012	2.693	2.477	2.299	2.213	26.145
2004	2.244	2.170	2.213	3.210	3.749	3.927	4.514	2.662	2.317	2.304	2.494	1.963	33.766
2005	1.903	0.166	0.968	2.341	3.353	3.903	4.106	3.195	2.310	1.686	1.559	1.064	26.555
2006	1.271	1.178	0.543	1.339	0.868	1.328	1.453	0.165	1.024	1.050	1.442	0.082	11.743
Mean	2.4	2.2	3.7	4.3	4.3	4.2	4.1	3.7	3.5	3.1	3.3	3.0	41.8
STDEV	1.3	1.4	3.2	2.4	1.8	1.1	1.0	1.8	1.9	1.6	2.2	2.2	18.7

Appendix Table 2. Dawe River near Gara Mulata's monthly flow (m<sup>3</sup>/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997	2.038	2.170	2.196	10.246	5.463	6.991	6.814	5.082	4.713	2.291	5.735	4.496	58.235
1998	3.713	4.099	1.744	1.929	5.845	4.712	5.740	6.149	7.929	6.393	2.980	2.228	53.461
1999	2.562	2.423	2.868	3.186	4.137	4.952	4.472	4.213	4.187	1.478	1.439	1.305	37.222
2000	1.388	1.389	1.530	1.876	0.775	0.873	1.821	3.048	0.945	0.421	0.321	0.373	14.760
2001	0.498	0.698	0.530	0.542	1.027	3.374	3.712	4.088	3.673	0.515	0.448	0.384	19.488
2002	0.421	0.408	0.390	3.907	3.631	2.959	2.813	2.943	5.499	4.375	3.904	3.950	35.200
2003	4.145	3.638	4.283	3.857	3.612	3.078	3.568	3.656	3.117	2.410	1.987	1.216	38.567
2004	0.961	1.588	1.811	4.448	6.028	5.105	5.927	4.545	5.193	3.966	4.025	4.183	47.779
2005	3.086	3.023	3.293	5.520	5.281	5.993	5.540	4.358	5.969	5.285	1.808	0.679	49.834
2006	0.601	0.524	2.797	4.337	4.271	5.773	4.993	5.026	4.462	3.531	3.378	2.046	41.739
Mean	1.9	2.0	2.1	4.0	4.0	4.4	4.5	4.3	4.6	3.1	2.6	2.1	39.6
STDEV	1.4	1.3	1.2	2.6	1.9	1.8	1.6	1.0	1.8	2.0	1.7	1.6	14.0

## 7.2. Meteorological data

### 7.2.1 Rain fall data

Appendix Table 3. Corrected monthly rainfall data at Haramaya (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985	0	0	46.9	164.2	87.6	29.7	88.3	90.2	69.6	9.9	6.3	0	592.7
1986	0	38.6	14.1	153.9	110	80.8	66	161.4	96.7	34	5.8	0	761.4
1987	0	8.1	180.2	148.6	248	29.6	63.3	123.2	112	31	2.7	0	946.8
1988	9.8	43.8	30.4	154.3	31.3	54.1	102	180.7	212	41.9	0	6	865.9
1989	0	14.4	154.9	114.5	69.4	52.6	104	146	104	41.2	3.6	45	850.0
1990	1.7	73.1	45.4	137.1	59.6	54.1	80.9	154.7	134	53.3	0	7	800.7
1991	0	51.7	136.2	73.2	58.6	25.7	109	107	120	25.8	0	52	759.4
1992	3.9	11	18.2	85.2	65.1	68.3	77.5	97.6	107	36.6	10.4	4.1	585.0
1993	21.6	19.3	109.3	98.6	112.6	34.3	97.8	154.6	132.8	65.5	10.8	12.5	869.4
1994	2.9	30.2	37.6	125.1	65.9	39.3	90.1	178.9	148.6	64.8	30.0	4.5	817.6
1995	4.7	30.7	97.9	117.9	83.6	78.7	87.6	104.9	83.5	28.3	27.1	38.3	783.1
1996	27.2	47.2	50.2	108.3	100.3	105.9	58.7	69.3	65.6	27.9	6.9	23.1	690.5
1997	0	0	78.1	124.6	156	59.8	149	102.7	61.7	204	60.4	16.1	1011.8
1998	86.5	51	33.7	59.9	55.4	24.8	129	110.4	176	54	21.3	0	801.2
1999	0	3.7	68.3	71.3	77.4	30	95.2	238.6	139	136	15.6	4.9	879.7
2000	0.0	0.0	6.3	137.6	95.1	18.9	82.7	141.5	109.4	28.4	104.2	16.8	740.9
2001	0.0	18.8	56.6	94.0	146.2	38.7	111.3	217.7	54.6	24.9	0.0	16.8	779.6
2002	17.9	0.6	56.3	84.4	47.9	43.3	64.8	165.3	83.4	21.7	0	21.5	607.1
2003	3.6	16.4	25.1	142.2	19.2	62.5	107	272.4	77.2	0.2	0	40.7	766.1
2004	38.2	0	27.4	215.1	39.7	25.3	74.2	116.4	127	43.8	33.6	4.5	744.9
2005	0.5	2	39.9	119.5	198	23.5	68.1	132.2	154	17	11.9	0	767.3
2006	4	35.9	49.2	191.2	71.4	74.1	120	191.4	180	112	1.6	88.4	1118.8
2007	0	3.5	25.4	142.7	55.7	61.4	197	110.5	137	27.1	6.5	0	766.2
2008	5.5	0	0.2	26.6	179	106.3	131	120.6	170	14.1	121	0	874.4
2009	23.6	5.3	5.7	78.2	90	53.8	164	96.5	65.2	139	12.4	26.2	759.7

2010	2.7	44.1	82.3	123.8	73.1	24.6	145	179.6	170	5.6	10.8	11	872.9
2011	0	0	0	39.7	113	57.7	120	227	162	0	0	0	719.1
2012	0	0	0	66.3	51	0	215	149.5	105	4.6	0.5	6.7	598.4
2013	6	0	159.3	171.6	55.1	15.8	215	185.1	142	71.4	81.6	0.8	1104.2
2014	0.0	0.0	50.3	85.7	104.8	39.9	141.8	166.0	150.2	20.4	23.2	4.6	786.9
2015	1.5	0.0	32.7	77.4	199.8	86.1	17.3	181.9	139.8	24.1	26.3	3.0	789.9
Mean	8.7	18.3	55.7	112.3	94.4	49.0	109.4	152.8	124.0	46.6	20.9	15.2	

Appendix Table 4. Corrected monthly rainfall data at Harar Indicative (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985	7.2	13.4	62.3	267.8	187.1	65.2	70.2	110.2	145.9	37.2	20.8	10.2	997.2
1986	0	19.8	6.6	248	99.6	151.8	24.9	78.9	50.3	2.2	1.2	0	683.3
1987	0	0	93.5	359.7	465	24.5	20.1	150.2	103	7.1	61.6	0	1284.7
1988	21.7	14.9	10.2	241.0	163.0	42.8	168.3	110.5	326.3	41.5	17.3	8.2	1165.6
1989	5.6	18.8	139.0	222.3	20.8	41.6	67.3	101.0	103.8	97.9	3.0	32.6	853.7
1990	0.0	54.0	101.1	134.0	66.8	30.0	62.1	158.0	10.3	37.2	3.3	0.0	656.8
1991	0.6	6.2	145.0	54.3	138.1	24.0	37.4	102.3	54.3	27.1	16.2	8.3	613.8
1992	6.8	21.9	86.0	239.3	178.9	34.7	79.5	129.9	135.9	37.5	20.5	10.3	981.0
1993	7.0	23.5	98.8	162.9	97.2	34.6	83.8	118.0	123.7	42.4	9.1	12.4	813.3
1994	4.6	59.9	95.1	183.4	72.6	35.9	77.8	110.8	69.3	38.7	7.9	12.6	768.7
1995	8.8	77.1	123.4	153.5	55.7	45.4	94.5	116.5	49.6	20.6	6.9	6.7	758.7
1996	14.1	97.4	137.9	149.4	41.5	59.1	107.0	106.2	44.1	21.1	9.7	7.8	795.2
1997	28.5	89.2	177.2	125.5	40.2	71.6	113.3	111.3	42.1	14.5	10.6	6.8	830.9
1998	59.1	38.4	16.5	50.6	59.5	47.5	147	141.3	88.4	38.8	2.4	18.5	708.4
1999	13.5	4.2	128.6	93.9	75.0	119.2	143.6	125.2	95.6	47.9	13.2	14.7	874.6
2000	12.9	0.0	24.8	71.3	89.7	29.8	115.8	113.2	112.2	37.2	13.6	17.2	637.7
2001	26.1	1.8	96.4	60.7	131.7	113.2	165.5	177.3	67.2	38.5	0.0	4.6	883.0
2002	38	0	137.8	112.6	60.3	99.8	156	125.1	115	76.8	0	34.5	955.9
2003	0	0	12.3	148.8	27.1	103.4	121	121.5	83.1	1.1	7.2	16.4	641.5
2004	73.9	0	24.9	261.3	6.7	88.1	83.8	73.3	105	28.5	39.7	4.9	789.8
2005	0.8	0.7	71.7	113.9	182	29.6	70.6	92.9	139	33.7	33.6	0.8	768.6
2006	4.5	5.3	53.5	174.7	133	73.9	121	163.8	170	131	3.3	61.2	1096.0
2007	0	1.4	30.7	139.7	94.5	40.4	118	147.7	190	6.7	7.1	0	776.0
2008	0	0	1.2	44.9	148	66.3	141	119.4	99.3	29.9	73.3	0	722.9
2009	21.5	2	71.4	145.7	69.4	33.8	120	138.8	59.9	140	44	10.4	857.1
2010	0	94.6	152.4	116	89.4	50.8	83.2	70.9	104	24	2.9	0	788.6
2011	0	0	10.5	29.1	172	115.5	73	168.6	179	1.3	21.3	0	770.0
2012	0	0	11.1	126.6	110	89.9	0	120.5	107	5	0	1	570.9
2013	10.3	0	116	171.3	70	27.5	163	85.4	118	174	59.8	0	995.1
2014	0.0	0.0	86.0	85.7	92.5	39.1	54.4	212.5	202.5	150.3	15.2	0.0	938.3
Mean	13.3	22.6	80.0	133.8	92.0	58.8	102.5	124.5	110.9	49.7	16.3	10.7	

Appendix Table 5. Corrected monthly rainfall data at Kersa (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985	23.9	15.1	62.8	82.8	66.3	77.6	103.8	139.4	86.5	37.2	20.5	9.6	725.5
1986	22.5	8.5	68.0	96.7	59.5	60.9	93.7	156.1	91.9	60.6	25.7	2.9	747.0
1987	32.8	20.2	68.6	83.9	75.9	88.4	106.1	164.3	79.6	34.4	21.4	2.9	778.5
1988	29.8	20.2	54.1	68.9	66.2	69.4	103.5	132.7	100.8	27.0	16.7	13.4	702.5
1989	10.4	11.6	60.3	81.9	63.9	91.8	111.7	104.5	73.9	26.7	18.3	19.1	673.9
1990	13.5	30.8	82.3	66.5	61.3	112.9	122.7	109.9	53.5	19.2	2.2	16.2	690.8
1991	5.0	32.1	88.6	86.1	112.7	126.0	222.1	180.6	87.6	11.6	1.6	19.6	973.6
1992	34.4	16.4	73.3	107.7	106.4	78.5	127.2	154.0	59.8	50.4	21.5	8.9	838.3
1993	23.0	12.1	70.8	76.8	100.5	66.1	163.5	151.1	87.2	72.5	22.6	7.1	853.4
1994	22.4	7.3	81.1	53.3	80.5	65.1	155.1	165.0	104.9	96.4	17.6	6.4	855.1
1995	12.8	5.0	80.3	315.1	71.3	57.1	6.9	11.5	94.6	211.6	52.9	27.6	946.8
1996	98.6	2.5	32	188.5	170	25.5	90.2	221	34.4	0	35.4	0	898.0
1997	20.4	0	90.1	89.8	81.6	49.6	73.7	104.6	63.5	171	46.7	0	790.7
1998	32.1	0	31.4	23.7	101	10.4	231	165.3	138	57.4	20.7	0	811.1
1999	0	0.7	149.1	4.9	13.9	105.4	98.9	189.5	135	205	5.5	9.5	917.8
2000	6	0	20.1	135.3	126	29.6	53.4	191.7	132	84.4	41.1	2.6	821.3
2001	15.75	1.75	69	25.5	88.9	15.8	84.3	148.4	0	0	0	0	449.4
2002	57	0	61.5	42.4	2.6	10.6	60.7	125	86.4	78.1	21.3	52.4	598.0
2003	0	6.3	47.3	128.4	2.6	92.1	149	105.3	146	1.4	0.2	63.4	741.6
2004	45.3	0.0	38.9	137.2	0.0	16.9	77.6	68.0	132.9	62.5	0.0	10.8	590.1
2005	0.0	0.0	91.6	108.5	82.6	20.3	47.2	167.2	157.5	73.9	32.6	0.0	781.4
2006	9.4	4.2	21.0	81.1	0.0	50.3	81.8	113.5	138.8	72.9	13.2	18.6	604.6
2007	0.0	0.0	95.4	87.3	13.9	14.7	53.3	113.3	119.5	153.7	19.8	0.0	670.9
2008	12.1	0.0	61.7	99.7	79.0	149.2	81.8	220.5	41.9	90.8	46.5	18.6	901.7
2009	4.0	0.0	82.9	98.5	58.5	61.4	60.8	167.0	106.3	106.1	33.0	6.2	784.7
2010	8.5	1.4	55.2	93.1	45.8	87.0	74.8	167.0	95.7	89.9	30.9	14.4	763.7
2011	19.3	26.8	93.5	95.3	147.8	59.7	212.4	161.6	144.0	17.1	17.1	5.7	1000.3
2012	9.2	57.5	87.0	151.9	89.9	112.4	107.3	148.3	104.2	25.7	24.5	2.7	920.6
2013	4.6	0.0	109.7	81.7	149.5	117.0	147.2	127.7	95.7	66.5	24.9	0.0	924.4
2014	3.7	145.7	57.9	48.5	120	47.8	73.5	116	132	29.8	27.8	0	803.0
Mean	18.9	14.4	69.8	95.1	75.4	65.4	106.3	142.7	98.0	69.1	22.0	11.6	

Appendix Table 6. Corrected monthly rainfall data at Girawa (mm)

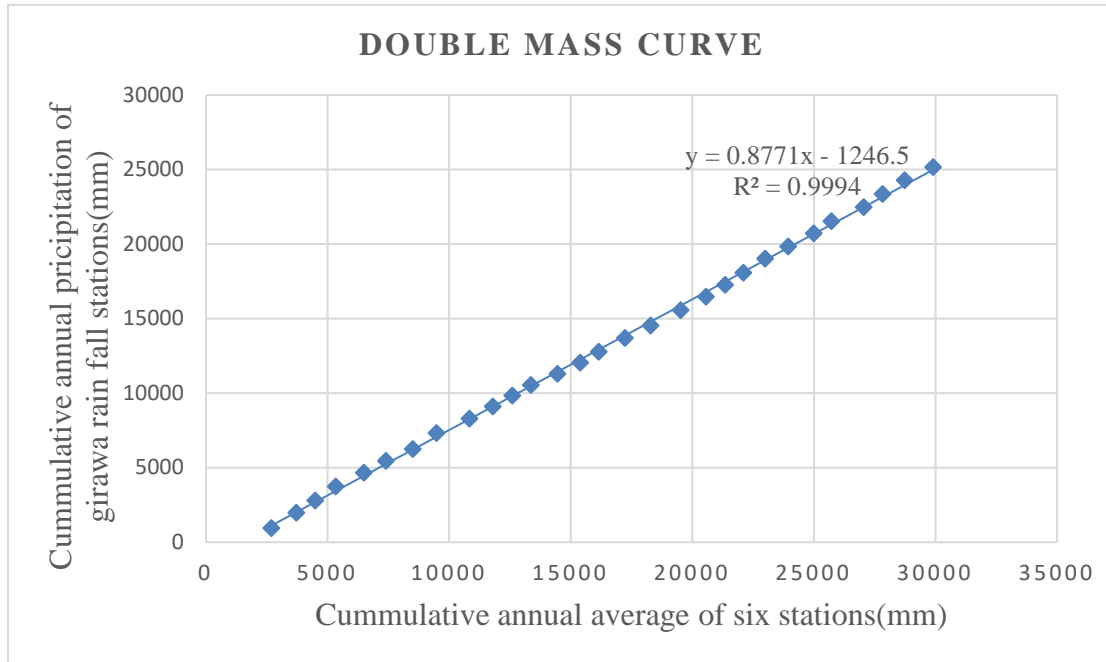
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985	11.3	24.6	67.9	223.3	151.2	69.1	72.8	126.4	156.2	22.5	15.5	10.1	951.0
1986	0	15.1	78.8	303	217	80	83.8	107.7	222	25.4	18.2	17.2	1167.7
1987	14.3	39.4	119.9	221.8	124.2	63.2	43.6	117	132.7	22.2	9.4	6.3	914.0
1988	19.5	19.4	5.1	145.2	112.5	64.1	91.0	154.5	114.2	20.0	18.7	7.0	771.3
1989	40.7	19.6	247.2	381.9	127.1	50	98.8	98.2	149	51.2	4.2	60.4	1327.8
1990	12	68.1	62.2	183.7	32.6	47	39.5	193.7	61.8	7	25.4	0	733.0
1991	31	35.1	218.7	129	123	42.8	120	176	114.5	21.0	12.3	19.8	1042.8
1992	13.3	39.3	99.9	149.6	90.1	86.4	109.7	170.6	95.6	43.2	43.2	8.2	949.1
1993	89.3	0	4	167.8	179	25	85	214.3	72	60.7	0	5.4	902.2
1994	0	0	36.1	104.4	87.6	96	201	48.9	136	15.7	19.5	0	744.9
1995	0	48.8	74.9	114.8	65.5	24.6	224	103.2	111	10	0	18.6	795.9
1996	10.1	5.2	43.7	171.1	139	231.3	55.5	209.5	94.8	0	59.7	9.1	1029.3
1997	0	0	181.4	202.9	132	113.2	142	185.8	72.3	179	37.5	0	1245.6
1998	90.3	108.5	91.2	112.4	90.1	96.2	157	57.3	114	96.3	40.3	0	1053.8
1999	0	9.7	168.3	74.5	63.4	79.9	191	241.3	104	135	9.8	3.5	1081.1
2000	0	0	23	163.1	47.5	80.2	58.5	132.5	157	23.1	54.1	12.5	751.5
2001	5.4	3.2	100	59.8	172	78.5	95.5	248.8	80.7	21.2	36	33.6	934.3
2002	111.8	2	72	126.5	90	100.6	167	166.5	143	78.9	0	38.5	1096.1
2003	34.5	0	16.7	163.4	27.5	73	94.2	205.7	89.1	19.2	2	46.5	771.8
2004	21.4	0	24.3	226.1	9.1	71.6	127	85.5	134	54.4	36.4	0	790.4
2005	14.0	0.8	33.0	198.9	93.8	66.2	131.6	193.9	146.3	68.1	11.4	12.8	970.6
2006	0	3.2	45.4	260	117	70.5	125	299.6	239	182	2	4.7	1348.2
2007	0	0	45.6	145.9	222	49.5	181	184.8	122	16.5	5	0	971.9
2008	0	0	5.8	59.4	168.1	83.6	182	147.3	153	158	151	0	1109.0
2009	2.5	0	18.7	144.5	88.2	40.7	145.3	173.6	88.6	149	48.2	9.9	908.9
2010	0	67.8	126.2	242.2	107.8	42.7	171	171.5	202	0	22.5	0	1154.0
2011	0	0	0	45.3	222	64.6	143	195.5	183	0	0	0	853.3
2012	0	0	10.3	172.9	111	92.2	43.6	180.2	156	0	0	1	767.5
2013	18.6	0	170.7	202.7	88.9	27.5	175	156.5	98.2	89.8	0	0	1027.7
2014		0	69.9	126.6	86.1	17.4	143	177.4	145.5	111	0.0	0.3	877.5
Mean	18.9	17.3	75.6	165.5	111.5	71.0	124.9	165.4	128.7	57.2	23.0	10.9	

Appendix Table 7. Corrected monthly rainfall data at Kulubi (mm)

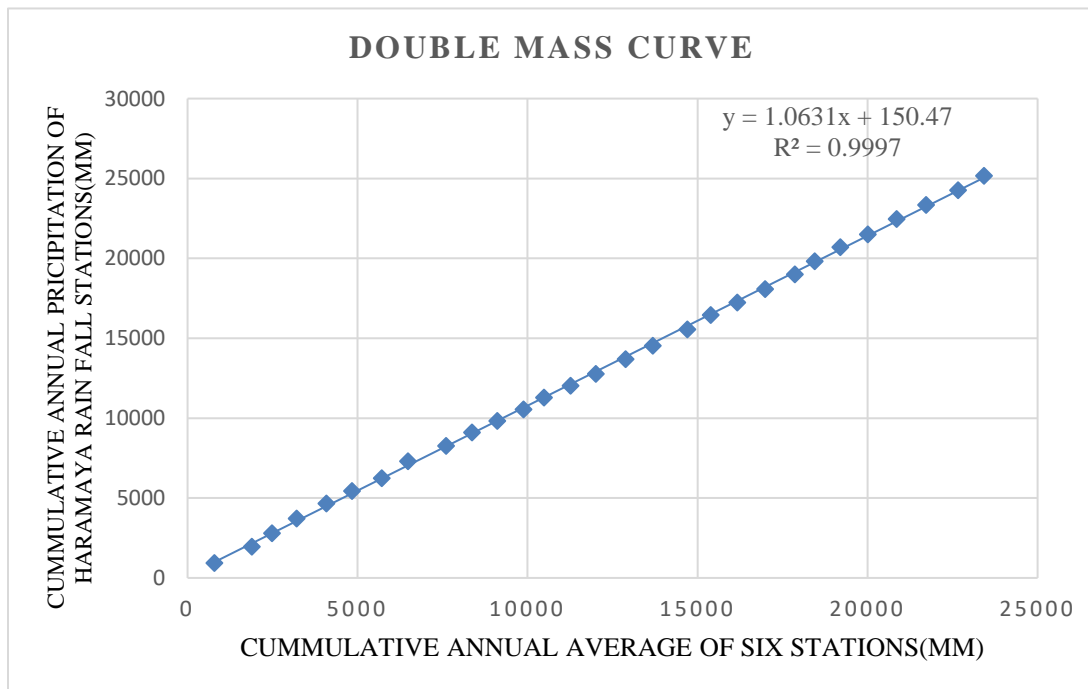
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985	15.6	0	82	291.4	146	7.5	183	136.7	107	0	30.5	3.1	1003.4
1986	0	46.9	70.6	197.4	86.7	116.9	63	190.2	99.4	47.8	5.3	10	934.2
1987	0.0	4.5	59.7	205.8	184.0	23.7	22.1	98.7	47.8	14.7	9.0	13.1	683.0
1988	8.3	16.1	11.2	123.8	1.3	87.2	130	137.6	142	0	0	0	657.1
1989	0	0	74.8	210.5	13.2	87.7	155	318.2	121	13.3	0	58.7	1052.1
1990	57.6	148.1	178.7	164.6	39.5	67.2	76.1	260.2	298.9	9.3	9.2	3.2	1312.6
1991	0.0	63.3	167.8	170.2	84.7	0.0	180.8	188.5	152.3	9.3	5.6	17.6	1040.0
1992	18.4	55.7	136.3	136.7	56.2	71.2	137.4	227.2	143.0	8.0	3.7	19.9	1013.4
1993	55.3	111.5	188.1	154.9	163.5	93.6	136.2	290.1	134.3	14.9	56.7	30.4	1429.5
1994	23.7	48.3	33.0	89.4	86.1	41.2	375.9	160.2	116.6	5.1	56.3	3.1	1038.9
1995	0	40.3	67.4	241.9	54.3	39.8	158	240	56.3	17.1	0	16.4	931.7
1996	9.8	10	194.5	93.5	263	72	187	252.7	61.7	0.9	46.2	0	1191.1
1997	17.6	0	111.2	96.4	67.5	123.9	194	167.7	87.2	181	55.7	7.5	1109.6
1998	101.5	23.1	17.1	40.2	62.4	53.4	125	140.5	220	24.4	24.5	0	832.2
1999	0	0.9	79.7	66.9	31	141.9	156	334.9	188	181	1.2	4.2	1185.2
2000	0	0	35.9	123.4	73.8	30.3	113	223.6	219	62.4	35.9	14.2	931.3
2001	9	3.6	101.2	73.7	120	75.3	222	329.7	91.2	39.1	0	11.6	1076.1
2002	105	7.2	71.4	68	25.7	55.9	102	253.7	89.9	29.9	0	115	923.4
2003	1.7	12.4	40.2	221.5	19.2	67.6	178	165.3	148	1.8	0.5	66.2	922.6
2004	43.2	0	69.3	227.1	4.8	70.6	106	176.2	127	68	12.7	21.8	926.9
2005	18.2	6.6	118.6	121.4	115.3	67.3	139.3	158.9	104.4	0.3	49.8	50.8	950.9
2006	10.6	15.4	96.2	241.8	86.5	67.3	149.4	216.8	112.2	27.8	12.6	53.1	1089.7
2007	248.5	108.5	351.0	360.5	370.0	69.5	255.5	194.2	116.4	25.6	15.1	61.4	1203.0
2008	3.5	0.0	0.2	41.7	71.6	106.8	165.6	182.3	121.7	24.7	31.2	0.0	749.3
2009	28.5	2.9	72.1	83.0	62.5	75.9	148.2	285.5	146.9	78.0	9.3	36.3	1029.0
2010	28.9	5.8	62.2	121.7	59.6	57.3	153.6	243.1	137.1	33.3	9.1	51.8	963.4
2011	39.7	5.8	70.5	147.6	42.3	67.4	152.0	231.2	114.1	34.7	3.3	53.7	962.3
2012	42.0	6.6	74.9	159.5	41.3	65.4	131.3	188.5	117.4	25.0	15.8	63.4	930.9
2013	18.4	8.6	81.1	203.0	56.5	68.2	143.2	179.3	123.0	24.5	18.9	48.0	972.5
2014	80.1	82.6	158.8	237.7	144.2	68.7	162.6	186.5	115.0	30.4	22.6	46.7	1335.9
Mean	32.2	34.1	95.1	156.0	88.1	67.8	151.5	209.1	127.9	34.8	18.0	28.8	

Appendix Table 8. Corrected monthly rainfall data at Hakim gara (mm)

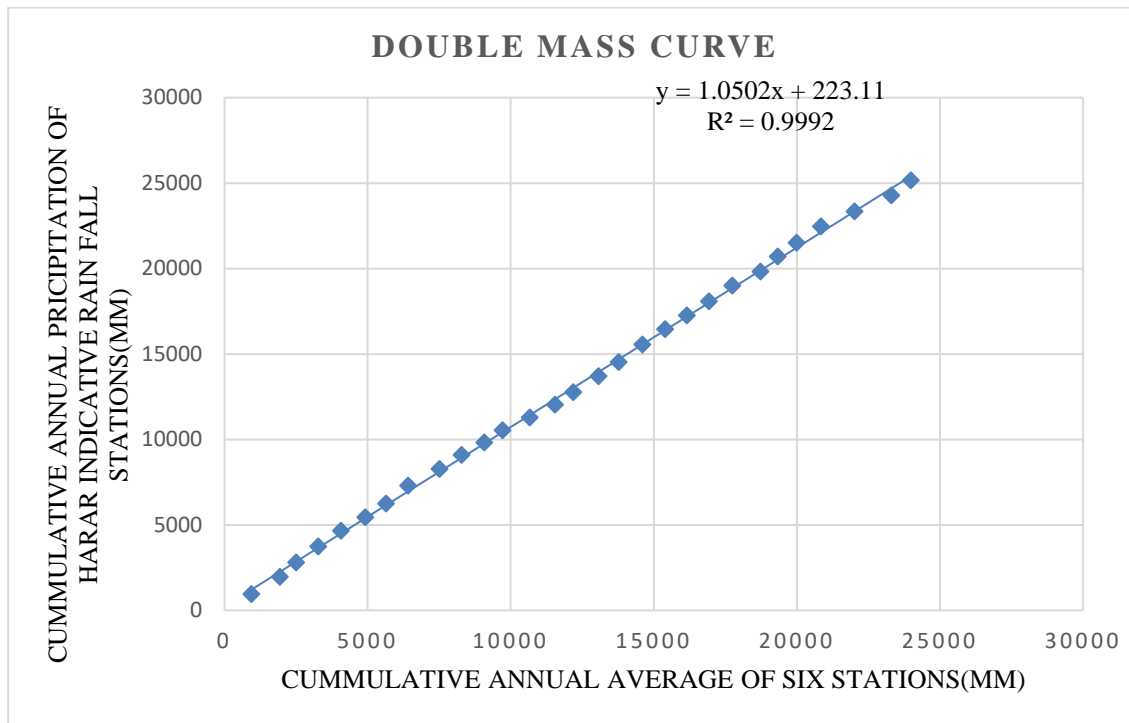
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985	6.3	6.9	61.0	239.1	278.1	62.4	111.5	102.8	138.5	28.7	2.7	0.2	1038.2
1986	0.0	0.7	28.0	207.5	152.1	227.1	124.8	147.4	100.1	22.7	2.3	1.1	1014.0
1987	0.0	73.0	135.7	61.6	279.5	158.8	49.6	96.1	75.5	37.8	2.0	9.0	978.7
1988	4.1	17.4	4.9	171.9	62.6	102.3	293.8	188.2	272.3	27.9	0.2	1.0	1146.9
1989	9.4	10.1	89.3	202.7	64.8	91.0	193.6	139.5	92.2	11.9	25.5	3.1	933.1
1990	28.3	105.3	91.7	105.4	61.3	27.1	64.0	106.8	58.9	1.6	4.3	9.2	664.0
1991	2.6	25.2	84.8	164.5	100.6	90.5	180.0	110.7	51.0	0.4	53.2	1.7	865.4
1992	31.8	38.6	67.4	17.1	42.0	58.5	110.0	89.7	56.7	7.2	5.6	3.5	528.1
1993	55.1	76.8	0.5	92.8	171.8	79.1	45.4	74.5	57.0	58.2	0.4	0.1	711.7
1994	0.0	0.1	4.4	131.7	123.1	92.6	207.9	63.6	28.1	46.0	36.5	0	733.9
1995	4.5	42.6	6.8	87.8	91.3	29.9	109.9	94.0	36.2	35.5	3.2	2.5	544.1
1996	1.1	1.6	51.3	57.3	212.0	111.7	165.2	102.0	108.3	12.5	9.3	0.4	832.4
1997	5.2	5.6	158.0	195.9	74.0	177.9	145.5	55.0	44.0	136.3	138.9	2.0	1138.3
1998	5.8	34.4	18.4	199.7	135.9	65.4	66.6	68.4	149.0	78.0	3.4	0.8	825.9
1999	0.6	17.4	42.6	52.0	35.4	38.8	159.2	72.3	67.8	97.9	12.0	0.0	596.0
2000	0.0	0.0	10.1	210.0	15.3	17.2	48.5	117.1	46.2	12.6	1.8	3.8	482.7
2001	0.5	2.6	13.3	124.3	10.5	12.7	60.1	78.6	23.9	38.9	6.7	10.4	382.4
2002	0.8	5.5	24.0	68.5	21.9	4.1	12.1	48.3	94.2	13.9	0.4	9.3	302.9
2003	4.5	4.7	11.4	116.1	4.1	79.0	55.1	82.3	28.2	3.8	40.4	0.0	429.6
2004	9.5	9.5	108.9	114.3	5.4	39.4	65.8	89.8	62.3	14.6	19.3	2.0	540.9
2005	1.8	23.7	6.5	295.0	151.6	52.6	53.8	51.3	65.6	8.4	13.3	0.0	723.7
2006	3.4	10.8	31.5	114.8	19.5	36.5	106.2	74.5	23.3	71.1	60.8	0.1	552.6
2007	8.4	9.7	27.9	104.7	82.6	128.9	128.1	114.7	103.4	35.3	31.3	0.0	774.9
2008	6.4	6.4	2.7	101.7	102.3	13.5	66.3	41.2	27.0	72.4	0.0	0.2	440.2
2009	16.3	16.6	48.7	26.8	26.0	33.0	72.1	20.0	26.9	132.0	10.6	2.0	431.1
2010	11	115.4	91.5	107	103.8	67.8	117.1	125	98.6	3.5	8.9	0.4	850
2011	0.2	7.2	29.8	20.3	118.4	107.8	251.3	120.1	243.1	16.5	5.1	0.2	920
2012	0.1	0.9	111.9	50.3	69.2	119.6	124.4	165.7	101.5	12.1	25.3	9	790
2013	1.9	7.9	81.1	41.2	69.4	97.9	101.7	129.7	98.8	22.6	27.3	0.5	680
2014	1.5	25	53.4	76.4	111.6	82	98.8	36.3	41.5	18.4	41.6	2.5	589
Mean	7.9	29.1	75.7	169.9	115.5	85.8	122.0	113.7	101.5	36.6	23.1	2.5	



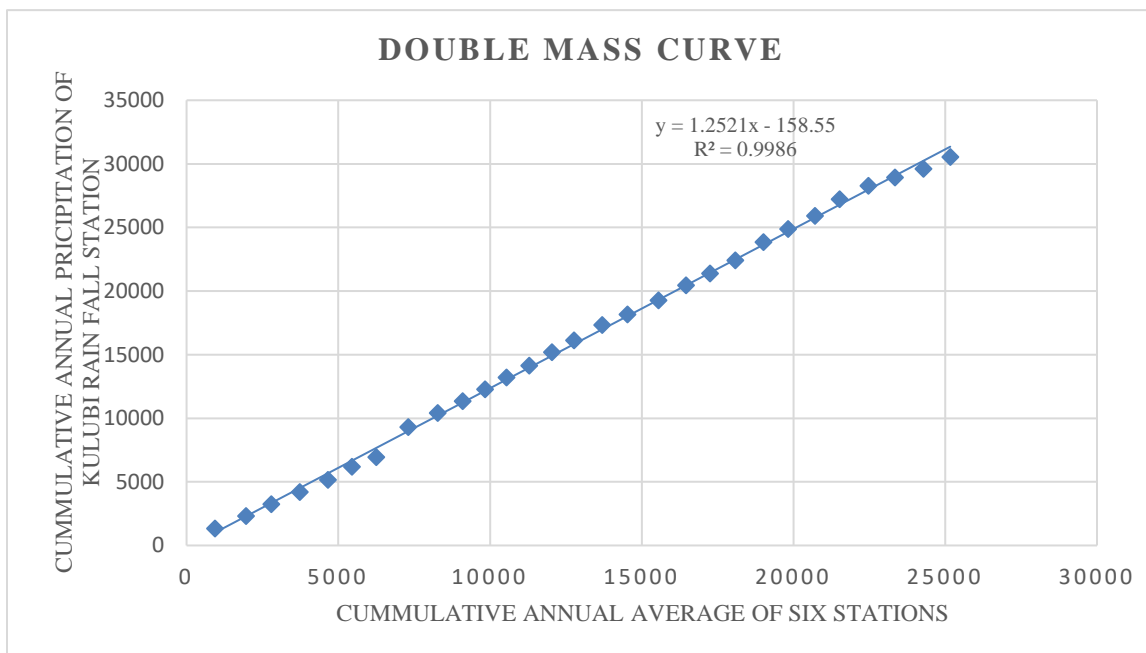
Appendix Figure 1. Double mass curve for the consistency of Girawa meteorological stations rainfall data



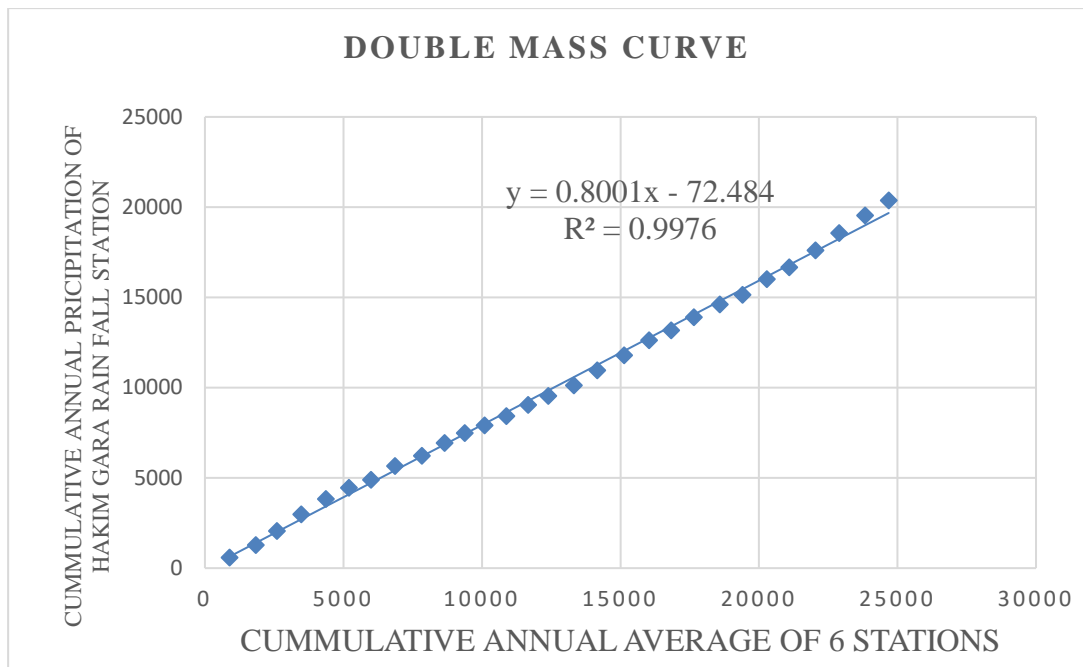
Appendix Figure 2. Double mass curve for the consistency of Haramaya meteorological stations rainfall data



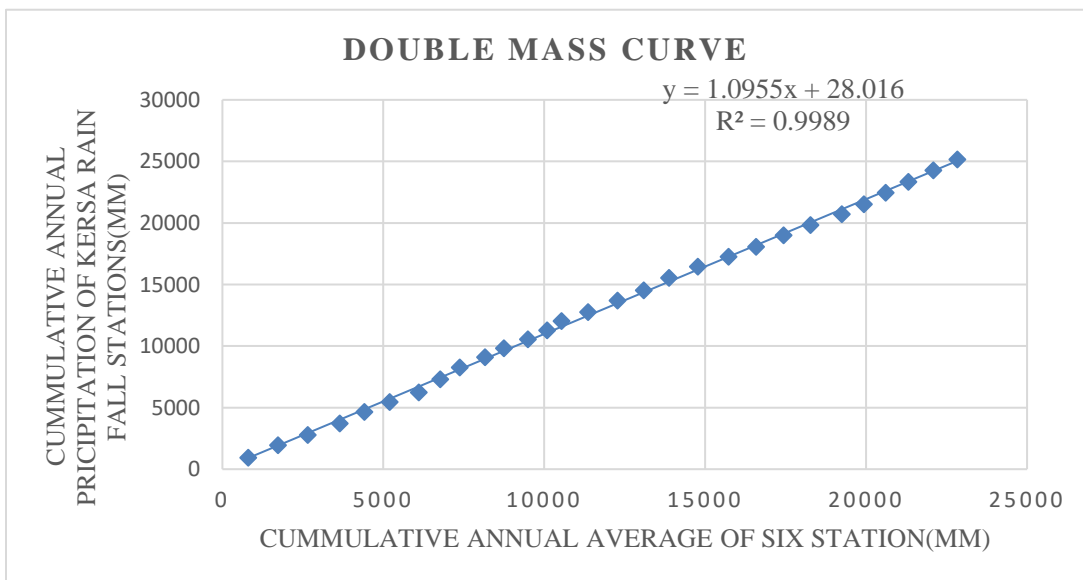
Appendix Figure 3. Double mass curve for the consistency of Haramaya meteorological stations rainfall data



Appendix Figure 4. Double mass curve for the consistency of Kulubi meteorological stations rainfall data



Appendix Figure 5. Double mass curve for the consistency of Hakim gara meteorological stations rainfall data.



Appendix Figure 6. Double mass curve for the consistency of Kersa meteorological stations rainfall data.

### 7.2.2. ETO and climatic data tables

No	Stations and recording	Parameters	Jan	Fab	Mar	Apr	May	Jun	Jul	Agu	Sep	Oct	Nov	Dec
1	Haramaya													
	2000-2016	Sunshine	9.4	9.4	8.2	7.6	7.8	7.0	6.3	6.7	6.7	8.0	9.0	9.3
	1986-2016	Tmax( <sup>0</sup> C)	23.2	24.7	25.6	25.1	25.3	24.6	23.4	23.4	23.6	23.9	23.3	22.3
	1986-2016	Tmim( <sup>0</sup> C)	5.5	7.2	10.4	12.3	13.0	13.4	13.0	13.0	12.2	7.7	4.4	3.9
	1998-2015	Wind(m/s)	1.4	1.5	1.5	1.5	1.4	1.9	1.8	1.5	1.1	1.0	1.1	1.3
	1989-2016	RH(average)	62.3	56.7	58.3	65.8	68.6	69.4	75.7	75.8	74.7	63.9	59.1	60.4
2	Harar Indicative													
	2001-2018	Sunshine	8.6	9.0	7.8	6.7	6.7	6.1	4.9	5.4	5.9	7.6	8.0	8.6
	1986-2018	Tmax( <sup>0</sup> C)	25.6	26.7	27.2	25.6	25.3	25.0	24.1	24.2	24.2	22.3	25.5	24.7
	1986-2018	Tmim( <sup>0</sup> C)	12.4	12.7	13.7	14.0	14.3	14.0	13.6	13.5	13.2	12.8	12.3	12.3
	1998-2016	Wind(m/s)	1.4	1.2	0.9	0.9	0.6	0.8	0.7	0.8	0.7	0.7	1.0	1.3
	1986-2016	RH(average)	57.8	52.3	55.3	67.0	71.7	73.9	75.0	75.1	74.6	61.4	58.7	55.8
3	Girawa													
		Sunshine	7.3	7.4	7.1	6.1	5.9	4.9	4.1	4	5.8	7.6	8	8.2
		Tmax( <sup>0</sup> C)	18.3	20.1	20.6	19.7	19.5	18.7	18.1	17.1	18.4	18.8	18.9	18.6
		Tmim( <sup>0</sup> C)	9.2	10	10.6	11	11	10.5	9.6	9.3	10.5	10.8	10.1	10.4
		Wind(m/s)	156	156	164	156	173	233	216	233	156	138	147	138
		RH(average)	72	70	71	78	81	85	87	90	83	74	68	65

4. Kulubi													
1985-2014	Sunshine	11.2	12.8	11.9	11.3	11.7	12.5	10.5	11.0	11.1	11.0	10.7	10.5
1985-2014	Tmax( <sup>0</sup> C)	25.8	27.4	28.9	29.1	30.0	30.8	28.0	28.5	30.1	27.9	26.5	25.4
1985-2014	Tmim( <sup>0</sup> C)	9.5	11.2	14.2	15.9	15.9	16.1	15.8	15.9	15.9	13.0	10.6	8.9
1985-2014	Wind(m/s)	2.3	2.4	2.3	2.5	2.9	3.6	3.9	3.6	2.8	2.6	2.4	2.3
1985-2014	RH(average)	52	47	46	52	51	51	57	56	51	48	48	51
5. Hakim gara													
1985-2014	Sunshine	11.0	11.8	8.9	8.3	9.6	9.7	5.0	8.2	8.3	9.4	8.9	10.4
1985-2014	Tmax( <sup>0</sup> C)	24.8	26.0	25.5	25.2	26.3	25.0	21.7	23.3	25.1	25.0	24.4	24.1
1985-2014	Tmim( <sup>0</sup> C)	9.5	11.1	12.8	13.7	13.3	12.7	12.5	12.7	12.4	10.4	8.9	8.5
1985-2014	Wind(m/s)	2.1	2.1	2.3	2.4	2.5	3.7	3.8	3.4	2.4	2.0	1.8	2.0
1985-2014	RH(average)	49	46	54	67	66	69	76	71	65	56	54	49
6. Kersa													
1985-2014	Sunshine	11.4	12.9	12.1	12.4	12.5	12.4	10.1	11.8	11.5	12.0	10.6	10.9
1985-2014	Tmax( <sup>0</sup> C)	26.5	28.3	29.7	30.1	31.4	31.7	28.8	30.5	30.5	28.2	26.7	25.8
1985-2014	Tmim( <sup>0</sup> C)	10.5	12.5	15.5	16.7	16.7	16.9	16.8	17.0	16.3	12.8	10.8	9.3
1985-2014	Wind(m/s)	2.4	2.4	2.3	2.6	3.1	3.7	3.7	3.2	2.7	2.7	2.4	2.4
1985-2014	RH(average)	52	47	47	51	47	49	55	52	47	46	49	51

Appendix Table 9. ETO and climatic data for Haramaya meteorological station

Monthly ETo Penman-Monteith - E:\MSC-Haramaya University\gm\My Proposal\GM\_Propos...

Country: Ethiopia Station: Haramaya

Altitude: 2020 m. Latitude: 9.40 °N Longitude: 42.03 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m <sup>2</sup> /day	mm/day
January	5.5	23.3	62	1	9.4	21.2	3.09
February	7.2	24.7	57	2	9.4	22.6	3.45
March	10.4	25.6	58	2	8.2	21.9	3.64
April	12.3	25.1	66	2	7.6	21.2	3.72
May	13.4	25.3	69	1	7.8	21.1	3.76
June	13.8	24.6	69	2	7.0	19.5	3.51
July	13.3	23.4	76	2	6.3	18.5	3.36
August	13.4	23.4	76	2	6.7	19.5	3.51
September	12.6	23.6	75	1	6.7	19.5	3.52
October	7.7	23.9	64	1	8.0	20.7	3.43
November	4.4	23.3	59	1	9.0	20.9	3.13
December	3.9	22.3	60	1	9.3	20.6	2.91
<b>Average</b>	<b>9.8</b>	<b>24.0</b>	<b>66</b>	<b>1</b>	<b>8.0</b>	<b>20.6</b>	<b>3.42</b>

Appendix Table 10. E TO and climatic data for Hara Indicative meteorological station

Monthly ETo Penman-Monteith - E:\MSC-Haramaya University\gm\My Proposal\GM\_Propos...

Country: Ethiopia Station: Harar Indicative

Altitude: 1977 m. Latitude: 9.30 °N Longitude: 42.08 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m <sup>2</sup> /day	mm/day
January	12.4	25.6	58	1	8.6	20.1	3.22
February	12.7	26.7	52	1	9.0	22.0	3.59
March	13.7	27.2	55	1	7.8	21.3	3.73
April	14.0	25.6	67	1	6.7	19.8	3.62
May	14.3	25.3	72	1	6.7	19.4	3.56
June	14.0	25.0	74	1	6.1	18.1	3.35
July	13.6	24.1	75	1	4.9	16.5	3.06
August	13.5	24.2	75	1	5.4	17.6	3.24
September	13.2	24.2	75	1	5.9	18.3	3.34
October	13.8	22.3	61	1	7.6	20.1	3.33
November	12.3	25.5	59	1	8.0	19.5	3.17
December	12.3	24.7	56	1	8.6	19.6	3.06
<b>Average</b>	<b>13.3</b>	<b>25.0</b>	<b>65</b>	<b>1</b>	<b>7.1</b>	<b>19.4</b>	<b>3.36</b>

Appendix Table 11.E TO and climatic data for Girawa meteorological station from climwat

Monthly ETo Penman-Monteith - E:\MSC-Haramaya University\gm\My Proposal\GM\_Propos...

Country: Ethiopia Station: GRAWA

Altitude: 2250 m. Latitude: 9.13 °N Longitude: 41.83 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m <sup>2</sup> /day	mm/day
January	9.2	18.3	72	156	7.3	18.4	3.00
February	10.0	20.1	70	156	7.4	19.7	3.39
March	10.6	20.6	71	164	7.1	20.2	3.60
April	11.0	19.7	78	156	6.1	18.9	3.32
May	11.0	19.5	81	173	5.9	18.2	3.13
June	10.5	18.7	85	233	4.9	16.3	2.74
July	9.6	18.1	87	216	4.1	15.3	2.52
August	9.3	17.1	90	233	4.0	15.4	2.34
September	10.5	18.4	83	156	5.8	18.1	2.96
October	10.8	18.8	74	138	7.6	20.2	3.36
November	10.1	18.9	68	147	8.0	19.6	3.30
December	10.4	18.6	65	138	8.2	19.2	3.23
<b>Average</b>	<b>10.3</b>	<b>18.9</b>	<b>77</b>	<b>172</b>	<b>6.4</b>	<b>18.3</b>	<b>3.07</b>

Appendix Table 12.E TO and climatic data for Kersa meteorological station from weather data

Monthly ETo Penman-Monteith - untitled

Country: Ethiopia Station: Kersa

Altitude: 1333 m. Latitude: 9.52 °N Longitude: 41.56 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine hours	Radiation MJ/m <sup>2</sup> /day	ETo mm/day
January	10.5	26.5	52	2	11.4	24.0	3.46
February	12.5	28.3	47	2	12.9	27.7	4.15
March	15.5	29.7	47	2	12.1	27.9	4.54
April	16.7	30.1	51	3	12.4	28.7	4.89
May	16.7	31.4	47	3	12.5	28.1	4.79
June	16.9	31.7	49	4	12.4	27.4	4.76
July	16.8	28.8	55	4	10.1	24.2	4.23
August	17.0	30.5	52	3	11.8	27.3	4.73
September	16.3	30.5	47	3	11.5	26.9	4.62
October	12.8	28.2	46	3	12.0	26.6	4.22
November	10.8	26.7	49	2	10.6	23.1	3.47
December	9.3	25.8	51	2	10.9	22.7	3.22
<b>Average</b>	<b>14.3</b>	<b>29.0</b>	<b>49</b>	<b>3</b>	<b>11.7</b>	<b>26.2</b>	<b>4.26</b>

Appendix Table 13.E TO and climatic data for Kulubi meteorological station from weather data

Monthly ETo Penman-Monteith - E:\MSC-Haramaya University\gm\My Proposal\GM\_Propos...

Country: Ethiopia Station: Kulubi

Altitude: 1434 m. Latitude: 9.52 °N Longitude: 41.87 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine hours	Radiation MJ/m <sup>2</sup> /day	ETo mm/day
January	9.5	25.8	52	2	11.2	23.7	3.40
February	11.2	27.4	47	2	12.8	27.6	4.07
March	14.2	28.9	46	2	11.9	27.6	4.41
April	15.9	29.1	52	3	11.3	27.0	4.60
May	15.9	30.0	51	3	11.7	26.9	4.61
June	16.1	30.8	51	4	12.5	27.5	4.75
July	15.8	28.0	57	4	10.5	24.8	4.31
August	15.9	28.5	56	4	11.0	26.1	4.49
September	15.9	30.1	51	3	11.1	26.3	4.55
October	13.0	27.9	48	3	11.0	25.2	4.07
November	10.6	26.5	48	2	10.7	23.2	3.49
December	8.9	25.4	51	2	10.5	22.2	3.17
<b>Average</b>	<b>13.6</b>	<b>28.2</b>	<b>51</b>	<b>3</b>	<b>11.3</b>	<b>25.7</b>	<b>4.16</b>

Appendix Table 14. E TO and climatic data for Hakim gara meteorological station from weather data

Monthly ETo Penman-Monteith - E:\MSC-Haramaya University\gm\My Proposal\GM\_Propos...

Country: Ethiopia Station: Hakim gara

Altitude: 1978 m. Latitude: 41.87 °N Longitude: 9.21 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sunshine	Radiation	ETo
	°C	°C	%	km/day	hours	MJ/m <sup>2</sup> /day	mm/day
January	9.5	24.8	49	2	11.0	11.8	0.39
February	11.1	26.0	46	2	11.8	15.8	1.34
March	12.8	25.5	54	2	8.9	16.7	2.39
April	13.7	25.2	67	2	8.3	19.3	3.33
May	13.3	26.3	66	3	9.6	23.1	4.20
June	12.7	25.0	69	4	9.7	23.9	4.41
July	12.5	21.7	76	4	5.0	17.0	3.16
August	12.7	23.3	71	3	8.2	19.8	3.39
September	12.4	25.1	65	2	8.3	17.1	2.71
October	10.4	25.0	56	2	9.4	14.6	1.72
November	8.9	24.4	54	2	8.9	10.8	0.72
December	8.5	24.1	49	2	10.4	10.4	0.13
<b>Average</b>	<b>11.5</b>	<b>24.7</b>	<b>60</b>	<b>2</b>	<b>9.1</b>	<b>16.7</b>	<b>2.32</b>

### 7.2.3. Crop water requirements

Appendix Table 15. Maize monthly irrigation water requirements at Haramaya stations

Crop Water Requirements							
ETo station		Haramaya		Crop		Maize	
Rain station		Haramaya		Planting date		08/02	
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.30	1.00	3.0	1.3	3.0
Feb	2	Init	0.30	1.04	10.4	4.8	5.5
Feb	3	Init	0.30	1.05	8.4	8.8	0.0
Mar	1	Deve	0.33	1.17	11.7	12.9	0.0
Mar	2	Deve	0.49	1.79	17.9	16.4	1.5
Mar	3	Deve	0.68	2.50	27.5	21.2	6.4
Apr	1	Deve	0.87	3.23	32.3	27.7	4.5
Apr	2	Mid	1.05	3.92	39.2	33.2	6.0
Apr	3	Mid	1.12	4.18	41.8	31.0	10.7
May	1	Mid	1.12	4.19	41.9	28.7	13.2
May	2	Mid	1.12	4.21	42.1	27.8	14.3
May	3	Mid	1.12	4.12	45.3	23.5	21.7
Jun	1	Late	1.12	4.02	40.2	16.4	23.7
Jun	2	Late	1.02	3.56	35.6	11.3	24.3
Jun	3	Late	0.85	2.95	29.5	17.6	11.9
Jul	1	Late	0.69	2.36	23.6	25.7	0.0
Jul	2	Late	0.55	1.86	13.0	21.7	0.0
					<b>463.3</b>	<b>330.1</b>	<b>146.9</b>

Appendix Table 16. Maize monthly irrigation water requirements at Hara Indicative stations

Crop Water Requirements							
ETo station		Harar Indicative		Crop		Maize	
Rain station		Hara Indicative		Planting date		08/02	
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.30	1.04	3.1	1.6	3.1
Feb	2	Init	0.30	1.08	10.8	5.8	5.0
Feb	3	Init	0.30	1.09	8.7	11.6	0.0
Mar	1	Deve	0.30	1.11	11.1	18.2	0.0
Mar	2	Deve	0.41	1.52	15.2	23.6	0.0
Mar	3	Deve	0.58	2.13	23.5	27.3	0.0
Apr	1	Deve	0.75	2.74	27.4	32.7	0.0
Apr	2	Deve	0.91	3.31	33.1	37.4	0.0
Apr	3	Mid	1.07	3.86	38.6	33.8	4.8
May	1	Mid	1.12	4.00	40.0	29.2	10.9
May	2	Mid	1.12	3.98	39.8	26.4	13.4
May	3	Mid	1.12	3.90	42.9	23.7	19.2
Jun	1	Mid	1.12	3.83	38.3	19.3	18.9
Jun	2	Mid	1.12	3.75	37.5	15.8	21.7
Jun	3	Late	1.11	3.61	36.1	20.1	16.0
Jul	1	Late	0.99	3.13	31.3	25.7	5.6
Jul	2	Late	0.84	2.57	25.7	29.4	0.0
Jul	3	Late	0.68	2.12	23.3	30.8	0.0
Aug	1	Late	0.55	1.75	10.5	19.7	0.0
					<b>496.9</b>	<b>432.0</b>	<b>118.7</b>

Appendix Table 17. Maize monthly irrigation water requirements at Girawa stations

Crop Water Requirements								
ETo station			GRAWA		Crop			Maize
Rain station			Grawa		Planting date			31/01
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.	
			coeff	mm/day	mm/dec	mm/dec	mm/dec	
Jan	3	Init	0.30	0.94	0.9	0.5	0.9	
Feb	1	Init	0.30	0.98	9.8	4.1	5.7	
Feb	2	Init	0.30	1.02	10.2	3.2	6.9	
Feb	3	Init	0.30	1.04	8.3	9.5	0.0	
Mar	1	Deve	0.38	1.33	13.3	16.2	0.0	
Mar	2	Deve	0.55	1.98	19.8	21.6	0.0	
Mar	3	Deve	0.73	2.56	28.2	27.9	0.3	
Apr	1	Deve	0.91	3.11	31.1	37.1	0.0	
Apr	2	Deve	1.09	3.59	35.9	44.7	0.0	
Apr	3	Mid	1.16	3.78	37.8	39.9	0.0	
May	1	Mid	1.16	3.71	37.1	33.7	3.4	
May	2	Mid	1.16	3.64	36.4	30.3	6.2	
May	3	Mid	1.16	3.49	38.4	27.0	11.4	
Jun	1	Mid	1.16	3.34	33.4	21.7	11.7	
Jun	2	Late	1.16	3.18	31.8	17.4	14.4	
Jun	3	Late	1.07	2.85	28.5	22.7	5.8	
Jul	1	Late	0.92	2.39	23.9	29.5	0.0	
Jul	2	Late	0.77	1.95	19.5	34.0	0.0	
Jul	3	Late	0.63	1.56	14.0	29.6	0.0	
					<b>458.4</b>	<b>450.5</b>	<b>66.7</b>	

Appendix Table 18. Maize monthly irrigation water requirements at Kersa stations

Crop Water Requirements							
ETo station		Kersa		Crop		Maize	
Rain station		Kersa		Planting date		08/02	
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.30	1.18	3.5	1.1	3.5
Feb	2	Init	0.30	1.24	12.4	2.2	10.2
Feb	3	Init	0.30	1.28	10.3	8.4	1.9
Mar	1	Deve	0.33	1.45	14.5	16.2	0.0
Mar	2	Deve	0.50	2.25	22.5	22.0	0.5
Mar	3	Deve	0.69	3.23	35.5	23.6	11.8
Apr	1	Deve	0.89	4.24	42.4	25.8	16.6
Apr	2	Mid	1.07	5.25	52.5	28.4	24.1
Apr	3	Mid	1.14	5.54	55.4	26.3	29.1
May	1	Mid	1.14	5.51	55.1	23.5	31.5
May	2	Mid	1.14	5.47	54.7	21.9	32.8
May	3	Mid	1.14	5.46	60.0	21.1	38.9
Jun	1	Late	1.14	5.44	54.4	19.2	35.1
Jun	2	Late	1.04	4.93	49.3	17.8	31.6
Jun	3	Late	0.88	4.02	40.2	21.6	18.6
Jul	1	Late	0.72	3.11	31.1	26.3	4.8
Jul	2	Late	0.58	2.40	16.8	20.8	0.0
					<b>610.7</b>	<b>326.4</b>	<b>291.2</b>

Appendix Table 19. Maize monthly irrigation water requirements at Hakim gara stations

Crop Water Requirements

ETo station: Hakim gara      Crop: Maize

Rain station: Hakim gara      Planting date: 08/02

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.30	0.31	0.9	1.9	0.9
Feb	2	Init	0.30	0.40	4.0	8.4	0.0
Feb	3	Init	0.30	0.51	4.1	13.0	0.0
Mar	1	Deve	0.33	0.67	6.7	17.3	0.0
Mar	2	Deve	0.49	1.18	11.8	21.3	0.0
Mar	3	Deve	0.69	1.85	20.4	28.0	0.0
Apr	1	Deve	0.88	2.65	26.5	37.6	0.0
Apr	2	Mid	1.06	3.53	35.3	45.3	0.0
Apr	3	Mid	1.13	4.08	40.8	40.7	0.1
May	1	Mid	1.13	4.40	44.0	34.4	9.6
May	2	Mid	1.13	4.73	47.3	31.0	16.3
May	3	Mid	1.13	4.81	52.9	28.9	24.0
Jun	1	Late	1.13	4.96	49.6	25.5	24.1
Jun	2	Late	1.02	4.61	46.1	22.6	23.5
Jun	3	Late	0.86	3.49	34.9	26.0	8.9
Jul	1	Late	0.70	2.45	24.5	30.9	0.0
Jul	2	Late	0.56	1.71	12.0	23.9	0.0
					<b>461.8</b>	<b>436.8</b>	<b>107.4</b>

Appendix Table 20. Maize monthly irrigation water requirements at Kulubi stations

**Crop Water Requirements**

ET<sub>o</sub> station:       Crop:

Rain station:       Planting date:

Month	Decade	Stage	Kc	ET <sub>c</sub>	ET <sub>c</sub>	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.30	1.15	3.5	2.7	3.5
Feb	2	Init	0.30	1.22	12.2	8.5	3.7
Feb	3	Init	0.30	1.25	10.0	14.7	0.0
Mar	1	Deve	0.33	1.41	14.1	21.9	0.0
Mar	2	Deve	0.50	2.19	21.9	27.5	0.0
Mar	3	Deve	0.69	3.09	34.0	31.3	2.7
Apr	1	Deve	0.89	4.02	40.2	37.5	2.7
Apr	2	Mid	1.07	4.92	49.2	42.8	6.5
Apr	3	Mid	1.14	5.24	52.4	36.9	15.5
May	1	Mid	1.14	5.24	52.4	29.0	23.4
May	2	Mid	1.14	5.25	52.5	23.9	28.5
May	3	Mid	1.14	5.30	58.3	22.7	35.6
Jun	1	Late	1.14	5.35	53.5	19.7	33.8
Jun	2	Late	1.03	4.92	49.2	16.9	32.3
Jun	3	Late	0.88	4.03	40.3	24.1	16.3
Jul	1	Late	0.72	3.19	31.9	33.2	0.0
Jul	2	Late	0.58	2.51	17.5	27.8	0.0
					<b>593.2</b>	<b>421.1</b>	<b>204.4</b>

Appendix Table 21. Potato monthly irrigation water requirements at Haramaya stations

**Crop Water Requirements**

ETo station: Haramaya      Crop: Potato

Rain station: Haramaya      Planting date: 08/02

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.50	1.67	5.0	1.3	5.0
Feb	2	Init	0.50	1.73	17.3	4.8	12.4
Feb	3	Init	0.50	1.76	14.1	8.9	5.2
Mar	1	Deve	0.54	1.94	19.4	13.0	6.4
Mar	2	Deve	0.73	2.64	26.4	16.6	9.9
Mar	3	Deve	0.93	3.42	37.6	21.3	16.4
Apr	1	Mid	1.08	4.00	40.0	27.8	12.3
Apr	2	Mid	1.09	4.05	40.5	33.2	7.3
Apr	3	Mid	1.09	4.07	40.7	31.0	9.6
May	1	Mid	1.09	4.08	40.8	28.7	12.1
May	2	Late	1.03	3.87	38.7	27.8	10.9
May	3	Late	0.81	2.96	32.5	23.5	9.0
Jun	1	Late	0.57	2.06	20.6	16.4	4.2
Jun	2	Late	0.44	1.55	3.1	2.3	3.1
					<b>376.7</b>	<b>256.5</b>	<b>123.7</b>

Appendix Table 22. Potato monthly irrigation water requirements at Harar Indicative stations

**Crop Water Requirements**

ETo station: Harar Indicative      Crop: Potato

Rain station: Hara Indicative      Planting date: 08/02

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.50	1.73	5.2	1.6	5.2
Feb	2	Init	0.50	1.80	18.0	5.8	12.1
Feb	3	Init	0.50	1.82	14.5	11.6	3.0
Mar	1	Deve	0.54	1.99	19.9	18.2	1.7
Mar	2	Deve	0.72	2.69	26.9	23.6	3.3
Mar	3	Deve	0.93	3.42	37.6	27.3	10.3
Apr	1	Mid	1.07	3.93	39.3	32.7	6.7
Apr	2	Mid	1.08	3.91	39.1	37.4	1.7
Apr	3	Mid	1.08	3.89	38.9	33.8	5.1
May	1	Mid	1.08	3.87	38.7	29.2	9.5
May	2	Late	1.02	3.63	36.3	26.4	9.9
May	3	Late	0.80	2.78	30.6	23.7	6.9
Jun	1	Late	0.57	1.95	19.5	19.3	0.1
Jun	2	Late	0.44	1.47	2.9	3.2	2.9
					<b>367.6</b>	<b>293.7</b>	<b>78.6</b>

Appendix Table 23. Potato monthly irrigation water requirements at Harar Indicative stations

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.50	1.63	4.9	1.3	4.9
Feb	2	Init	0.50	1.69	16.9	3.2	13.7
Feb	3	Init	0.50	1.73	13.8	9.5	4.3
Mar	1	Deve	0.54	1.92	19.2	16.5	2.7
Mar	2	Deve	0.73	2.64	26.4	21.9	4.5
Mar	3	Deve	0.95	3.32	36.5	28.1	8.4
Apr	1	Mid	1.10	3.76	37.6	37.1	0.5
Apr	2	Mid	1.11	3.67	36.7	44.6	0.0
Apr	3	Mid	1.11	3.61	36.1	39.9	0.0
May	1	Mid	1.11	3.54	35.4	33.8	1.6
May	2	Late	1.05	3.29	32.9	30.5	2.4
May	3	Late	0.83	2.50	27.5	27.3	0.2
Jun	1	Late	0.61	1.75	17.5	22.1	0.0
Jun	2	Late	0.48	1.32	2.6	3.6	2.6
					<b>344.2</b>	<b>319.3</b>	<b>45.9</b>

Appendix Table 24. Potato monthly irrigation water requirements at Hakim gara stations

**Crop Water Requirements**

ETo station: Hakim gara      Crop: Potato

Rain station: Hakim gara      Planting date: 08/02

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.50	0.51	1.5	1.9	1.5
Feb	2	Init	0.50	0.67	6.7	8.4	0.0
Feb	3	Init	0.50	0.85	6.8	13.0	0.0
Mar	1	Deve	0.54	1.10	11.0	17.3	0.0
Mar	2	Deve	0.72	1.73	17.3	21.3	0.0
Mar	3	Deve	0.93	2.51	27.6	28.0	0.0
Apr	1	Mid	1.08	3.26	32.6	37.6	0.0
Apr	2	Mid	1.09	3.61	36.1	45.3	0.0
Apr	3	Mid	1.09	3.93	39.3	40.7	0.0
May	1	Mid	1.09	4.24	42.4	34.4	8.0
May	2	Late	1.03	4.30	43.0	31.0	12.1
May	3	Late	0.81	3.44	37.9	28.9	9.0
Jun	1	Late	0.58	2.56	25.6	25.5	0.1
Jun	2	Late	0.45	2.04	4.1	4.5	4.1
					<b>332.1</b>	<b>337.9</b>	<b>34.8</b>

Appendix Table 25. Potato monthly irrigation water requirements at Kersa stations

**Crop Water Requirements**

ETo station:       Crop:

Rain station:       Planting date:

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.50	1.96	5.9	1.1	5.9
Feb	2	Init	0.50	2.07	20.7	2.2	18.5
Feb	3	Init	0.50	2.14	17.1	8.4	8.7
Mar	1	Deve	0.54	2.39	23.9	16.2	7.7
Mar	2	Deve	0.73	3.31	33.1	22.0	11.1
Mar	3	Deve	0.94	4.37	48.1	23.6	24.4
Apr	1	Mid	1.09	5.21	52.1	25.8	26.3
Apr	2	Mid	1.10	5.37	53.7	28.4	25.3
Apr	3	Mid	1.10	5.33	53.3	26.3	27.0
May	1	Mid	1.10	5.30	53.0	23.5	29.4
May	2	Late	1.04	4.97	49.7	21.9	27.9
May	3	Late	0.82	3.92	43.1	21.1	22.0
Jun	1	Late	0.59	2.83	28.3	19.2	9.1
Jun	2	Late	0.46	2.21	4.4	3.6	4.4
					<b>486.5</b>	<b>243.4</b>	<b>247.7</b>

Appendix Table 26. Potato monthly irrigation water requirements at Kulubi stations

Crop Water Requirements

ETo station: Kulubi      Crop: Potato

Rain station: Kulubi      Planting date: 08/02

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Feb	1	Init	0.50	1.92	5.8	2.7	5.8
Feb	2	Init	0.50	2.03	20.3	8.5	11.8
Feb	3	Init	0.50	2.09	16.7	14.7	2.1
Mar	1	Deve	0.54	2.33	23.3	21.9	1.4
Mar	2	Deve	0.73	3.22	32.2	27.5	4.7
Mar	3	Deve	0.94	4.19	46.1	31.3	14.8
Apr	1	Mid	1.09	4.94	49.4	37.5	12.0
Apr	2	Mid	1.10	5.04	50.4	42.8	7.6
Apr	3	Mid	1.10	5.04	50.4	36.9	13.5
May	1	Mid	1.10	5.05	50.5	29.0	21.5
May	2	Late	1.04	4.77	47.7	23.9	23.8
May	3	Late	0.82	3.80	41.9	22.7	19.2
Jun	1	Late	0.59	2.78	27.8	19.7	8.2
Jun	2	Late	0.46	2.20	4.4	3.4	4.4
					<b>466.9</b>	<b>322.5</b>	<b>150.6</b>

Appendix Table 27. FAO Table value of crop wat for Maize and Potato

Crop characteristic	Stages of Development(potato)					Plant date
	Initial	Crop Development	Mid-season	Late	Total	
Stage length, days	25	30	30/45	30	115/130	Jan/Nov
	25	30	45	30	130	May
	30	35	50	30	145	April
	45	30	70	20	165	Apr/May
	30	35	50	25	140	Dec
Depletion Coefficient, p:	0.5	>>	0.6	0.9	0.5	
Root Depth, m	0.3	>>	>>	1	-	
Crop Coefficient, Kc <sup>1</sup> :	0.5	>>	1.15	0.5	-	
Yield Response Factor, Ky	0.2	0.8	-	1	0.85	
Crop characteristic	Stages of Development(Maize)					Plant date
	Initial	Crop Development	Mid-season	Late	Total	
Stage length, days	30	50	60	40	180	April
	25	40	45	30	140	Dec/Jan
		35	40	30	125	June
	20	35	40	30	125	Oct./Dec
	30	40	50	30	150	April
	30	40	50	30	150	April
30	40	50	50	170	April	
Depletion Coefficient, p	0.5	0.5	0.5	0.8	-	
Root Depth, m	0.3	>>	>>	1	-	
Crop Coefficient, Kc	0.3	>>	1.2	0.5	-	
Yield Response Factor, Ky	0.4	0.4	1.3	0.5	1.25	

