JIMMA UNIVERSITY
SCHOOL OF POSTGRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
DEPARTMENT OF HYDRAULIC AND WATER RESOURCES ENGINEERING
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

ASSESSEMENT OF PHYSICAL LAND RESOURCE POTENTIAL FOR SURFACE IRRIGATION: (A CASE STUDY OF MUGA WATERSHED)

BY: GASHANEW YESHITA

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

JANUARY, 2019

JIMMA, ETHIOPIA

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Advisor: Mr.Mamuye Busier. (Asst. Professor)

Co-Advisor: Mr. Andualem Shigute (Msc)

JANUARY, 2019

JIMMA, ETHIOPIA

Declaration

I, Gashanew Yeshita, hereby declare that the thesis entitled as “Assessment of Physical land resources potential for surface irrigation a case study of Muga watershed” submitted for the partial fulfillment of the requirements for the degree of Master of Science in Hydraulic Engineering, is the original work done by me under the supervision of

i. Mr.Mamuye Busier. (Asst. Professor) Signature………………dates………….
ii. Mr.Andualem Shigute (MSc) Signature………………dates…………...

This thesis has not been submitted elsewhere for the requirement of a degree program to the best of my knowledge and references are listed at the end.

Gashanew Yeshita Signature………………dates………….

Thesis Approval Sheet

This is to certify that the thesis entitled "assessment of physical land resource potential for surface irrigation: a case study of Muga watershed" submitted in partial fulfillment of the requirement for the degree of Master of Science in Hydraulic Engineering,

Submitted By Gashanew Yeshita Signature…………………Date…………………….

As members of the Examining Board of the Final Msc Open Defense, we certify that we have read and evaluated the thesis prepared by: Mr. Gashanew Yeshita entitled: Assessment of Physical land resources Potential for surface irrigation of Muga watershed. We recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in Hydraulic Engineering.

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Abstract

Assessing available land and water resources for irrigation is important for planning water resources projects. This study is initiated with the objective of assessing the land resources potential of Muga watershed for surface irrigation development by using Geographic Information System and analytical hierarchy process with multi criteria analysis. The evaluation of land in terms of the suitability classes for surface irrigation is based on the method as described in FAO (food and agricultural organization) guideline for land evaluation. The factors that were considered for evaluation of the land for surface irrigation were slope, soil drainage, soil texture, soil depth, land use/cover and distance to water sources. After evaluating the physical land capability for surface irrigation, irrigation suitability map was developed AHP method was utilized to identify the weight of each criterion from the pair wise comparison matrix. The weighted sum overlay analysis was then used to generate the suitability map in a GIS environment. This map was classified in to four suitability classes as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N) suitability classes independently and the final potentially irrigable land was identified by weighting the factors of suitability. The suitability analysis of the parameters with the method of multi criteria analysis indicates that 20.19% slope (covering an area of 14905.03 ha), 83.93%(61961.08 ha) soil texture, 40.37%(29801.64 ha)soil depth, 85.98% (63478 ha)soil drainage and 64.78%(47825.92 ha) land use/cover of the study area were classified as potentially suitable for irrigation development in the study area. By weighting analysis of all parameters 2.99 %(2191.04 hectare) of the study area was found to be highly suitable whereas about 24658.80 hectare (33.63%) was restricted for irrigation developments. Resulted from CropWat software the annual total gross irrigation water requirement was found to be 74.78 m3/s and the the annual total minimum flow of the river was 35.78m^3/s. this result indicates that the annual minimum flow of river couldn't fulfill the water requirements of the crop commonly grown in the area so construction of any storage structure is necessary.

Key words: *- Arc GIS, land suitability, Potential surface irrigation. Soil suitability, Suitability factor*

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Acronyms

AHP	Analytical Hierarch Process
CSA	Central static agency
DEM	Digital Elevation Model
DFID	Department for International Development
EMA	Ethiopian Mapping Agency
ESMA	Ethiopian Soil Map Agency
ESRI	Environmental Systems Research Institute
ETc	Crop Evapo-transpiration
Eto	Reference Evapo-transpiration
FAO	Food and Agriculture Organization
GDP	Gross domestic product
GIS	Geographic Information System
GLCN	Global Land Cover Network
IFAD	International Fund for Agricultural Development
ILRI	International Livestock Research Institute
IWR	Irrigation Water Requirement
LULC	Land Use Land Cover
MAP	Mean Annual Precipitation
MCA	Multi criteria analysis
MCDM	Multi criteria decision making
Mha	Million Hectares
MoA	Ministry of Agriculture
MoWR	Ministry of Water Resources
NASA	National Aeronautics and Space Administration
NGA	National Geospatial intelligence Agency
NMSA	National Meteorological Services Agency
PWCM	Pair wise comparation matrix
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission
WOT	Weighted overlay analysis

1. INTRODUCTION

1.1. Background

Ethiopia is the second most populous country in Africa with an estimated population 98,352,000 (CSA, 2016).The majority of the population of Ethiopia consists of farmers and they reside in rural areas and whose life is almost entirely dependent on agriculture. Land is the most important limited natural resource that makes up the fundamental resource base in any agricultural production system; hence it needs to be managed effectively for the creation of wealth in many societies in general and agrarian society in particular (Stein *et al*, 2009*)*.

Agriculture plays a key role in the economies of most African countries (IFAD, 2011).For example, Ethiopia's agricultural sector employs about 80% of the labor force on a formal and informal basis and accounts for approximately 45-50% of the gross domestic product and 85% of export earnings. However, the agriculture industry in Ethiopia is traditionally subsistence based and rain fed, which frequently suffers from rainfall variability (Bewket and Conway, 2007).

The average crop yields per hectare from irrigated land increases 2.3 times higher than the yield produced by rain fed agriculture (FAO, 2007).However, currently irrigated agriculture produces less than 3% of the total food production of the country (Atnafe, 2006).As a result, the productivity of the agricultural sector is very low and lags behind the rate of population growth and partially reinforcing food insecurity in the country (Awulachew *et al*., 2010).

This is mainly due to inappropriate management and selection of best-fit land for irrigation for wise utilization of scarce physical resource of land and water, poor water storage capacity and large spatial and temporal variations in rainfall, there is no sufficient water available for most small-holder farmers to produce more than one crop per year (MoFED, 2006). This results infrequent crop failures followed by dry spells, occurrence of severe droughts and produce significant soil erosion which may reduce the potential productivity of farmlands (Awulachew *et a*l., 2010).

Geographical information system (GIS) is serving as a powerful analytic and decision making tool for irrigation development (Rossiter, 1995). Large area extent of GIS as well as its ability to collect store and manipulate various types of data in a unique spatial database, helps performing various kinds of analysis and thus, extracting information about spatially distributed phenomena. In this kind of situation, the factors that are involved for irrigation potential assessment such as soil, land use/ land cover, slope gradient and distance from water supply could be weighted and evaluated using ArcGIS according to their suitability for irrigation using the method of multiple criteria analysis.

Multiple- Criteria Analysis is a suite of methodologies that can help decision makers and analysts to combine multiple factors, and it typically results in a rating or ranking of alternatives (Eastman *et al.,* 1995). The integration of Geographical Information System and Analytical Hierarchy Process is the demanding method for the result oriented and meaningful land evaluation approach for the land area with rough topography and climatically variable area like hilly region of Ethiopia (Baniya, 2008). Conducting research on irrigation land suitability by integrating Multiple Criteria Analysis, Geographical Information System and Analytical Hierarchy Process bring sustainable land resource management. In view of this fact, it is worth investigating irrigation land suitability.

East Gojjam Zone of Amhara national regional state has abundant water and land resources, but its agricultural system does not yet fully productive and mainly depends on rain-fed agriculture. This resulted from lack of systematic land suitability assessment, land use planning and lacking of clearly, current land use and irrigation land suitability description for potential natural resource in the area. To introduce improved irrigation technology and expand irrigation investment, irrigation land suitability assessment is very important tool in terms of agriculture development planning and choosing of suitable irrigation method. Therefore, the main objective of this study is to assess the land resources potential of the Muga watershed for irrigation and providing geo-referenced map of these resources using GIS.

1.2. Statement of the problem

Ethiopia has 12 river basins with an estimated renewable surface and ground water amounts to 123 and 28 billion cubic meters perineum, respectively, its distribution in terms of area and season does not give adequate opportunity for sustainable growth to the economy (MoWR, 2010). However, due to lack of water storage infrastructure and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year (Awulachew *et al*., 2007). 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).

Muga is a Perennial River; it has not been used for irrigation purpose. Due to this fact agricultural production is very low in this area. This is due to lack of information about the availability and suitability of land. The efforts to establish small, medium and large-scale irrigation schemes in the area are constrained by a number of uncertainties. From such problem physical land resources which is suitable for surface irrigation in the basin have not been identified well is one of the major problems To overcome such difficulties, Analysis of irrigation land suitability is needed for various reasons in the study area, in which the community is highly reliant on agriculture. Though, systematic land suitability assessment, current land use and irrigation land suitability description for potential natural resource is needed.

Since there is no study which was conducted in the study area based on weighting the land resources for irrigation potential, this study add some asset to explore the irrigation potential and matched with the water requirements of some crops commonly grown in the study area.

1.3. Objectives of the study

1.3.1. General objective

The General objective of this study is to assess Physical land resources potential of Muga watershed for surface irrigation by using Geographic Information System (GIS).

1.3.2. Specific objective

The specific objectives of this study are

i. To estimate suitable area of Muga watershed for surface irrigation.
ii. To estimate total irrigation water requirement for the selected crop commonly grown in the area.
iii. To provide Land suitability maps based on the suitability parameters for surface irrigation.

1.4. Research Questions

i. How much area of Muga watershed is suitable for surface irrigation?
ii. How can we estimate total irrigation water requirement of crops in the watershed?
iii. How was the distribution of the lands potentially suitable for surface irrigation?

1.5. Scope of the study

The scope of the study mainly focuses on assessment of physical land resource potential and its suitability for surface irrigation without considering chemical property of the soil type so these work only investigates soil physical property, land use/cover, River proximity and land slope for determining land suitability for surface irrigation.

1.6. Significance of the study

The agricultural development highly depend on how we manage sectors and all other resource, this appeals to knowing total land resource potential for irrigation in Muga watershed Because of this area is practiced rain fed agriculture once in a year as a result agriculture production drastically decreased. After knowing the irrigable area and suitable land resources in this watershed, it helps for planner and decision maker to lunch any physical structures to store or divert sufficient water for agriculture purpose. So that the population can beneficiary or profitable by producing yields 2 or 3 times per year this leads to, the development of Ethiopian economy.

In addition this study provided relevant information on current land resources potential suitable for surface irrigation. Therefore it is used as bench mark for other researchers who are interested to make another study around the topic. Furthermore, it is useful for the government body and interested sectors of this issue by providing overview of the current land resources potential of the study area in order to take actions to solve land management related problem.

1.7. Limitations of the study

The main important data necessary for the modeling work, determination of watershed water resources and irrigation water requirement is a rainfall data: however, most of meteorological stations from which data were collected are not fully recorded. Thus Shortage of data of the study area was encountered a problem in order to conduct the study. The chemical properties of soil of the study area were not evaluated to determine the physical land suitability for surface irrigation. Only the physical characteristics of the land under the study area were evaluated for determining the suitability of irrigation. The study considers only available minimum water resources for irrigation. Thus, the storage requirements and the place where it is located were not determined. When calculating crop water requirement, only three crop samples was taken and this is also the limitation of the study.

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2. LITERATURE REVIEW

2.1. Land resources Potential of Ethiopia

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

Ethiopia is a landlocked country, with a land area of 1.13 Million km^2, found in Eastern Africa (Awuachew *et al*., 2007). Geographically, it is located in between the latitudes 5°N and 15°N and longitudes 35°E and 45°E (yazew, 2005). The country is bordered by six countries, Eritrea in the North, Djibouti and Somalia in the East, Kenya and Somalia in the South, and Sudan and South Sudan in the West. Most of the population in Ethiopia lives in highland areas, with 85 percent being rural and dependent on agriculture with a low level of productivity (Bekele *et al*., 2012).

Proper evaluation of land resources in irrigation command area is prerequisite for better utilization of land resources which help to optimize and sustain the productivity of these land resources. Availability of irrigation leads to land use change as well as intensive cropping system. Improper use of irrigation water has resulted in environmental degradation of natural resources that leads to decline in the productivity of land resources and deterioration of land quality for its future use (Boelle, 2005).

To assess the information on land and water resources at the river basin level, knowledge of physical irrigation potential is necessary. The area which can potentially be irrigated depends on the Physical resources 'soil' and 'water', combined with the irrigation water requirements as determined by the cropping patterns and climate. Therefore, physical irrigation potential represents a combination of information on gross irrigation water requirements, area of soils suitable for irrigation and available water resources by basin (FAO, 1997).

2.2. History of Irrigation in Ethiopia

In Ethiopia, traditional irrigation was practiced before centuries (Bekele *et al*., 2012). Moreover, in the highlands of Ethiopia, irrigation practices have long been in use since ancient times for producing subsistence food crops (MoA, 2011). Different authors; (Awulachew *et al*., 2007); (Makombe *et al*., 2007); (Hagos *et al.*, 2009) stressed that supplementary irrigation has been practiced by smallholder farmers of Ethiopia for centuries to solve their livelihood challenges.

Modern irrigation, however, was started in the early 1960's by the bilateral agreement between the government of Ethiopia and the Dutch company jointly known as HVA-Ethiopia sugar cane plantation (MoA, 2011). Most of the traditional irrigated lands in Ethiopia are dominantly supplied by surface water sources. The Rift Valley is a place where modern irrigation in Ethiopia starts especially in the Awash River Basin at which adoption of pump-irrigation commences. Surface irrigation methods predominantly furrow irrigation and basin irrigation methods were practiced for cotton and wheat productions and for commercial fruits such as bananas respectively (Awulachew *et al*., 2007).

Makombe et al. (2011) Noted that irrigation development is a key for sustainable and reliable agricultural development which leads to overall development in Ethiopia Irrigated agriculture is being practiced under smallholders, medium and large scale farming. Many authors such as Hagos *et al*. (2009) were used government based irrigation schemes classification systems for their description during their studies. According to Ministry of Water Resources of Ethiopia (MoWR, 2002) irrigation development in Ethiopia is classified based on the size of the command area, in three types as (1) Small-scale irrigation systems (<200 hectares (ha), (2).Medium-scale irrigation systems (200-3,000 ha), (3).Large-scale irrigation systems (>3,000 ha).This irrigation Classification system is the most common in Ethiopia. Accordingly, 46% of proposed irrigation developments are in the small-scale irrigation category (Makombe *et al*., 2011).

2.3. The need for Irrigation development in Ethiopia

Ethiopia is endowed with a substantial amount of water resources but very high hydrological variability (Awulachew *et al*., 2012) compounded with lack of appropriate soil fertility management contribute to lower crop yield (Worqlul *et al*., 2017) resulting in high food insecurity and dependent country on food aid. Growing season rainfall has declined by 15 to 20 percent while temperature increases. This intensifies the impacts of droughts and could reduce the amount of productive cropland. It is explained that coincidence of densely-populated areas and observed declines in rainfall makes the agriculture sector dominated by subsistence rain-fed systems with low productivity in high levels of risk.

Irrigated agriculture represents 20% of the total cultivated land but contributes 40 percent of the total food produced worldwide (FAO, 2015). Thus, irrigation plays a significant role in the substantial increase in food production for food security enhancement and economic development of Ethiopia with the efficient use of land and water resources (Sultan, 2013). The production function analysis done by (Makombe *et al*., 2007) shows that irrigation could shift the agricultural production frontier to a higher level. However, its contribution to the national economy is not significant when compared to rain fed agriculture. But global agricultural production has doubled within an area that has only increased by 12%, and a part of this gain can be attributed to an increase in irrigation (Begue *et al*., 2018).

According to (Worldbank, 2006) increasing irrigation has long been seen as the most direct strategy to alleviate the impact of drought and ensure food security. The report emphasizes without increased irrigation, the unpredictability of rains in Ethiopia is an overwhelming disincentive to investments in agricultural improvements. (Awulachew *et al*., 2010) explained that well-managed irrigation development is key in helping Ethiopia overcome major challenges of population pressure, soil and land degradation, high climate variability and low agricultural productivity. Research in the Lake Tana Basin revealed that, on average, household incomes of those that practiced irrigation were 27% higher than those that did not (IWMI, 2015). Another study at Gubalafto District, North Wollo (Mengiste and Kidane, 2016) indicated that irrigation has a great impact on enhancing farmers' livelihoods through different dimensions, such as diversification of crops grown, as well as increased agricultural production, household income, employment opportunity and participation in community decisions.

2.4. Irrigation Potential in Ethiopia

According to FAO (1997) definition irrigation potential represents combination of information on gross irrigation water requirements, area of soil suitable for irrigation and available water resources by basin and also considers the environmental and socioeconomic constraints.

The cultivated agricultural land of Ethiopia currently under cultivation is about 12 million ha (MoA, 2011). Moreover, even if the potential and actual irrigated area is not precisely investigated (Belay and Bewket, 2013) estimates of irrigable land in Ethiopia reaches 6 million hectares (Mha) .However, it is surprising that the total land under irrigation now is estimated to be in the range between 160, 000-200,000 ha which is less than 5% of the countries irrigable land(Worldbank, 2006).However, (MoA, 2011a) reported about 10- 12% of the total irrigable potentials are currently under production using traditional and modern irrigation schemes.

2.5. Over view of Surface irrigation

The term "surface irrigation" refers to a broad class of irrigation methods in which water is distributed over the field by a free-surface, gravity flow (Walker, 2003). Following the pull of gravity, the water flows over the fields from one end to the other, infiltrating into the soil as it goes. The most common surface irrigation techniques are level basins (with or without level furrows), sloping borders and sloping furrows to distribute irrigation water (Fasina *et al*., 2008). Surface irrigation systems can be as efficient as most other methods. This requires improving the management and control of water, knowing how much water is applied and scheduling applications according to soil water levels and crop needs.

Surface irrigation has evolved into an extensive array of configurations that can broadly be classified as: Basin irrigation, Border irrigation, furrow irrigation and wild flooding. The distinction between the various classifications is often subjective. For example, a basin or border system may be furrowed. Wild flooding is a catchall category for the situations where water is simply allowed to flow onto an area without any attempt to regulate the application or its uniformity (USDA, 2006).According to (Walker, 2003) stated that surface irrigation as the oldest and most common method of applying water to croplands, surface irrigation has evolved into an extensive array of configurations. Efforts to classify surface systems differ substantially, but generally include the following: (1) basin irrigation, (2) border irrigation, (3) furrow irrigation, and (4) wild flooding.

2.6. Land Evaluation and Suitability

Land evaluation is a process for matching the characteristics of land resources for certain uses using a scientifically standardized technique (FAO, 1985). The results can be used as a guide by land users and planners to identify alternative land uses (Driessen and Konijn, 1992). Land suitability is the degree of appropriateness of land for a certain use. Land suitability could be assessed for present condition (actual land suitability) or after improvement potential land suitability (Ritung *et al*., 2007).

The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for a defined use and Suitability is assessed by comparison of the land use requirements with the land qualities (FAO, 2007).

2.7. Land Suitability Classification

According to FAO (1995) there are four categories recognized for classification of land suitability. Land Suitability Orders indicating in the simplest of whether land is suitable(S) or not suitable (N) for specified use. Land Suitability Classes showing the degree of suitability within an order; Land Suitability Sub classes reflection the kinds of limitation or required improvements measures within classes and Land Suitability Units indicating differences in required management within sub classes.

Table 2.1.Catagories of suitability classification

Categories of suitability	**Description**
Land suitability orders	Reflecting kinds of suitability
Land suitability classes	Reflecting degrees of suitability within orders
Land suitability subclasses	Reflecting kinds of limitation or main kinds of improvement measures required, within classes
Land suitability Unit	Reflecting minor differences in required management

(Source: FAO, 1995)

2.7.1. Land suitability orders

Land suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. As stated by (FAO, 2007) there are two orders represented in maps tables by the symbols S and N for suitable and not suitable, respectively. Order S (suitable): land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources. Order N (not suitable): land, which has qualities that appear to preclude sustained use of the kind under consideration. 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 to make it suitable (FAO, 1976).

2.7.2. Land suitability classes

Land suitability classes reflect quantitatively the degree of suitability. In accordance with human preference three classes were adopted: highly suitable (having no significant limitations to development or only minor limitations), moderately suitable (having limitations which are moderately severe and within a moderately acceptable category), and marginally suitable having major limitations (Jansen, 1990).

Table 2.2.Structure of land suitability order and classes

Suitability order	suitability classes	Description
Suitable(S)	S1 (Highly suitable)	Land having no or in significant limitations to the given types of use.
	S2 (Moderately suitable)	Lands having minor limitation to the given type of use
	S3 (Marginally Suitable)	Lands having moderate limitation to the given types of use
Unsuitable(N)	N1 (Currently not suitable)	Land having severe limitations that preclude the given types of use, but can be improved by specific management
	N2 (Permanently not suitable)	Land with so severe limitations which are very difficult to be overcome.

(Source: FAO, 2007)

2.7.3. Land Suitability Sub Classes

Land Suitability Subclasses reflect kinds of limitations, example moisture deficiency, and erosion hazard. Subclasses are indicated by lower-case letters with early significance, exampleS2m, S2e, and S3me. There are no subclasses in Class S1. The number of Subclasses recognized and the limitations chosen to distinguish them will differ in classifications for different purposes. The number of subclasses should be kept to a minimum that satisfactorily distinguish lands within a class likely to differ significantly in their management requirements or potential for improvement due to differing limitations. As few limitations as possible should be used in the symbol for any subclass. One, rarely two, letters should normally suffice. The dominant symbol,(which determines the class) should be used alone if possible. If two limitations are equally severe, both may be given. Land within the Order Not Suitable may be divided into suitability subclasses according to kinds of limitation, e.g. N1m, N1me, N1m although this is not essential. As this land will not be placed under management for the use concerned it should not be subdivided into suitability units (FAO, 1985).

2.7.4. Land Suitability Units

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

2.8. Irrigation Land Suitability Evaluation Factors

Land suitability analysis using a scientific procedure is essential to assess the potential and constraint of a given land parcel for agricultural purposes (Rossiter, 1995) Suitability of land for surface irrigation method and for the given land utilization types were assessed by considering slope, land use land cover, soil depth soil texture pH and drainage using GIS techniques (Meron, 2007).Therefore the Land evaluation parameter used to address the suitability of the selected irrigation method were soil depth, soil texture, drainage and slope factors, distance from water sources and land cover/land use types are considered as limiting factors in evaluating suitability of land for surface irrigation method in the study area.

2.8.1. Slope

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

2.8.2 Soils

Soil is defined as the unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants (SSSA, 2008).Different types of soil exhibit diverse behavior and physical properties. Soil act as a storehouse of water, supplying plant needs during dry period when rain is inadequate (Meron, 2007). Therefore, it is imperative to maintain soil functions and qualities to sustain the ecosystem and the human being (*De Groot et al., 2002*) this alarmed authorities to plan and assess suitable parameters for land uses. It has been recognized that the quality of land suitability assessment and the reliability of land use decisions depend largely on the quality of soil information used to derive them (Ziadat, 2007).

2.8.3. Land use/ cover

According to the International Geo sphere-Biosphere Program and The International Human Dimension Program (IGBP-IHDP, 1999).land cover refers to the physical and biophysical cover over the surface of earth, including distribution of vegetation, water, bare soil and artificial structures. Land use refers to the intended use or management of the land cover type by human beings such as agriculture, forestry and building construction.

Although the terms Land use and Land cover are often used interchangeably, each term has a very specific meaning with some fundamental differences. Land cover on the one hand denotes the biophysical cover over the surface including such features as vegetation, urban infrastructure, water, bare soil or other. It does not describe the use of land, which may be different for lands with the same cover type. On the other hand, land use refers to the purpose the land serves, and describes human influence of the land, or immediate actions modifying or converting land cover (Ellis, 2009). 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.

2.8.4. Water availability

According to (Albaji *et al*., 2015) available water resources will not be able to meet various demands in the near future and inevitably result into the seeking of newer lands for irrigation in order to achieve sustainable global food security. A key question is whether there will be sufficient freshwater to satisfy the growing needs of agricultural and non-agricultural users (Alexandratos and Bruinsma, 2012) The truth is water has always been the main factor limiting crop production in much of the world where rainfall is insufficient to meet crop demand (Steduto *et al*., 2012). Thus, assessment of irrigation potential should take into account water Limitations.

It is important to make sure that there will be no lack of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle (FAO, 2001). Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available (FAO, 1985).Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source be near the center of the irrigated area to minimize the size of the delivery channels and pipelines. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length) and thereby develop the irrigation system economical (Seleshi, 2001).

2.9. GIS-based Land Suitability Analysis for Irrigation

2.9.1. Overview of Remote Sensing and GIS Technology

Remote sensing (RS) is defined as the acquisition of information about an object without being in physical contact with it (Elachi *et al*., 2006).Therefore, the intrinsic characteristics of agriculture make remote sensing an ideal technique for its monitoring and management (Zhongxin *et al*., 2004) This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. RS 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. RS is a technology that has close tie to GIS. RS can provide timely data at scales appropriate to a variety of applications. Land cover mapping is one of the most important and typical applications of RS (Lillesand, 2004).

A Geographic Information System (GIS) is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data (Goodchild, 2000). It is an organized collection of computer hardware, software, geographic data and personal designed to efficiently capture, store, update, manipulate, analysis and display all forms of geographically referenced information (ESRI, 1996). GIS has the ability to perform numerous tasks utilizing both spatial and attribute data. The major GIS functions can be grouped into data input and outputs, data storage and management, data management and analysis, and output generation in the final analysis (Frew, 2003). This powerful tool allows decision makers to simulate effects of management and policy alternatives within a geographic area prior to implementation. Also, GIS is a tool that can be used to predict alternative crop growth and yield (Ghasemi *et al*., 2008).Remote Sensing (RS) in combination with GIS techniques proved to be effective in sustainability and planning studies (Zhongxin *et al*., 2006).

GIS technology is being increasingly employed by different users to create database and to arrive at appropriate solution for sustainable development of agricultural resources. GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multi- source datasets such as data on land use, population, topography, hydrology, climate, vegetation, transportation network, public infrastructure, etc. the data are manipulated and analysis to obtain information useful for a particular application such as land use suitability analysis (Malczewski *et al*., 2003). In this way, the result of GIS analysis can provide support for decision- making.

2.9.2. Application

GIS have the ability to perform numerous tasks utilizing both spatial and attribute data stored in it. It has the ability to integrate variety of geographic technologies like Global Positioning System (GPS) and Remote Sensing.

2.9.2.1. Mapping

A map, however, is not just an image (Wood, 1992) explains, The map image is accompanied by a crowd of signs, titles, dates, legends, keys, scale statements How these signs come together is the province of a presentational code, which offers a structured, ordered, articulated and effective display. Mapping is the main application of GIS where things are editing tasks as well as for a map based query and analysis (Campbell, 1984). It is the most common view for a user to work with geographic information system. It represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame, scale bar, north arrow, title, descriptive text, and a symbol legend (Kebede, 2010).

2.9.2.2. Watershed delineation

A watershed, also called a drainage basin or catchment area, is defined as an area in which all water flowing into it goes to a common outlet. People and livestock are the integral part of watershed and their activities affect the productive status of watersheds and vice versa. From the hydrological point of view, the difference phases of hydrological cycle in a watershed are dependent on the various natural features and human activities. Watershed is not simply the hydrological unit but also sociopolitical-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people (Winchell *et al*., 2008).

Delineation of a watershed means determining the boundary of the watershed i.e. ridgeline. GIS uses DEMs data as input to delineate watersheds by hydrology tool in Arc GIS spatial analysis (Winchell *et al*., 2008*)*. DEMs provide good terrain representation from which watersheds can be derived automatically using GIS technology. The techniques for automated watershed delineation have been implemented in various GIS systems and custom applications.

2.9.2.3. Weighted overlay analysis

Overlay operation is a part of spatial analysis process based on the value of Weightage of each sub class within each thematic map. A Weightage overlay used to combine all factor layer maps in to new information to produces individual value for each pixel and new map was produced. The Weightage value used in overlay operation is only performed on raster map (Attual and Fisher, 2014).Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from water (Yang, 2003).

2.9.2.4. Spatial analysis in GIS

GIS has-been seen as the key to implementing methods of spatial analysis, making them more accessible to broader range of users, and hopefully more widely used in making effective decisions and in supporting scientific research. A linkage between GIS and spatial data analysis is considered to be an important aspect in the development of GIS into a research tool to explore and analyze spatial relationships (Openshaw, 1990). In the past few years, this has resulted inconsiderable research activity in this area, as evidenced by an increasing number of review articles, conceptual outlines and guides for practical implementation of the Linkage (Bailey, 1992) .The spatial analysis was used in this study, it can be defined as the analytical techniques associated with the study of locations of geographic phenomena together with their spatial dimensions and their associated attributes.

2.9.3. GIS for Suitability Analysis

Land suitability classification is the appraisal and grouping of specific areas of land in terms of the fitness of a given type of land for defined uses (FAO, 1985). based on the evaluation of the biophysical resources (FAO, 2007). Parametric evaluation approach (Sys *et al*., 1991), Multi-Criteria Evaluation (Malczewski, 2004) and Analytical Hierarchy Process (Saaty, 2008) are the common approaches for land suitability analysis.

Parametric evaluation approach (Sys *et al*., 1991) is a method of evaluation for irrigation purposes based on the standard physio-chemical characteristics of a soil profile. The factors affecting soil suitability for irrigation purposes are physical properties determining the soil-water relationship in the soil and chemical properties interfering with the salinity/alkalinity status, drainage properties, and environmental factors such as slope. Several studies have applied parametric evaluation approach for potential land suitability mapping for irrigation.

Multi-criteria decision making. The MCDM method presents a potential framework which reflects the opinions of the people involved in the decision-making process. This information framework combines a number of criteria and forms an assessment index unit (Yu *et al*., 2011). The combination of the MCDM method and the GIS method represents a powerful tool for spatial analysis (Yu *et al*., 2009).With regard to the large number of factors which affect decision-making, land suitability analysis can be recognized as a multi-criteria evaluation method (Reshmidevi *et al*., 2009).

AHP is a procedure that seeks to consider the context of the spatial planning decision, identifying and arranging the criteria into different groups (Vogel, 2008). AHP is based on three principles: decomposition, comparative judgment and synthesis of priorities (Eldrandaly *et al*., 2007). for assessing the relative importance of the factors to analyze the suitability of land for agriculture.

2.9.4. Previous GIS Based Irrigation Suitability Studies in Ethiopia

In the past, several studies have been made to assess the irrigation potential and water resources in Ethiopia by using GIS tool (Negash, 2004; Hailegebriel, 2007; Meron, 2007 and Kebede, 2010). Negash (2004) conducted a study on irrigation suitability analysis in Ethiopia a case of Abaya Chamo lake basin. It was a Geographical Information System (GIS) based and had taken into consideration soil, slope and land use and water resource availability in perennial rivers in the basin to identify potential irrigable land.

Meron (2007) carried out similar work on surface irrigation suitability analysis of southern Abbay basin by implementing GIS techniques. This study, considered soil, slope and land cover/use factors to find suitable land for irrigation with respect to location of available water resource and to determine the combined influence of these factors for irrigation suitability analysis, weighted overlay analysis was used in ArcGIS. Kebede (2010) conduct a study on GIS- based surface irrigation potential assessment of river catchments for irrigation development in Daleworeda, Sidama zone, SNNP. In this study irrigation suitability factors such as soil type, slope, land use/cover and distance from water supply (sources) were taken into account and weighted overlay analysis of these factors has been accomplish to identify potential irrigable land.

As far as the researchers reviewed, in Ethiopia, the combination between FAO procedure, MCA and AHP evaluation technique using GIS and RS for land suitability analysis was experimented in some areas. Aiming at evaluating the physical land characteristics and its quality of the study area for suitability of surface irrigation potential and crops in GIS environment using multi-criteria decision evaluation (MCDE) method, Hailegebriel (2007) conducted a study on irrigation potential and crop suitability. His study is entitled irrigation potential evaluation and crop suitability analysis using GIS and remote sensing technique in Beles sub basin, Beneshangul Gumuz Region and he found out that 65.7 % of the Beles sub basin is classified under suitable for surface irrigation. This study demonstrates the application of the combined (GIS, MCDM and AHP) approach to address the complex decisions of mapping the crop and surface irrigation suitability.

Dual (2010) conducted his study. His study aims at evaluating the land suitability using multi-criteria evaluation technique for agricultural crops and producing land allocation map for sustainable land use. Dula's (2010) research was conducted on land suitability for agricultural crop. His study is entitled GIS and remote sensing based land suitability analysis for agricultural crops in Mojo watershed, upper awash sub-basin, Ethiopia and he found out that only 21.1%, 18.3%, and 2.0% of the study area are highly suitable for teff, wheat, and chickpea, respectively. This study demonstrates the application of the combined (GIS, MCDM and AHP) approach to address the complex decisions of mapping the suitable area for agricultural crop.

Henok (2010) conducted his study on land suitability for main agricultural crop. His study aims at evaluating the land physical characteristics and its quality for land suitability of main agricultural crops in Legambo Woreda. His study is entitled land and crop suitability analysis using remote sensing and GIS application; a case study in Legambo Wereda,Ethiopia and he found out that 712 km^2 for maize and 814 km^2 of the study area are exploitable for wheat production purposes. This study demonstrates the application of the combined (GIS, MCDM and AHP) and fuzzy membership function approach to address the complex decisions of mapping the suitable area for main agricultural crop.

2.10. Multi Criteria Decision Making

Decision-making is the process that leads to a choice between a set of alternatives, and is often use in land suitability evaluation of alternatives like S1, S2, S3 and N. The Multi Criteria Analysis (MCA) technique is to investigate a number of alternatives in the light of multiple criteria and conflicting objective (Mendoza, 1997). Multiple-Criteria Decision Making (MCDM) can be defined as a collection of formal approaches, which seek to take explicit account of key factors in helping individuals, or groups explore decisions that matter. For approximately 20 years, MCDM methods have been used for spatial problems by coupling them with GIS (Malczewski *et al*., 2003).

The objective of MCDM is to assist the decision-maker in selecting the 'best ‘alternative from the number of feasible choice-alternatives under the presence of multiple choice criteria and diverse criterion priorities. The problem of multi-criterion (multi-objective) choice in decision-making is the paramount challenge faced by individuals, public and private corporations. The challenge of multi criterion choice can be attributed to many spatial decision making problems involving search and allocation of resources. These problems often analyzed in GIS, include location/site selection (Jankowski, 1995). Hence, Site suitability assessment is inherently a multi-criteria problem. That is, land suitability analysis is an evaluation/decision problem involving several factors.MCDM which refers to the application of Multi-Criteria Analysis deal with these spatial decisions problems. Spatial decision problems typically involve a large set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria (Malczewski, 2006).

2.11. Multi-Criteria Analysis (MCA)

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

2.12. AHP Application Concept for Land Suitability Analysis

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

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

2.13. Crop Water Requirement

Crop water requirements and crop irrigation requirements can be carried out from basic information from the crops selected and should include, average planting date and average harvesting date (FAO, 1996). The water requirements are different from one crop to another. Although growing crops are continuously using water, the rate of water use depends on (1) the kind of crop, (2) the degree of maturity and (3) atmospheric condition, such as radiation, temperature, wind and humidity. The rate of growth at different soil water contents varies with different soils and crops. During early stages of growth the water needs are generally low but they increase rapidly during the maximum growing period to the fruiting stage. During the later stages of maturity, water use decreases as the crops ripen (FAO, 1996).

CROPWAT model is a computer program for irrigation planning and management, developed based on the FAO Penman-Monteith method (Smith, 1992). Calculation of water requirements utilizes inputs of climatic, crop and soil data, as well as irrigation and rainfall data. Its basic function includes the calculation of reference Evapotranspiration, crop water requirement and crop and scheme requirement. Reference Evapotranspiration can be calculated from the actual maximum and minimum temperatures, relative humidity, sunshine/radiation and wind speed data, According to Penman-Monteith method (Allen *et al*., 1998).The assessment of the irrigation potential, based on soil and water resources, can only be done by simultaneously assessing the irrigation water requirements (FAO, 1997).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Muga watershed (study area) is found in Upper Blue Nile Basin, which is about 248 km far from North West of Addis Ababa between the towns of Dejen and Bichena. This area is one of the choke mountain watersheds which is located in the northern highlands of Ethiopia, within10°6’00’’North to 10°43’30’’North and 37°49’00’’East to 38°16’30’’East.It covers an area of 738.15 km^2. Muga River originates from Bibugn district near Choke Mountain at elevation of 4094 m.a.s.l and drains to Abbay River.

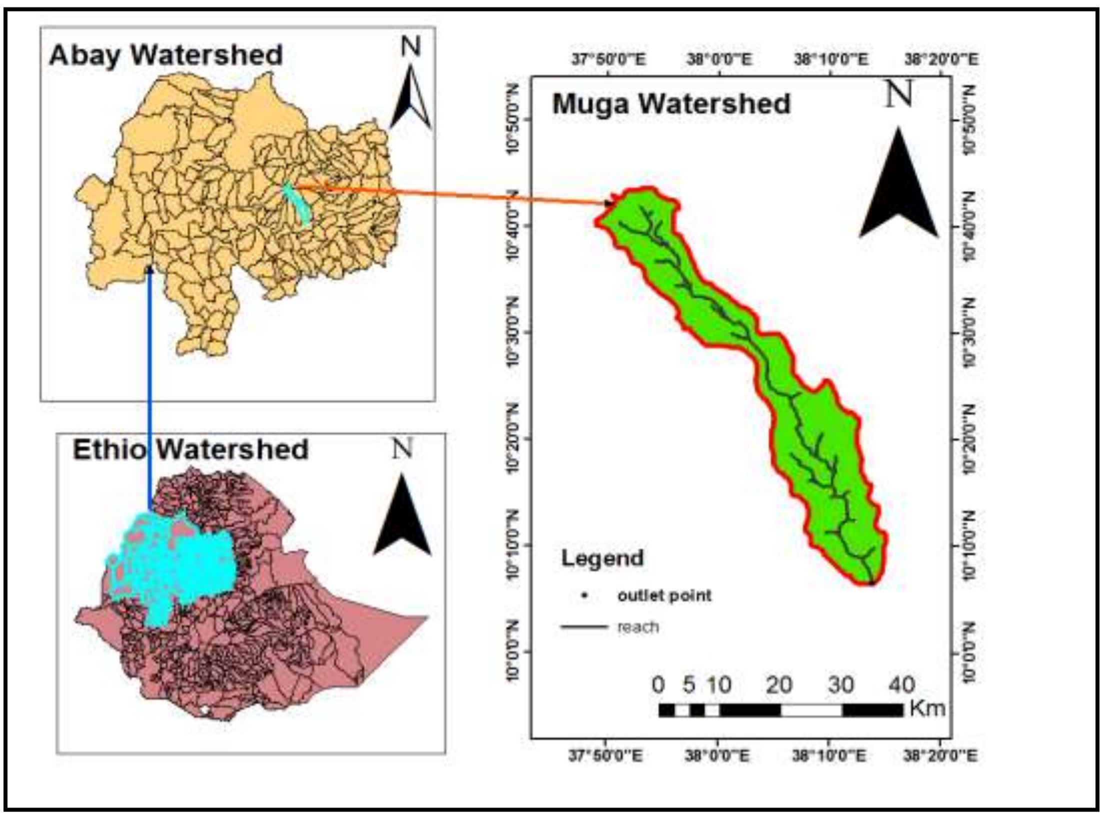


Figure 3.1.Location map of the study area

3.1.2. Topography

Topography is a major factor affecting irrigation, particularly surface irrigation. It influences drainage, erosion, irrigation efficiency, cost of land development, size and shape of fields' labors requirements, range of possible crops, etc. The elevation of the study area is extends from 1045 to 4094m above mean see level.

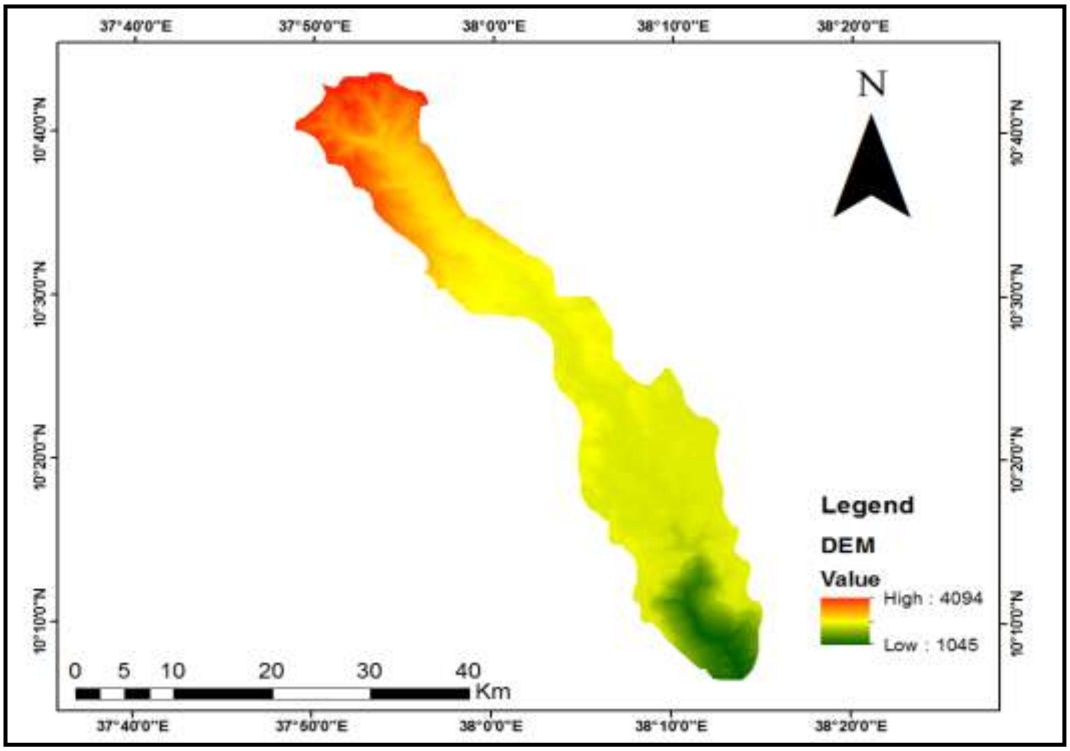


Figure 3.2.Elevation map of Muga watershed

3.1.3. Climate

Temperature and rainfall are the most important elements in characterizing the climatic condition of a given region. The study areas have mean annual rainfall of 1445 mm, and The Monthly mean maximum temperature is varying from 19.8°C in July and 25.6 °C in March and monthly mean minimum temperature varies from 7.7 °C to 11.9°C in December and April Respectively. Average monthly maximum and minimum Temperature for each station from 1990-2015 can be seen in Appendix table 5. The average maximum and minimum annual precipitation of Muga watershed is vary from 2000 to 800 respectively. Average maximum and minimum monthly precipitation is varying from 300.2 mm and 12.2 mm respectively. As shown below in the figure maximum and minimum precipitation was record in Dejen and Motta station in July and February respectively. Average maximum and minimum annual precipitation of each station is shown in the Appendix table.

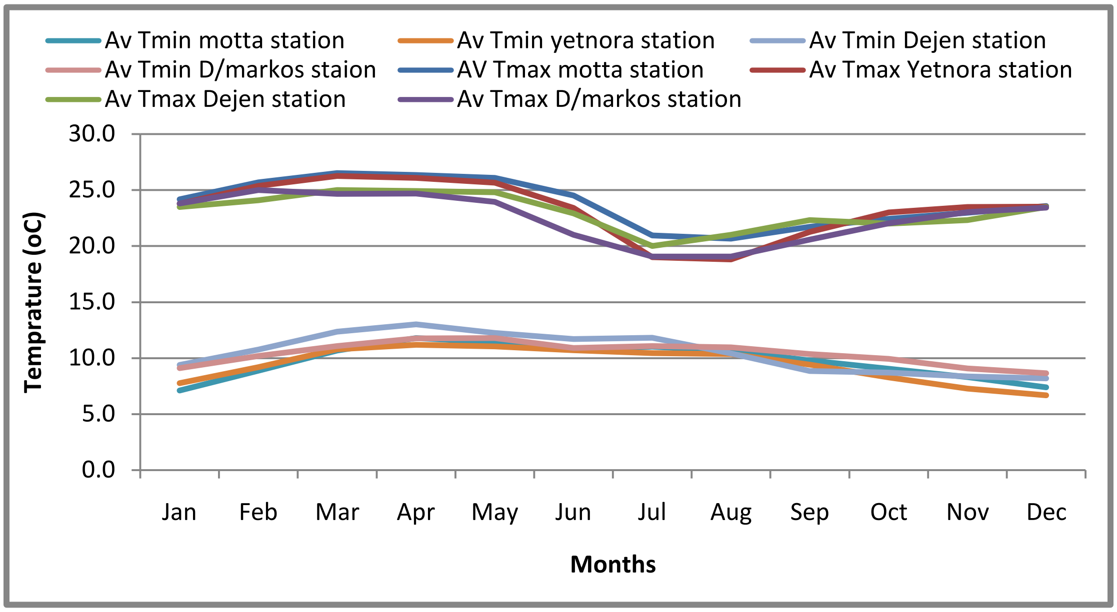


Figure 3. 3.average monthly maximum and minimum temperature

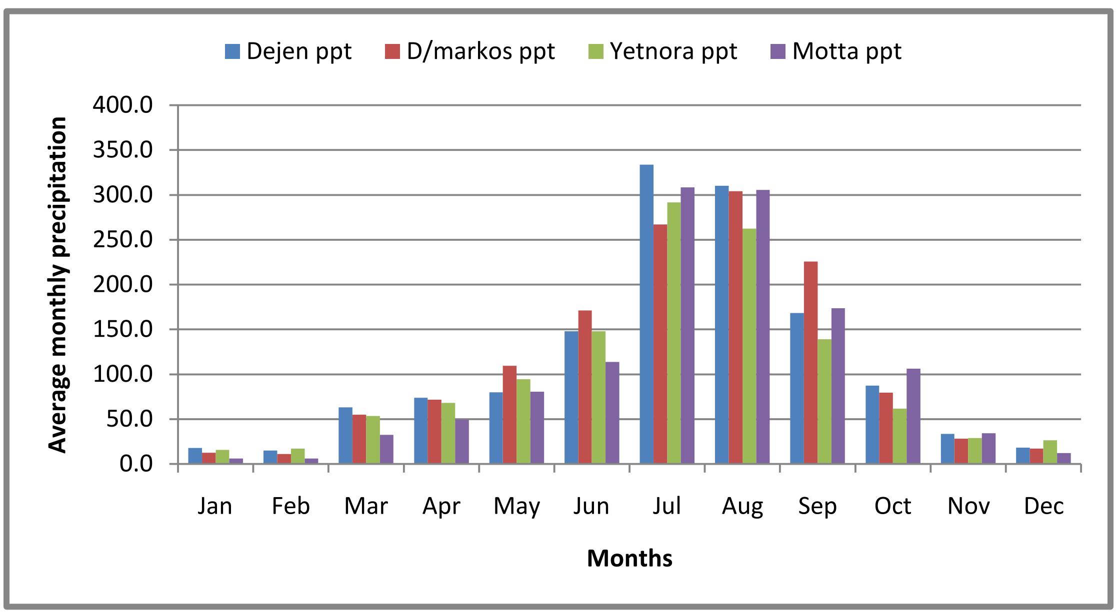


Figure 3. 4.average monthly precipitation

The monthly rainfall distributions of the stations in and around the study area indicate that June, July, August and September are the wettest months of the year in all the selected stations.

3.1.4. Soil

There are eight major soil groups in the Muga watershed. From these Eutric Vertisols covers the largest area (48.74%) and Urban covers the smallest area (0.06 %). The soil type was taken as one input to develop irrigation suitability map for the basin. Because irrespective of their depth, texture, drainage and other soil characteristics all types of soils are not suitable for crop production through irrigation.

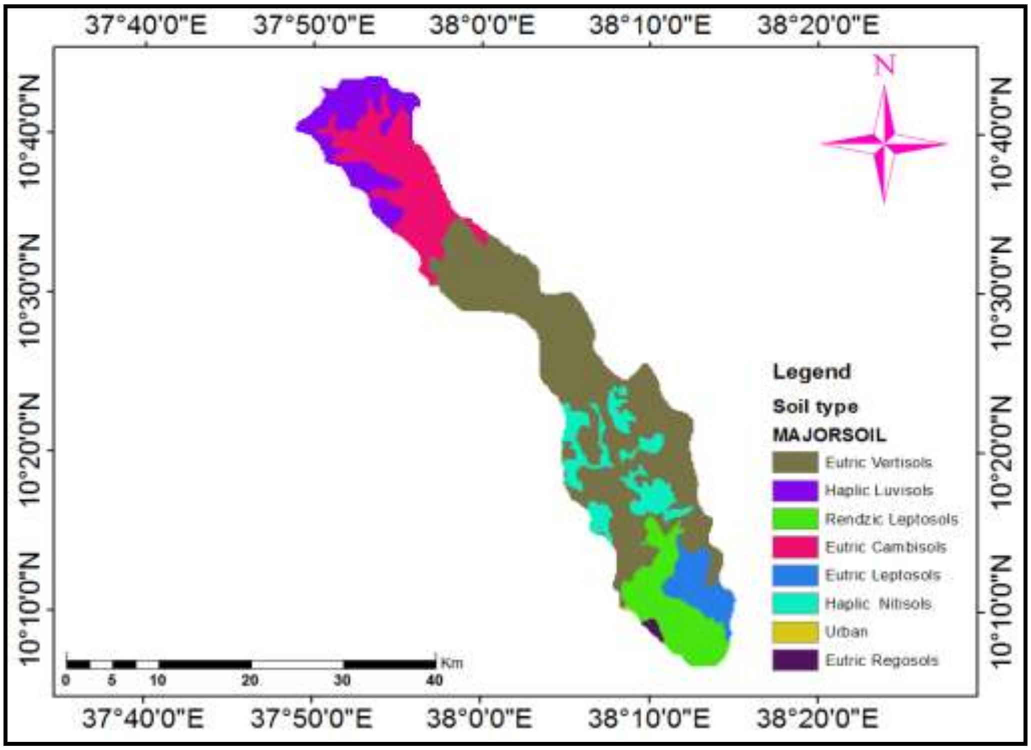


Figure 3. 5.soil map of the study area

3.1.5. Land use/ cover

Muga watershed has eleven types of land use/cover such as Woodland, wetland, Sparse Forest, perennial Crop, Open Shrub, Lava Field, Dense Forest, Closed Shrub, Closed Grass, Bare Soil, and Annual Crop. Each of these cover types are tremendously influenced by properties of land forms, soils and climate as elsewhere in Ethiopia. From this land use/cover; Annual crop is the most dominant.

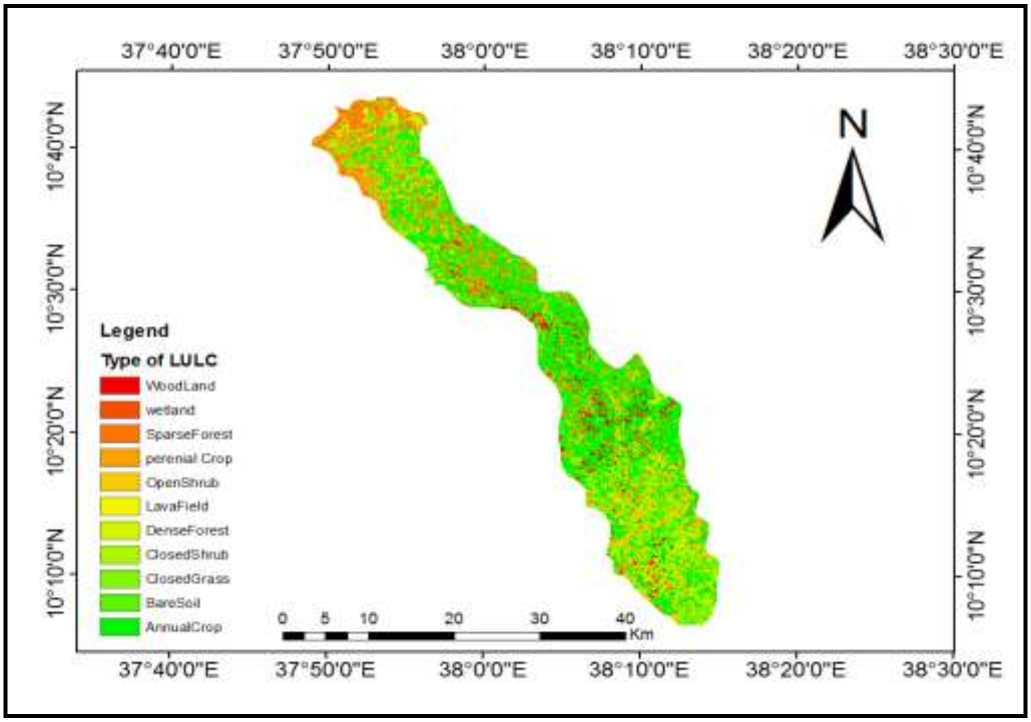


Figure 3.6.Land use land cover map

3.2. Materials used

Materials that used for this study include CROPWAT8.0, Arc GIS10.4.1, Global Mapper12, Micro soft word and Microsoft excel.

Arc GIS 10.4.1; Geographical information system is an information system focusing on the collection, modeling, management, display and interpretation of geographical data.

Dem (digital elevation model): This data was obtained from Ethiopian mapping Agency with resolution of 20m by 20m dem. this digital elevation model which is an input data for ArcGIS to delineate watershed to derive slope map of the study area, drainage condition/flow direction and check suitability analysis for surface irrigation.

Microsoft Word and Microsoft Excel were used for writing and preparation of the report.

Global Mapper12; for organize and configure the projection system of digital elevation model.

3.3. Methodology

3.3.1. Methods of data collection

Primary or secondary data is very important for any researcher to successes their objective. So, to quantify the amount of available water and land resource potential for irrigation the following Secondary data has been collected from any responsible organization. On this study, only secondary data was collected from MoWIE, NMSA, MoA, and EMA. The required data for this study includes Digital Elevation Model (DEM), land use/land cover data, and soil data, weather data; Meteorological data and stream flow data and the data was collected by using the following methods Field visit, inspection and observation, Internet and library, Downloading DEM, Google earth and soil type data.

1. Meteorological data

Meteorological data such as precipitation temperature wind speed, sunshine were collected from National meteorological service agency (NMSA). These data have been used to quantify crop water requirement of some selected crops using cropwat8.0 software. This software uses the Climate data (Mean daily hours of sunshine, (hours/day), Mean monthly wind speed (m/s),Monthly precipitation (mm), Mean monthly maximum and minimum temperatures, mean monthly precipitation (mm), and agronomic data as an input data for estimation of irrigation water demand.

2. Agronomic data, the data was collected from Agriculture development office in East Gojjam Zone. Agronomic data include types of crop, cropping pattern (planting date, growth length, (early stage, medium stage development stage and late stage) in days.

3. Stream flow data: Discharge of the gauge station has been collected from hydrology department minister of water, irrigation and electricity (MoWIE). This data is very critical to assess the available water potential for the site to meet the objective.

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

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

Table 3.1.Important data inputs and sources

Data Type	Source
SRTM- DEM	Amhara design and supervision work enterprise
Land cover data of 2013	EMA (Ethiopian Mapping Agency)
Metrological Data	NMSA(National Metrological Service Agency)
Soil Data	Ethiopian ministry of Agriculture
Stream Flow	MoWIE, Hydrology department

3.3.2. Data pre- processing and checking

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

3.3.2.1. Estimation of missing data

The goal of any filling technique is the production of a complete data set, which may then be analyzed using complete data inferential methods. For example, it may be useful to apply data generation techniques to synthesize or generate hydrological data in cases where 1) there are gaps in the series of observed data 2) the observation period is short and 3) data are not available at the site of interest but in the neighboring region (Patrra, 2000).

Before conducting any hydrological studies/modeling in any river basin for water resources project planning and management, it is important to make sure that data are correct, sufficient and complete with no missing values (Villazón *et al.*, 2010). Errors resulting from lack of appropriate data processing are serious because they can lead to wrong conclusions (Wong *et al.*, 2012). Some of the techniques which are used to estimate missing rainfall data are the normal ratio method, arithmetic mean, inverse distance method, areal precipitation ration method multiple regression analysis methods and using datasets from other selected stations in the surrounding and applying appropriate spatial interpolation methods (Ramos *et al*., 2008). In this study missing rainfall data was estimated using normal ratio method which is recommended to estimate missing data in regions where annual rainfall among stations differ by more than 10% (Dingman, 2002). This approach enables an estimation of missing rainfall data by weighting the observation at N gauges by their respective annual average rainfall values as expressed by equation 3.1 (Yemane, 2004). Thus missing rainfall data analysis was conducted for each station to fill the missed rainfall data's from the neighboring rain gauge stations having complete data set. In this study area missing data in the four considered stations i.e., Debre markos,Dejen,Yetnora and Motto gauge stations were executed by using normal ratio method (Equation 3.1) which was recommended to estimate missing data in regions where annual rainfall among stations differed by more than 10% (Dingman, 2002).

$$Px = \frac{1}{N}\left(\sum \frac{PX}{Pi} * Pg\right) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad 3.1$$

Where:

Px = missing data,

PX = the annual average precipitation at the gauge with the missing data,

Pi = annual average values of neighboring stations

Pg = monthly rain fall data in station for the same month of missing station

N = the total number of gages under consideration

3.3.2.2. Checking the Consistency of Rainfall Data

Spatially consistent historical records are required for various hydrological applications. However, several non-climatic factors could affect the spatial consistency of records at a given station. They may include damage and replacement of a rain gauge, change in the gauge location, growth of high vegetation or construction of a building around the station, change in measurement procedure, or human and instrumental errors in taking readings. In this study Commonly used data consistency checking method, the double mass analysis was used to check the spatial consistency of the rainfall data as it has got wider applications in hydrological areas and is considered to be reliable (Dingman, 2002). The method assumes that stations have regional consistency over long time period. Inconsistency is detected by plotting accumulated annual rainfall of reference stations against accumulated annual rainfall of the evaluation station and inspecting for abrupt changes in slope. Slope changes are considered to be significant if they persist for at least five years (Dingman, 2002).

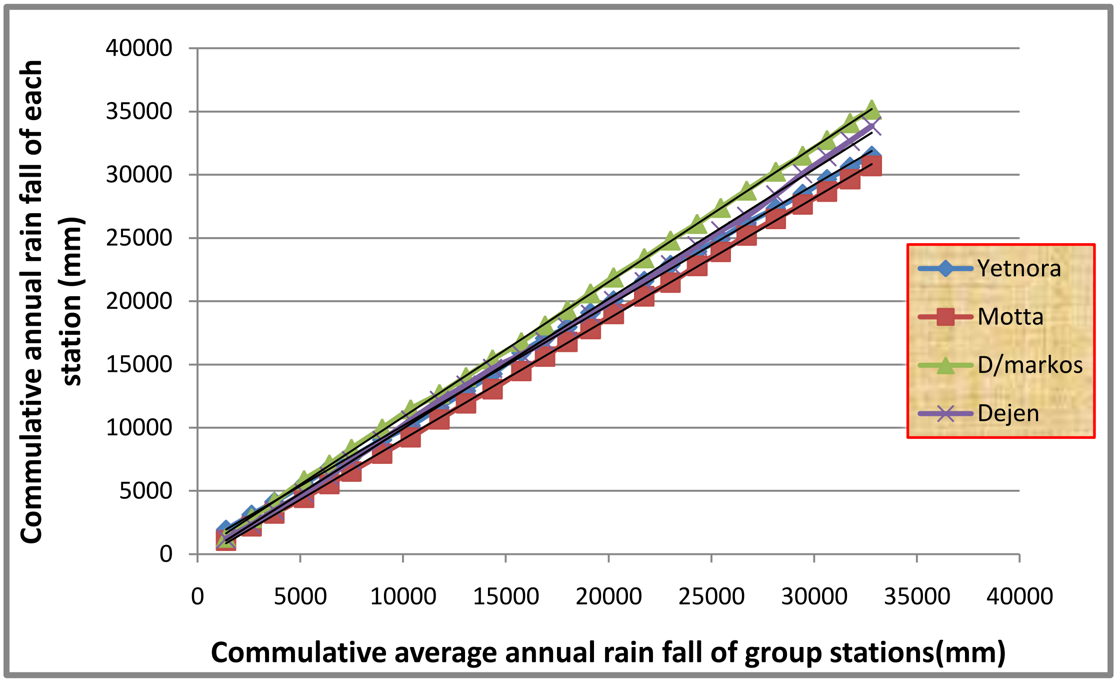


Figure 3.7.DMC of all four rain fall station

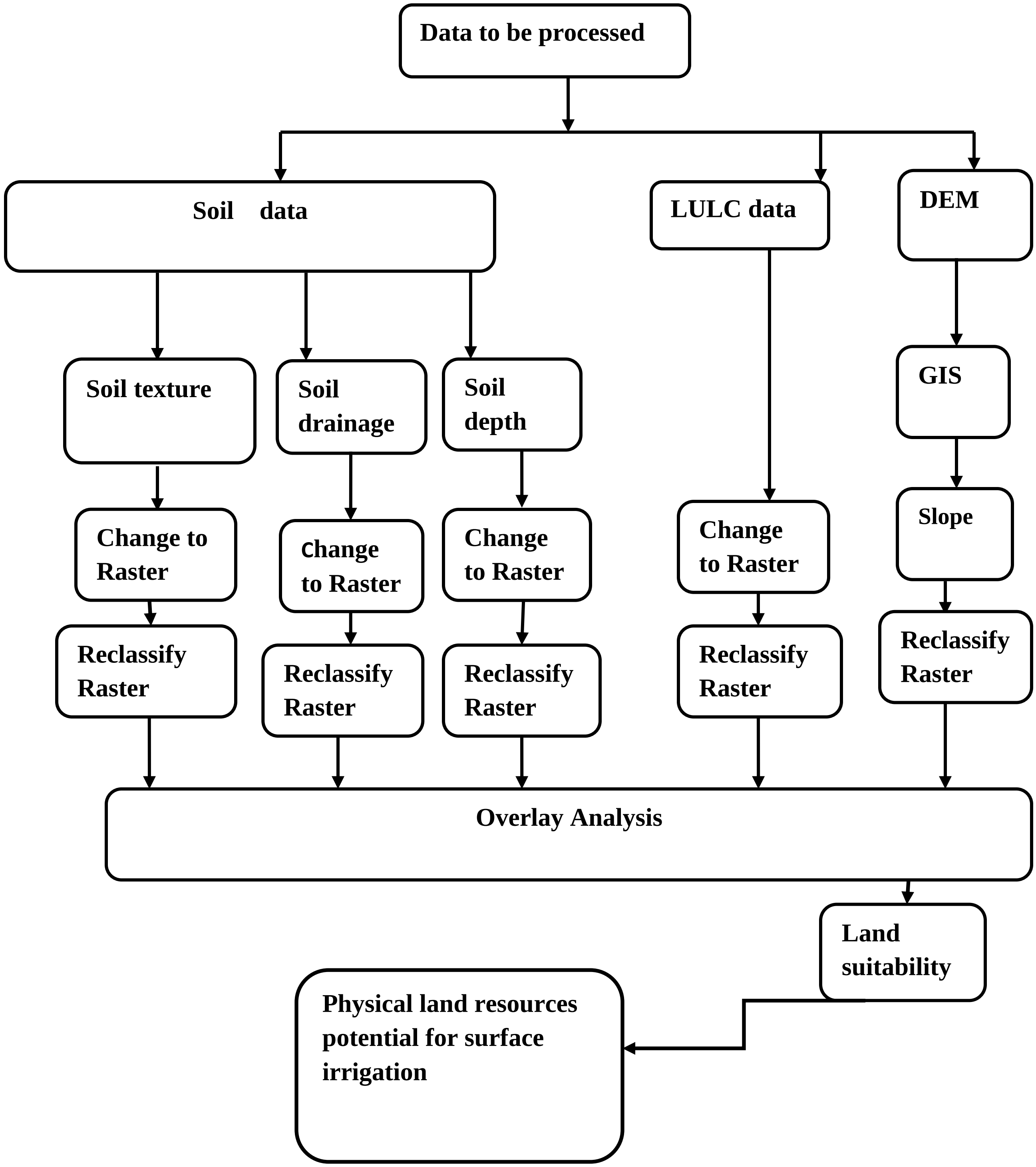


Figure 3.8.Conceptual frame work of the study

3.4. Assessment of irrigable area

Identification of suitable sites for surface irrigation was carried out by considering the suitable slope, suitable soil and land cover/use. The individual suitability of each factor were first analyzed and finally weighted to get potential irrigable sites. This procedure is discussed as follows.

3.4.1. Slope Suitability Assessment

As it was mentioned earlier, slope gradient has great impact on work efficiency, erosion control practices and crop adaptability. First Rating factors were given for each slope gradient of the study area based on literature review and FAO guidelines. Using this rating the basin was reclassified in to four classes according to its land qualities and characteristics of the slope for the selection of the land for suitability of surface irrigation. The classes include very suitable (S1), suitable (S2), marginally suitable (S3), and not suitable (N). This type of land classification is very common and widely used in many researches and also recommended by FAO guidelines.

To derive slope suitability maps of the study area, digital elevation model of the area was clipped from DEM obtained from Amhara design and supervision work enterprise with 20 meter resolution by masking layer of the study area. Then slope maps of the study area were derived using the “Spatial Analysis tool” in 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 classified raster data layers were then converted to feature (vector) data layers using the conversion tools in the arc tool box. Further areas of each parcel of land with different slope class were calculated in the attribute table of the slope shape file.

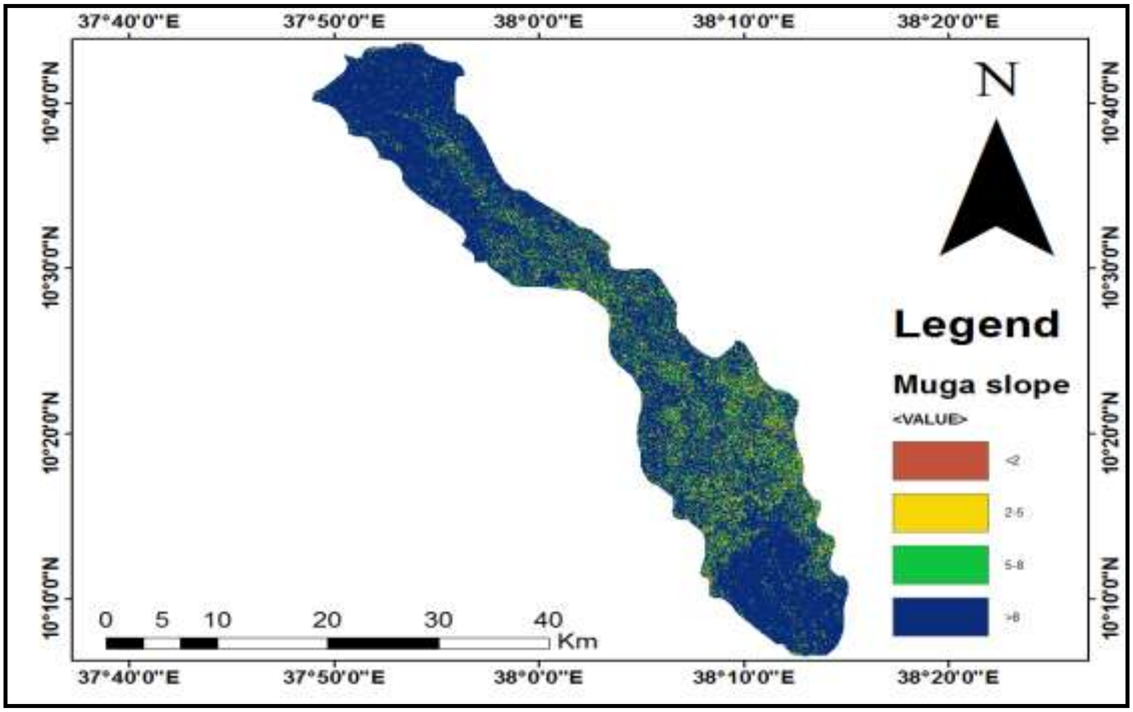


Figure 3.8.Slope map of the study area

Table 3.2.Slope range from irrigated land

Slope (%)	Factor of rating
0-2	Highly suitable(S1)
2-5	Moderately Suitable(S2)
5-8	Marginally Suitable(S3)
>8	Marginally not Suitable(S4)

(Source: FAO, 1996)

3.4.2. Soil Suitability Assessment

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 considered not suitable for surface irrigation could be suitable for sprinkler irrigation or micro-irrigation and selected land utilization types. Several soil characteristics must be evaluated to determine soil suitability for irrigation.

The basic physical parameters of the soils in the watershed are texture, depth and drainage classes were used in the suitability analysis. The following soil suitability ratings were used based on FAO guidelines for land evaluation (FAO, 1991) and FAO land and water bulletin (FAO, 1997).

Table 3.3.Soil suitability factor for irrigation suitability

Factors	Factor rating			
Suitability class	S1	S2	S3	N
Depth(cm)	>100	80-100	50-80	<50
Texture	C	Si-CL,CL-C	SL	Course sand
drainage class	W	M	I	P

(Source: FAO, 1991).

The soil vector layer was converted into a raster layer using conversion tools in the Arc tool box of Arc GIS. The rasterized soil map of the study area was then reclassified based on texture, depth and drainage classes. In the way of weight overlay tool in spatial analyst tool (Arc GIS version Spatial analyst > overlay > weighted overlay analysis) of these factors were executed to determine their suitability for surface irrigation. The new values were given based on a common evaluation scale from 1 to 4 available in the weighted overlay analysis. A value 1 represents highly suitable, 2 for moderately suitable, 3 for marginally suitable and 4 for not suitable classes.

3.4.2.1. Soil Texture

Soil texture is relative proportion of sand, silt and clay in the soil and it is one of the physical characteristics of soil that affects infiltration rate and water holding capacity of soil. Fine texture soil is high water holding capacity and low infiltration rate and course texture soil is low water holding capacity with high infiltration rate. The infiltration rate may influence selection of the irrigation method, length of irrigation runs, field size, irrigation development costs, and crop selection. Fine-textured soils will have higher available moisture than coarser-textured soils. However, soils with extremely high clay content may actually have less available water than medium-textured soils (Hailegebriel, 2007). According to FAO (1999) guidelines for soil evaluation, the soil texture of the study area was evaluated and classified in to Clay, Loam, Sandy loam, Silt loam, Clay loam and Sand clay and their distribution in the study area were mapped on figure 3.9.

Table 3.4.Soil texture and their classes

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

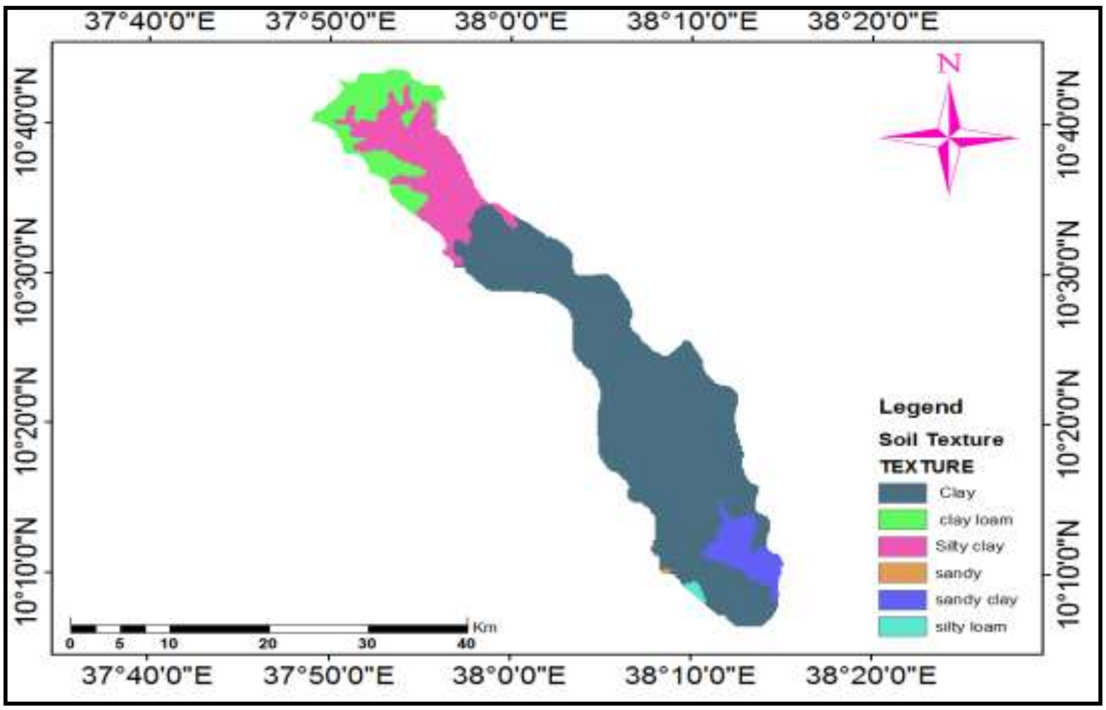


Figure.3.9.Soil texture map

3.4.2.2. Soil Drainage

Soil drainage permits normal plant growth. Evaluation of the soil drainage requirement is a critical element in selecting land for irrigation, particularly with diversified upland crop production (FAO, 1997). Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. Soil permeability of water is one of the major factors that determine crop production. Based on its soil permeability of water in the study area, the study area was classified in to well, moderate, imperfect drained and poorly drained (Fig 3.10). To assess soil suitability for irrigation soil map obtained from ministry of agriculture was used.

Table 3.5.Factor rating for suitability of soil drainage

Factor	Factor rating			
	S1	S2	S3	N
Drainage	Well drained	Moderately drained	Imperfectly drained	Poorly drained

Sources FAO, 1997

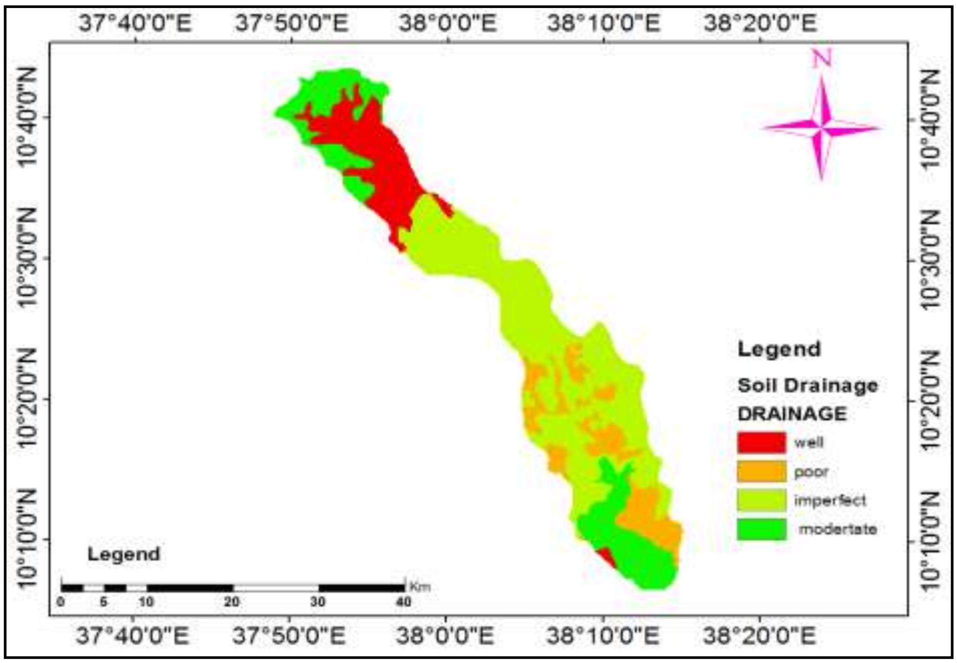


Figure 3.10.Soil drainage map

3.4.2.3. Soil Depth

The thickness of the soil materials, which give structural support, nutrients and water for crops, is referred as soil depth. A soil depth variation from place to place determines the growth of plants and also affects the growing of plant roots. Soil depth, which is needed by crops for optimum root growth, is called effective soil depth. The required effective soil depth for crops is varied based on their requirements (Hailegebriel, 2007).Rating factor was given for the values of depth and weighting them to evaluate the suitability of surface (gravity) irrigation potential of the study area. Rating factor was adopted from FAO guidelines FAO (1991) table 3.6. Based on the weighting factors for each soil depth of the study area, soil depth suitability map of the study area for surface irrigation potential was developed figure 3.11.

Table 3.6.Factor rating for suitability of soil depth

Factor	Factor rating			
	S1	S2	S3	N
Soil depth	>100	80-100	50-80	<50

(Source: FAO, 1991)

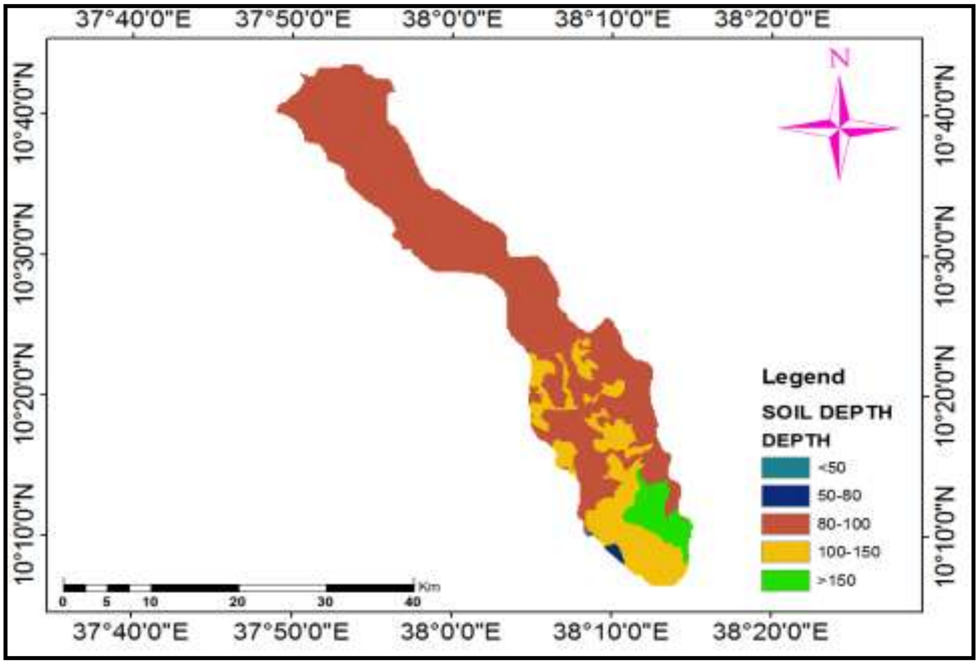


Figure 3. 11.Soil depth map

3.4.3. Land Use Land Cover Suitability Assessment

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

The land cover in the Muga watershed is represented by cultivated lands, natural vegetation and built-up areas. Each of these cover types are tremendously influenced by properties of land forms, soils and climate as elsewhere in Ethiopia. The natural vegetation cover especially the forest land is encroached by cultivated fields as a result of high population growth followed by peoples and the government preferences for food and export crops in order to alleviate the prevailing food and employment insecurity (MoWIE, 2002).

Table 3.7.Land covers evaluation criteria description

Category	Name	Description of LULC types
S1	Highly Suitable	✓ Cultivated……Dominantly, Moderately
S2	Moderately Suitable	✓ Shrub land ✓ Grassland…… Open
S3	Marginally Suitable	✓ Seasonally Wet & swamp area ✓ Forest ………...Open ✓ Bush land……. Dense
N	Not suitable	✓ Wood land……Dense ✓ Bamboo ✓ Urban area ✓ water bodies ✓ Lava field

(Source: FAO, 1996)

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

3.5.1. Applying MCE and Assigning weight of factors

To determine relative importance/weight of criteria and sub criteria, AHP method of MCE was used. In order to compute the weights for the criteria and sub-criteria, a pair wise comparison matrix (PWCM) was constructed, each factor was compared with the other factors, relative to its importance, on a scale from 1/9 to 9 introduced by (Saaty, 2008). Once the pair wise matrix is made, Saaty’s method of Eigen vectors/relative weights is calculated.AHP identifies and takes into account the inconsistencies of the decision makers which is one of the strength (Saaty, 2008).

Table 3.8.Saaty rating scale

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

(Source: Saaty, 1980)

The diagonal elements of PWCM are assigned the value of unity (i.e., when a factor is compared with itself).Since the matrix is symmetrical, only the lower triangular half actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half (Murage, 2013). The weight for each criterion was calculated through PWCM by determining the approximate eigenvector. In order to determine which criteria (and at what levels or weights) affect to land evaluation for agriculture; experts are consulted to provide judgments on important of criteria. Using Analytical Hierarchy Process technique these judgments on important of criteria are converted to criteria weights (Wi). Score for each criterion (Xi) on each sample point is then determined. The AHP is developed by Saaty (1980). The principles utilized in AHP to solve problems are to construct hierarchies. The hierarchy allows for the assessment of the contribution individual criterion at lower levels make to criterion at higher levels of the hierarchy.

The pair-wise comparisons of various criteria were organized into a square matrix. The diagonal elements of the matrix were 1. The principal Eigen value and the corresponding normalized right eigenvector of the comparison matrix gave the relative importance of the criteria being compared. The elements of the normalized eigenvector were weighted with respect to the criteria or sub-criteria and rated with respect to the alternatives (Bhushan and Rai, 2004).When performing pair wise comparison, some inconsistencies may typically arise. The AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision maker. In the AHP, the pair wise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (CR) is less than 10% (Triantaphyllou and Mann, 1995). To calculate CR, the consistency index (CI) is estimated by multiplying judgment matrix by the approximated eigenvector. Each component of the resulting matrix is then divided by the corresponding approximated eigenvector. This yields an approximation of the maximum Eigen value (λ_{max}). Then, the CI value is calculated by using the formula:

$$CI = \frac{\lambda \text{max} - \text{n}}{\text{n} - 1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{3.2}$$

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

Table 3.9.Random consistency index

N	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

(Sources: Saaty, 1980)

3.5.2. Standardization

All the criteria are in different unit's so to perform weighted overlay they need to be in same units and hence needed to be standardized. Standardization makes the measurement units uniform, and the scores lose their dimension along with their measurement unit (Malczewski and Rinner, 2005).Vector layers were converted to raster further which were reclassified for the input to the weighted overlay which finally gave the suitability map. Reclassify tool in spatial analyst in ArcGIS standardizes the value of all criteria for comparison.

Pair wise technique was used for standardizing the factors. Ratings were given for all factors on a 9-point continuous scale (Table 3.9). For example, if one feels that proximity to slope gradient is very strongly more important than soil texture in determining physical land suitability for surface irrigation, one will enter a 7 on this scale. If the inverse is the case (soil texture was very strongly more important than slope gradient), one will enter 1/7. But the value given for the factors was based on requirements of surface (gravity) irrigation and reviewed from different literature.

3.5.3. Creating a new model

To find suitable site for surface irrigation, a suitability model was created using model builder in Arc tools box and tools from spatial analysis tool sets. Then, after their individual Suitability was assessed, the irrigation suitability factors which were considered in this study were used as the input for irrigation suitability model to find the most suitable land for surface irrigation a toolbox was initially created to hold the model, after which a model was created to perform spatial analyst tasks. A model was built by stringing tools together in model builder.

After the criteria weights were appointed to the related layers in the ArcGIS 10.4 environment, raster maps were overlaid using the weighted overlay analysis and an agricultural land suitability map was generated. The weights of the criteria were multiplied with the score of the sub criteria this multiplication was performed in raster format on the map using Raster Calculator in GIS operation. The result was then reclassified as four classes of suitability [2]: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N), according to the following formula (Khan, 2014).

$$S=\sum W_i X_j \qquad 3.3$$

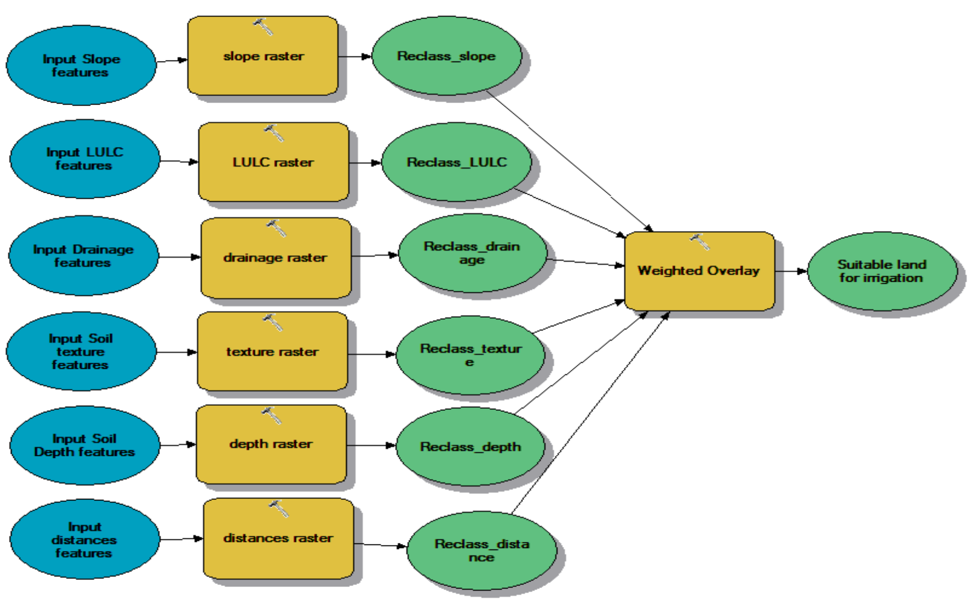


Figure 3. 12.A tool box suitability model

3.6. Determination of crop water requirements

The crop water requirement (CWR) is calculated as a product of the potential Evapotranspiration (ETo) and the crop coefficient (Kc) (*Allen et al., 1998)*.

$ET_c=K_c*ET_o$……………………………………………………………………3.4

Where, ETo is crop water requirement for the growing period, Kc is crop coefficient for crop, ET_o is Reference crop Evapotranspiration.

3.6.1. Reference crop Evapo-transpiration (ET_o)

The Evapo-transpiration rate from a reference surface, not short of water, is called the Reference crop Evapo-transpiration or reference Evapo-transpiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions. The concept of the reference Evapo-transpiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference Evapo-transpiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors (FAO, 2006).

ETo can be computed from meteorological data. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the sole standard method for the definition and computation of the reference Evapotranspiration. The FAO Penman-Monteith method requires radiation, air temperature, air humidity and wind speed data. Calculation procedures to derive climatic parameters from meteorological data and to estimate missing meteorological variables required for calculating ETo. The FAO Penman-Monteith method has been developed by unambiguously defining the reference surface as a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m and an albedo of 0.23' (FAO, 1998). The reference surface closely resembles an extensive surface of green grass that is of uniform height, actively growing, completely shading the ground and adequately watered. The Penman Monteith Equation is given as below (FAO, 1998).

$$\mathrm{ETo} = \frac{0.408\,\Delta\,(\mathrm{R_n} - \mathrm{G}) + \gamma\,\frac{900}{\mathrm{T} + 273}\,\mathrm{u_2}\,(\mathrm{e_s} - \mathrm{e_a})}{\Delta + \gamma(1 + 0.34\,\mathrm{U_2})} \ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

Where: ET_o Reference Evapotranspiration (mm); R_n= Net radiation at the crop surface (MJ/ m^2 Per day); G= Soil heat flux density (MJ/m^2 per day);T = Mean daily air temperature at 2 m Height (°C); u_2 = Wind speed at 2 m height (m/sec); e_s = Saturation vapor pressure (kPa); e_a =Actual vapor pressure (kPa); e_s - e_a = Saturation vapor pressure deficit (kPa); Δ = Slope of Saturation vapor pressure curve at temperature T (kPa/°C); γ = Psychometric constant(kPa/°C).The equation uses standard climatologically records of solar radiation (sunshine), air Temperature, humidity and wind speed for daily, weekly, ten-day or monthly calculations.

3.6.2. Net Irrigation Water Requirement (NIWR)

Irrigation water requirements (IWR) refer to the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirements. If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement (FAO, 2002).

$$\mathrm{NIR} = \mathrm{CWR} - \mathrm{P_{eff}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where, NIR is Irrigation Water Requirement, CWR is crop water requirement for the growing period, Peff is effective rainfall.

3.6.3. Effective rainfall.

The rain water retained in the root zone can be used by the plants and represents what is called the effective rainfall. The effective rainfall is, therefore, the difference between the total rainfall and the losses (Runoff, evaporation and deep percolation).

The fraction of effective rainfall depends on the climate, soil texture, soil structure and depth of the root zone. There are various approaches that can be used to estimate the effective rainfall from the total monthly rainfall. However, the following formula was developed by FAO based on analysis carried out for different arid and sub-humid climates and is more suitable for Ethiopia.(FAO,2002). Effective rainfall was calculated according to FAO/AGLW formula (Smith, 1992).

$P_e = 0.6\, P_{mon} - 10$ for $P_{mon} < 70$ mm…..3.7

$P_e = 0.8\, P_{mon} - 24$ for $P_{mon} > 70$ mm…..3.8

Where: Pe = Monthly effective rainfall (mm),Pmon = Monthly rainfall (mm).

3.6.4. Gross Irrigation Water Requirement (GIR)

The gross irrigation water requirement accounts the losses of water incurred during conveyance, distribution and application to the field. it is defined as the net irrigation water requirement, plus conveyance losses between the source of the water and the field, plus any additional water for leaching over and above percolation (FAO, 2002).

$$GIR = \frac{NIR}{\eta} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \; 3.9$$

Where GIR = Gross Irrigation Water Requirement, NIR= Net Irrigation Water Requirement and $\boldsymbol{\eta}$=efficiency.

Finally the effective irrigable area can be estimated in each month using the following equation.

$$X = \frac{Ac * Eff * \min flow}{GIWR} \ldots \ldots \ldots . \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \; 3.10$$

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

4. RESULTS AND DISCUSSIONS

4.1. Slope Suitability

Slope is one parameter to determining surface irrigation development. Resulted from slope analysis in Arc GIS, the slope of the study area was classified in to four suitability classes (S1, S2, S3 and N) based on the FAO (1999) suitability classes. Based on this classification the following result was achieved and shown in table 4.1. The slope of study area was given in percent and the result obtained after the evaluation of Muga watershed shows that 2.26 % of the watershed was less than 2%,7.38% of the watershed was between (2-5)%, 10.55% was between (5-8)% and 79.81 % of the basin greater than 8%.

Table 4. 1.Result of slope suitability of Muga watershed

Slope (%)	Area Coverage		Suitability class	Description
	Ha	%		
0-2	1671.72	2.26	S1	Highly Suitable
2-5	5447.75	7.38	S2	Moderately Suitable
5-8	7785.56	10.55	S3	Marginally Suitable
>8	`58910.85	79.81	N	Not Suitable

The results in Table 4.1 revealed that 20.19 % of the total area of the Muga watershed (covering an area of 14905.03 ha) had been in the range of highly suitable to marginal suitable for surface irrigation whereas the remaining 79.81 % of the area (covering an area of 58910.85 ha) could not be suitable for surface irrigation in terms of work efficiency and erosion control. And the final slope suitability map was developed accordingly as shown on Figure 4.1.

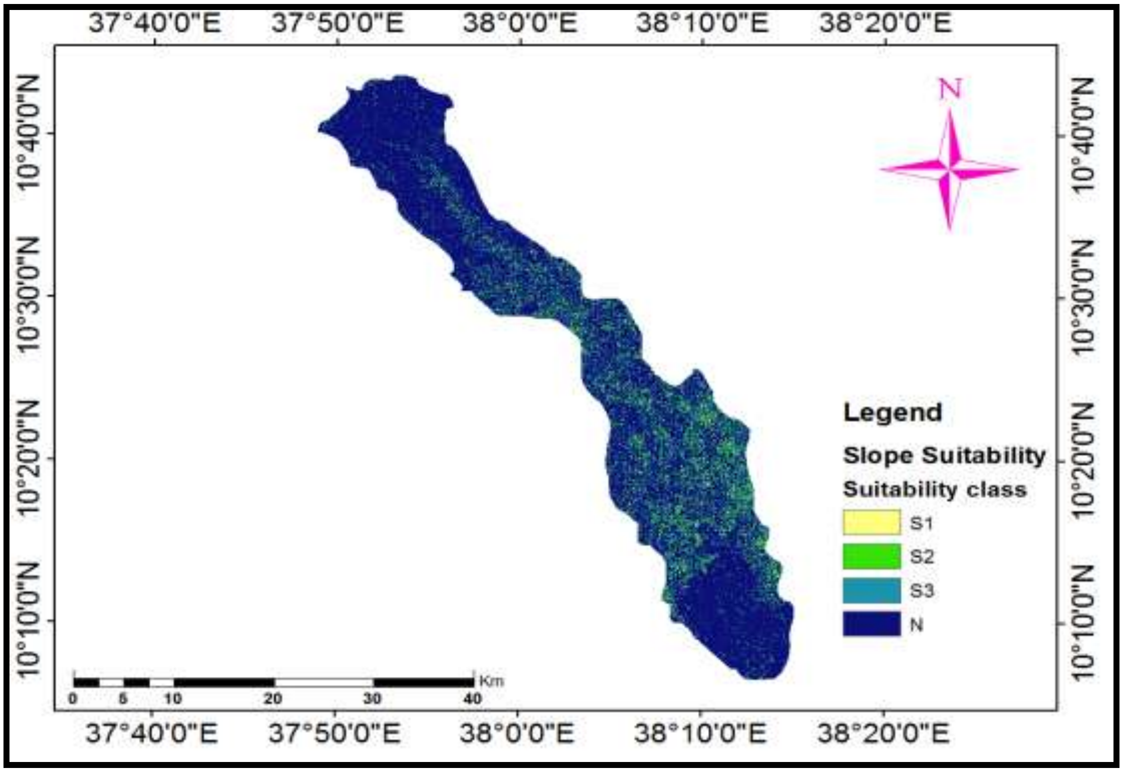


Figure 4. 1.Slope suitability map

4.2 .Soil Suitability

There are a number of soil physical parameters to determine soil suitability analysis, but mainly there are three soil physical properties to evaluate soil suitability in the watershed. These are soil texture, soil depth and soil drainage properties each data's was taken accordingly from FAO standards and general Blue Nile soil master plans to describe in detail as follows.

4.2.1. Soil Drainage

Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. According to FAO evaluation techniques used for evaluation of permeability of soil properties of the land, soil drainage area can be classified as well drained, moderately well drained, imperfectly drained, poorly drained and very poorly drained. The soil texture can determine the permeability of the soil for water in the study area. Therefore the soil drainage properties of the study area was classified in to well, moderately poorly and imperfectly drained (Fig.4.2).

Table 4. 2.Result of drainage suitability on the study area

Soil Drainage	Area coverage		Suitability Classes	Description
	Ha	%		
Well	11758.92	15.93	S1	Highly Suitable
Moderate	15655.24	21.20	S2	Moderately Suitable
Imperfect	10350.88	48.85	S3	Marginally Suitable
Poor	36063.84	14.02	N	Not Suitable

According to this classification, The results in Table above revealed that 15.93 % (11758.92 ha) and 21.20 % (15655.24 ha) of the total area of the Muga watershed had been highly suitable and Moderately suitable for surface irrigation system with respect to soil drainage respectively, whereas the remaining 48.85% (36063.84 Ha) and 14.02% (10350.88Ha) classes in the study area were classified as marginally suitable and not suitable for surface irrigation.

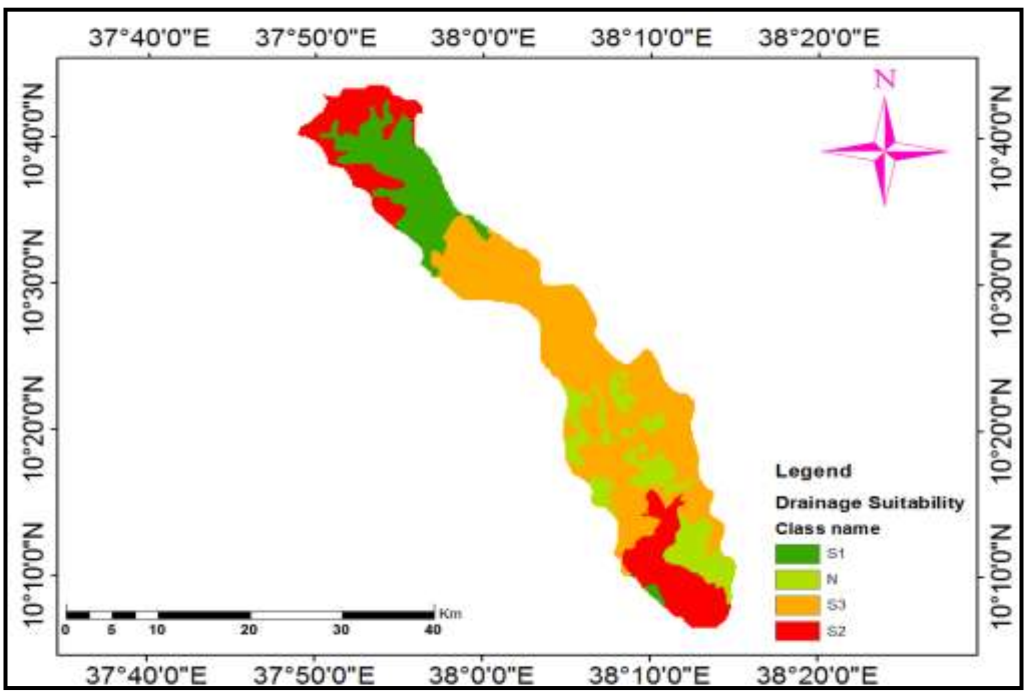


Figure 4.2.Soil drainage suitability map

4.2.2. Soil Depth:

Soil depth is one of the important physical soil parameters used to evaluate soil suitability for surface irrigation development. According to FAO soil depth evaluation techniques the soil depth properties of the Muga watershed was classified as unsuitable, moderately suitable, marginal suitable and highly suitable for surface irrigation .Soil depth class in the study area was found in (Table 4.3) and their distributions in the study area were mapped on Figure4.3.

Table 4. 3.Soil depth and their suitability

Soil Depth	Area coverage		Suitability Classes	Description
	Ha	%		
>100	29801.64	40.37	S1	Highly suitable
80-100	7626.48	10.33	S2	Moderately suitable
50-80	36063.84	48.85	S3	Marginally suitable
<50	336.92	0.46	S4	Not suitable

Resulted from soil analysis in Arc GIS, the soil depth of the study area was classified in to four suitability classes (S1, S2, S3 and N) based on the FAO (1999) suitability classes. As shown in table 4.5. 40.37 % (29801.64 ha) was highly suitable, 10.33 % (7626.48 ha) moderately suitable, 48.85 % (36063.84 ha) marginally suitable and 0.46 % (336.92 ha) Not suitable for surface irrigation.

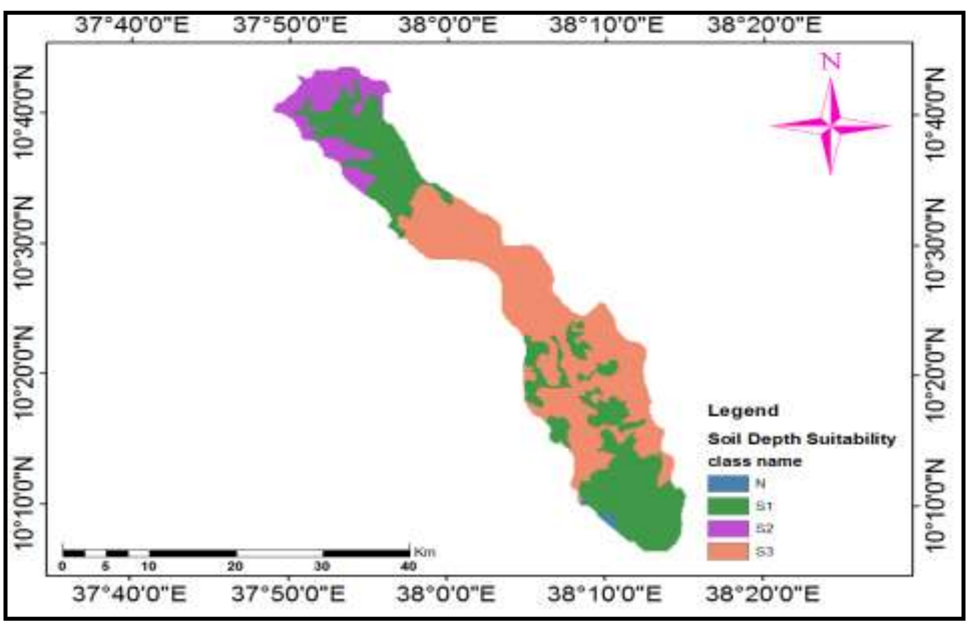


Figure 4. 3.Soil depth suitability map

4.2.3. Soil Texture

Accordingly soil textures suitability map was developed (Figure 4.4) with S1, S2, S3 and N. Soil textural classes such as silt clay and clay soils were classified as highly suitable (S1), whereas clay loam were classified as S2 (moderately suitable), sandy clay soil texture was classified as S3 (marginally suitable) and sandy soil classified as Not suitable for surface irrigation with limiting factor of high infiltration rate.

Table 4.4.Soil texture and their suitability

Soil texture	Area coverage		Suitability class	Description
	Ha	**%**		
Silt clay, clay	61961.08	83.93	S1	Highly suitable
clay loam	7626.48	10.33	S2	Moderately suitable
sandy clay	4193.24	5.68	S3	Marginally suitable
Sandy	48.08	0.07	S4	Not suitable

The soil texture suitability of the study area for the development of surface irrigation system show in (figure 4.4) and area coverage of suitability classes are presented in (table 4.4), indicated that 83.93% (61961.08 ha) is highly suitable, 10.33 % (7626.48 ha) is moderately suitable, 5.68 % (4193.24 ha) is marginally suitable and 0.07 % (48.08 ha) is not suitable for surface irrigation systems. Hence, the majority of the study area is highly suitable to moderately suitable for surface irrigation in terms of soil texture suitability.

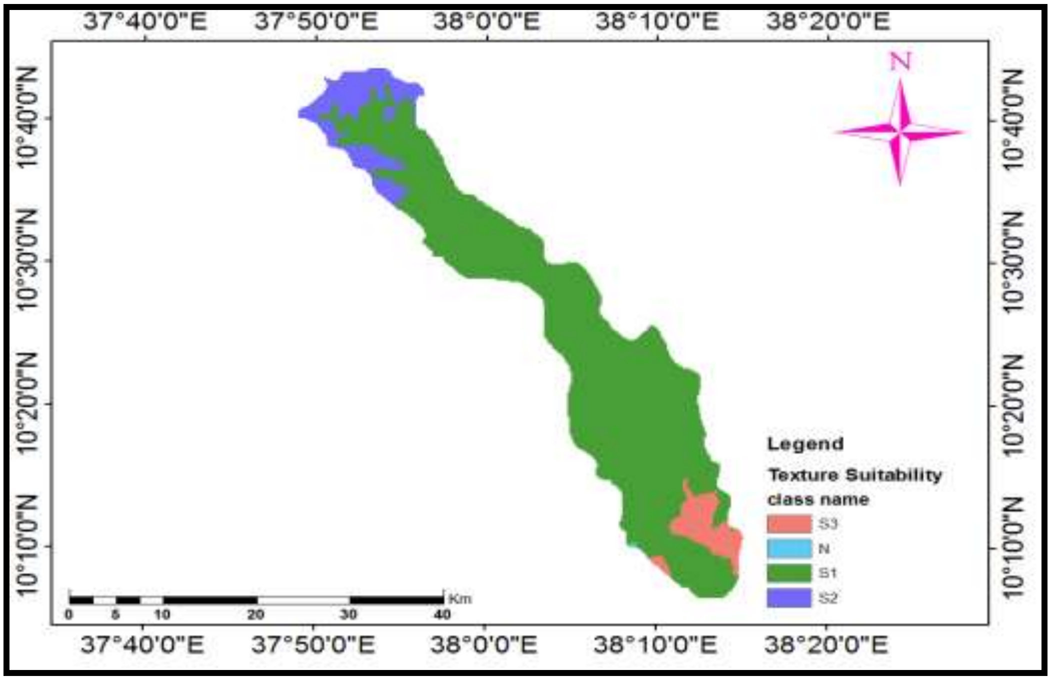


Figure 4. 4.Soil texture suitability map

4.3. Land Use/Cover Suitability

Different land use land covers in the study area were identified and ranked based on their importance for surface irrigation, costs to remove or change for cultivation and environmental impacts under the watershed. After rank was given for the land use types, reclassified map of the study area was developed (Fig.4.5). The land use type was reclassified in to four suitability classes, highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N) Table 4.5.

Table 4. 5.Land use land cover suitability

Land use /cover	Area coverage		Suitability class	Description
	Ha	%		
Cultivated Land	47825.92	64.78	S1	Highly suitable
Grass and shrub land	6728.32	9.11	S2	Moderately suitable
Forest and Bush land	15942.76	21.59	S3	Marginally suitable
Wood land(dense) and Lava field	3335.96	4.52	N	Not suitable

Land use land cover map of the study area shows most of the areas are covered with agricultural lands in almost of all parts of the watershed. So the cultivated or agricultural land covers a higher percentage than the other LU/LC types as indicated in the table. The land use land covers suitability class categorized in four groups. These are: highly suitable which covers 64.78 % (47825.92 Ha) of the total LULC, Moderately suitable 9.11 % (6728.32 ha), marginally suitable class covers 21.59 % (15942.76 ha) and not suitable class covers 4.52 % (3335.96) as shown below in the Map 4.5 and summarized in tabulated form above.

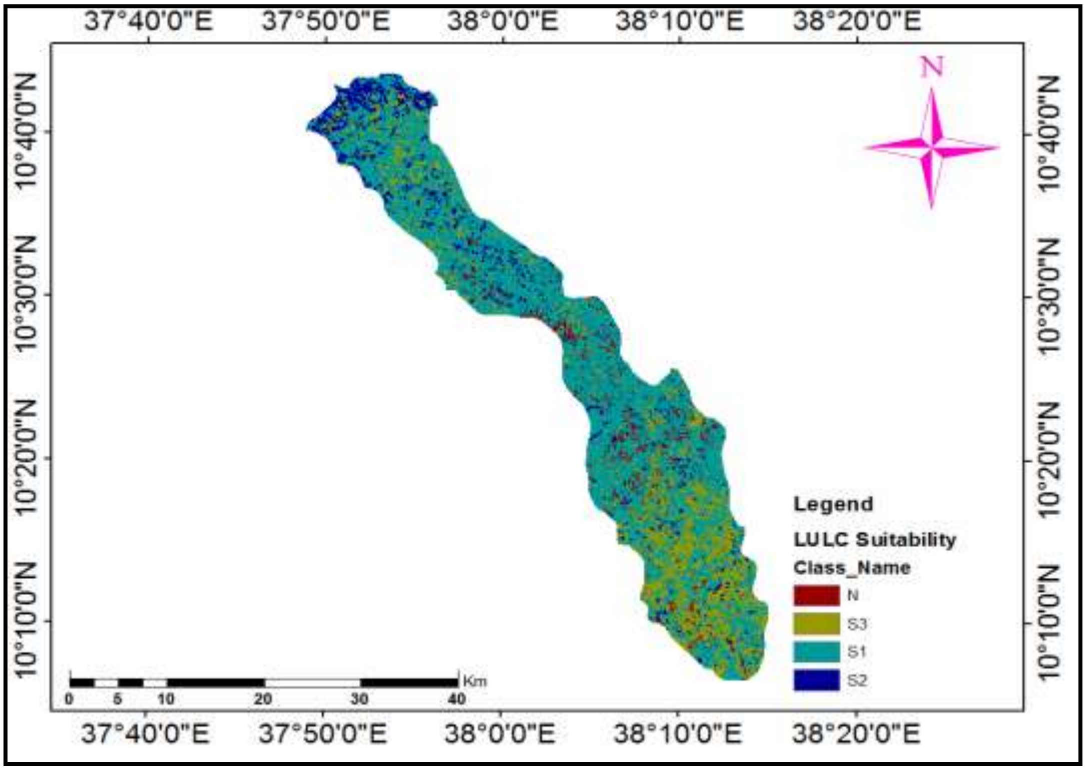


Figure 4. 5.Reclassified land use land cover suitability

4.4. Distance from Water Supply

Determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source be near the center of the irrigated area to minimize the size of the delivery channels and pipelines. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length) and thereby develop the irrigation system economical (Seleshi, 2001). By considering delineated watershed, command areas which were closest to the water supply (Muga River) were classified as high suitable land for irrigation. These areas far away from the water source were classified as not suitable especially for small scale and traditional irrigation. Because of these factors irrigation suitability is decreased as distance increase away from the water source river. The final reclassified result of the distance suitability analysis of the irrigable land was used for weighting overlay for further analysis together with other factors.

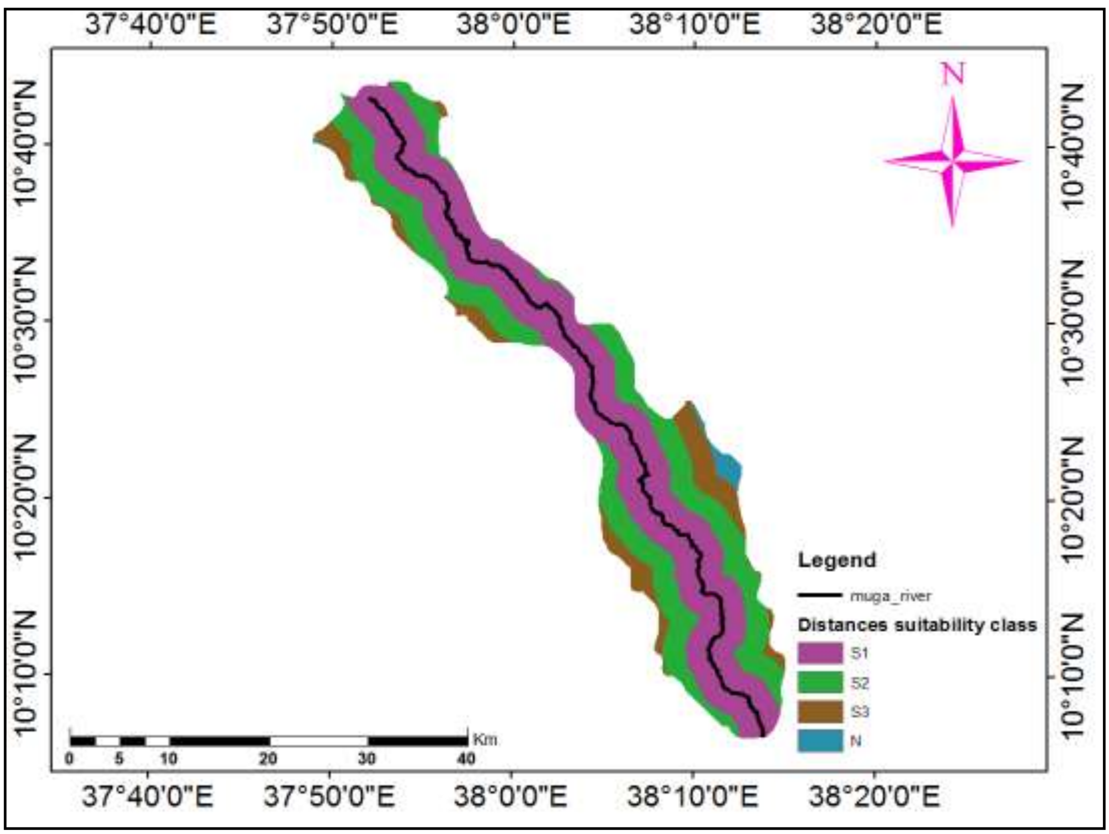


Figure 4. 6.Distances suitability map

The suitability of the study area for the development of surface irrigation system show in (figure4.6) and area coverage of suitability classes are presented in (table 4.6), indicated that 54.13%(39962ha) is highly suitable, 34.01% (25110.64 ha) is moderately suitable, 10.61%(7829.28 ha) is marginally suitable and 1.25% (921.68

ha) is not suitable for surface irrigation systems. Hence, the majority of the study area is highly suitable to marginally suitable for surface irrigation in terms of distance.

Table 4. 6.Distances suitability and their classes

Distance (Km)	Coverage area		Suitability class	Description
	Ha	%		
0.03-2.5	39962.6	54.13	S1	Highly suitable
2.5-5	25110.64	34.01	S2	Moderately suitable
5-7.5	7829.28	10.61	S3	Marginally suitable
>7.5	921.68	1.25	N	Not suitable

4.5. Overall suitability

Land suitability for surface irrigation development was identified by assessing slope, land use/cover, distance from water sources and soil suitability. This identification was done by using Arc GIS model weighted overlay analysis in spatial analysis tool. According to Saaty (1990), cited in (Mendoza, 2008) the analytic hierarchy process derived scales of values for pair wise comparisons, developed pair wise comparison matrix to calculated relative weights. The scoring process was based on relative importance of criterion.

Table 4 .7.Pair wise computation matrix result from scouring for physical irrigation suitability criteria

Factors	Slope	Drainage	Depth	Texture	distance	LULC
Slope	1.000	3.000	3.000	5.000	5.000	5.000
Drainage	0.333	1.000	3.000	3.000	3.000	5.000
Depth	0.333	0.333	1.000	5.000	3.000	3.000
Texture	0.200	0.333	0.200	1.000	0.333	3.000
Distance	0.200	0.333	0.333	3.000	1.000	3.000
LULC	0.200	0.200	0.333	0.333	0.333	1.000

Physical irrigation suitability criteria of the watershed calculated with spreadsheet. Steps (a) and (b) showed calculation of criteria weights. Step (c), (d) and (e) showed calculation of consistency ratio (CR) to evaluate the consistency of the data.

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

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

b) The summation of the normalization matrix in each row is divided by the number of factors and the quotient is the weight of criteria and the result shown in table 4.8

Table 4. 8.Normalized matrix

Factors	Slope	Drainage	Depth	Texture	Distance	LULC	Weight
Slope	0.441	0.577	0.381	0.288	0.395	0.250	0.389
Drainage	0.147	0.192	0.381	0.173	0.237	0.250	0.230
Depth	0.147	0.064	0.127	0.288	0.237	0.150	0.169
Texture	0.088	0.064	0.025	0.058	0.026	0.150	0.069
Distance	0.088	0.064	0.042	0.173	0.079	0.150	0.099
LULC	0.088	0.038	0.042	0.019	0.026	0.050	0.044

The steps followed for the calculation of the consistency ratio as:

c) To compute lambda (λ)

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

Example

(1*0.39)+(3*0.23)+(3*0.17)+(5*0.07)+(5*0.10)+(5*0.04)=2.647/0.389=6.808 for slope row using similar procedures the value become 6.808,6.915,6.802,6.154,6.520 and 6.354 for slope,drainage,depth ,texture distance and lulc row respectively. Then, λ= (6.808 +6.915+6.802+6.154+6.520+6.354)/6 =6.592

d) The Consistency Index (CI) is $(\lambda - n)/(n - 1)$, (6.592-6)/5 = 0.1184

e) The Consistency Ratio (CR) is CI/RI, where RI is the Random Consistency Index. For n = 6, RI is = 1.24 from table 3.11. CR =0.1184 /1.24 = 0.095

The consistency ratio (CR) was 0.095, which was acceptable for weighting the factors to evaluate the physical land capability of the Muga watershed for developing irrigation suitability map. This was less than 0.1, the maximum allowable as recommended in Saaty (1990), cited in (Mendoza *et al.*, 2008) for consistent pair wise comparison of 10 %. If the data obtained through scoring process are acceptable, the weight proceeds to criteria map creation. Weighted linear combination method for this study is selected based on Eastman's et al. framework. using equation 3.3 we get the overall suitability analysis as follows.

$$[S = (0.389 * SP) + (0.23Dr) + (0.169 * D) + (0.069 * T) + (0.099 * D + 0.044LU) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.1]$$

Where S is the suitability irrigation area, SP is the Slope, SD is Soil drainage, D is the soil depth, T is the texture and L.U is the land use.

Multiplying the reclassified factors map based on the given weights and adding them by Raster calculator technique in spatial analyst module in ArcGIS 10.4.1 software obtained the final physical land suitability map of the basin. The result was given with values in four classes. The physical land suitability map was divided in to four suitability classes (Fig 4.7). These were highly suitable, moderately suitable, marginally suitable and not suitable From the total land of the basin 2191.04 hectare (2.99%) was highly suitable, 23445.48 hectare (31.97%) moderately suitable, 23038.76 hectare (31.42%) marginally suitable, 24658.80 hectare (33.63%) not suitable for surface irrigation

Table 4. 9.Result of land suitability of the study area

Area coverage		Suitability class	Description
Ha	%		
2191.04	2.99	S1	Highly suitable
23445.48	31.97	S2	Moderately suitable
23038.76	31.42	S3	Marginally suitable
24658.8	33.62	N	Not suitable

Generally, the area coverage of land suitability for surface irrigation with in Muga watershed is 66.38 %(48675.28 ha) from the total area.

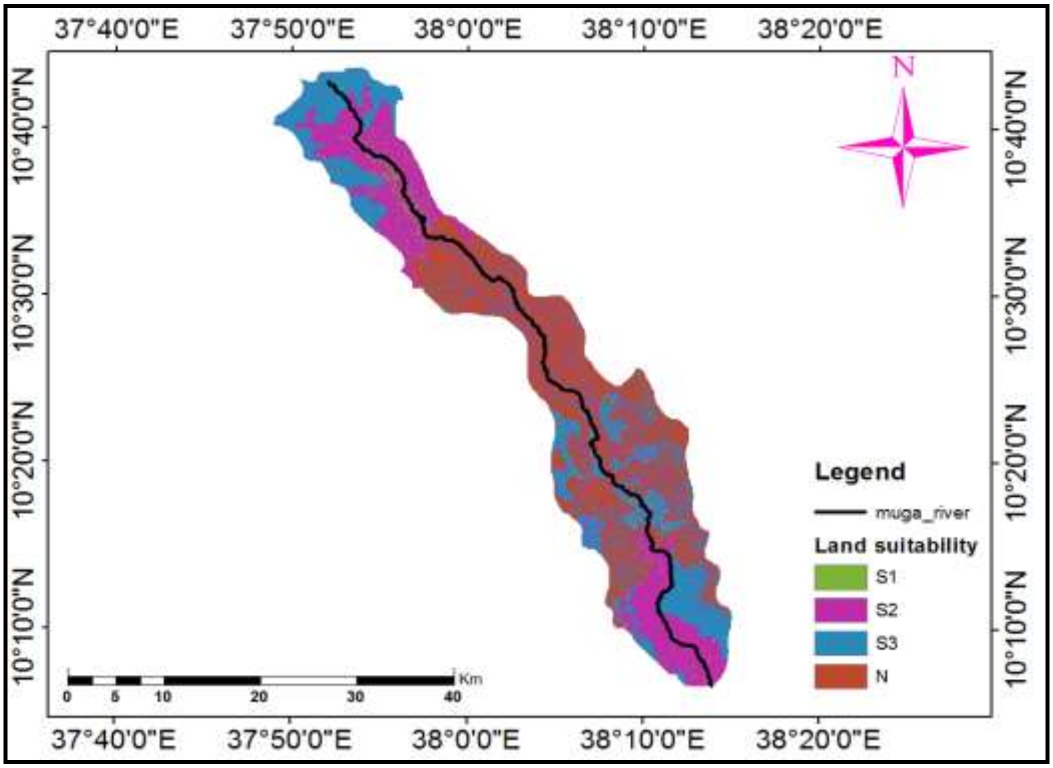


Figure 4. 7.Over all suitability map for surface irrigation

4.6. Crop and Irrigation Water Requirements

Water requirements and the Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop and soil data. Once all the data is entered, CROPWAT8 Windows automatically calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly.

To determine irrigation water demand, crops such maize, Tomato and potato were identified in the study area. These crops were selected based on their suitability for irrigation practice and their extent in comparing with other irrigated crops grown in the region. Irrigation water demand for each selected crop was determined by using Yetnora meteorological station. Since, Yetnora station has full metrological data which is an input for CROPWAT8 software in appendix table3.

According to FAO (1997), recommendations on the irrigation efficiency of different irrigation schemes, irrigation efficiency for Ethiopian highlands is given as 50%. The monthly total net irrigation water requirement (TNIWR) was computed by summing net irrigation water requirement of each crop. Crop water requirement (CWR), net irrigation requirement (NIWR) and gross irrigation water requirement (GIWR) of each crop were calculated for each month using Equations 3.4,3.6 and 3.9 respectively and summarized in appendix table 16.Available Surface water on the study area was evaluated by using stream flow discharge obtained from ministry of water, irrigation and electric city. But effective irrigable area was calculated based on minimum stream flow. Thus, the annual total gross irrigation water requirement was found to be 74.78 m^3/s.

4.7. Physical irrigation potential on Muga watershed

According to (FAO, 1997) Physical surface irrigation potential for surface irrigation was obtained by comparing irrigation water requirement in identified irrigable land and the available stream flow of watershed. In the whole Growing season from December-April irrigation water demand was greater than the available stream flow. Minimum monthly stream flow and grosses irrigation water requirement of selected crop such as, maize, potato and tomato were present in the table 4.10 below.

Table 4. 10.Irrigation demands and available river flows in the study area for maize, tomato and potato crops.

GIWR(m3/s)					90% probability of river flow(m3/s)
Month	Maize	Potato	Tomato	SUM GIR	
Jan	6.08	4.50	3.93	14.51	0.24
Feb	10.74	7.75	7.67	26.15	0.14
Mar	8.04	7.81	8.78	24.62	0.18
April	0.00	0.00	5.31	5.31	0.20
May	0.00	0.00	0.00	0.00	0.23
June	0.00	0.00	0.00	0.00	0.42
Jul	0.00	0.00	0.00	0.00	10.55
Aug	0.00	0.00	0.00	0.00	16.99
Sep	0.00	0.00	0.00	0.00	5.31
Oct	0.00	0.00	0.00	0.00	0.89
Nov	0.00	0.00	0.00	0.00	0.37
Dec	1.03	1.41	1.73	4.17	0.26
Total	25.89	21.47	27.42	74.76	35.78

The area was assigned for each crop based on their productivity and profitable in traditional farming system in Dejen woreda agriculture and development office Based on the Minimum available water, the effective irrigable area can be estimated in each month using equation 3.7.

The effective irrigable area of each month is varies from month to month due to variation of minimum flow. Due to lack of available water, most of irrigable area is not irrigated and is not covered by agricultural production. As shown in the table, the maximum irrigable area within the minimum flow for each month Dec, Jan, Feb and Mar were 2457.39, 384.28, 126.89 and 217.95 ha respectively. The actual average irrigable area of land is 304.57 ha out of 19470.11 ha was irrigated within the total minim flow of 0.81 m^3/s and 25.89 m^3/s gross irrigation water covered by the maize crop. The remaining effective irrigable area was calculated on the same procedure and tabulated in Appendix table 17.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The assessment of physical land resources potential for surface irrigation was carried out through Arc GIS technique's in terms of land suitability parameters; land slope, soil type and land use land cover were identified in Muga watershed.

Land Slope of the area was evaluated based on FAO guide line for land evaluation of surface irrigation development and geographic locations (maps) of suitable sites were also presented on Arc GIS. Lands with slope of < 8 % were categorized under highly suitable to marginally suitable class which covers 20.19 % and > 8% were categorized in unsuitable class covers 79.81 % of the total area.

The soil drainage classification implies that 15.93% of the study area was classified under well drainage; soil texture classification indicates that 83.93% of the study area was classified under Clay and silt clay soil and the soil depth indicates that 40.37 % of the study area indicates the depth greater than 100 cm. The distance suitability also indicates that 54.13% of the total area was classified as highly suitable and 1.25% is not suitable for surface irrigation. The LULC indicates that 64.78 % is highly suitable and 4.52% restricted for irrigation.

The overall suitability of the area for surface irrigation were made using weighted overlay of the parameters with the help of multi criteria evaluation methods (soil, slope, distance and LU/LC) developed on Arc GIS 10.4 . About 66.37 % of) the total lands in the watershed were in the range of highly suitable to marginally suitable for surface irrigation development, whereas (33.63 %) were grouped in unsuitable class due to the combined effect of slope, soil, distance and land use land cover suitability of Muga watershed. Crop water requirement of the selected crops was made using climatic data through CROPWAT model 8.0.Irrigation water requirement (GIWR) calculated using Penman–Monteith methods. The irrigation water demands of the selected three crops were calculated separately and the result implies the annual total gross irrigation water requirement was found to be 74.78 m^3/s.

5.2 Recommendations

Irrigation is an important investment for improving rural income through increased agricultural production. However this can be achieved, by assessing suitable land and water resources for surface irrigation. Therefore, identified land resources potential of the watershed in the study area can assist in policy and decision makers for irrigation development to alleviate the recurrent domestic food shortage facing the country particularly in Muga watershed East Gojjam zone.

This study was limited with soil texture, soil depth, soil drainage, LULC and distance from river to assess Land suitability for surface irrigation. Since, other factors may have its own influence to characterize the suitability of land for surface irrigation. Therefore, further research which will be incorporate additional factors such as soil chemical characteristics of alkalinity, acidity, electric conductivity with the aid of laboratory analysis to assess land suitability over the study area.

The current land suitability evaluation is in terms of slope, soil and LULC of the area only, but other suitability factors like water quality, environmental, economic and social terms should be assessed to get a reliable result.

Suitability analysis of land for irrigation was done by considering only surface irrigation Furth investigates is recommended to increase suitability of land for irrigation by considering drip and sprinkler irrigation method.

Since irrigation water demand is greater than the available stream flow, construction of storage structures is recommended to fully develop the identified irrigation potential in the study area.

REFERENCES

Albaji,T.,Mohammad,R., Mona G, Saeed B, Saeed B and Farzad N.,(2015).Investigation of Surface, Sprinkler and Drip Irrigation Methods Based on the Parametric Evaluation Approach in Jaizan Plain. Journal of the Saudi Society of Agricultural Sciences 14 (1): 1 –10.

Alexandrite,M., Nikos,B and Jelle Bruinsma.(2012). World Agriculture towards 2030 /2050: The 2012 Revision, ESA Working Paper No. 12-03,Food And Agriculture Organization Of The United Nations, Rome.115–118.

Allen,F., Richard G, Luis S Pereira, Dirk Raes, Martin Smith, and a B W. (1998). Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization of the United Nations, Rome.

Atnafe,M. (2006). Irrigation Policies, Strategies and Institutional Support Conditions in Ethiopia.Proceedings of Symposium on Best Practices and Technologies for Agricultural Water Management in Ethiopia. Ethiopia.Addis Ababa.

Attual,N and Fisher,S.(2014). Land Suitability Assessment for Pineapple Production in the Akwapim South District, Ghana:. A GIS-MultiCriteria Approach,. Ghana Journal of Geography,vol. 2,pp. 47-84.

Awulachew, S. B. (2011). Performance of Irrigation: An Assessment at Different Scales in Ethiopia. Journal of Experimental Agriculture. , 47 (1): 57- 69.

Awulachew, S. B., Merrev., J., D., B., A., Van Koopen, B., Veris, F. P.,(2005). Experiences and Opportunity For Promoting Small-Scal/Micro Irrigation and Rainwater Harvesting for Food Security In Ethiopia. IWMI Working Paper 98, 2005. Journal Of International Water Management Institute. , 11(3):346-358.

Awulachew , Seleshi B, Teklu E, and Regassa E. (2010). Irrigation Potential in Ethiopia: Constraints and Opportunities for Enhancing the System. International Water Management Institute, July: 1–59.

Awulachew, S. B., Merrev., J., D., B., A., Van Koopen, B., Veris, F. P. (2007). Water Resources and Irrigation Development in Ethiopia. International Water ManagementInstitute , Institute. 78p. (Working Paper 123).

Awulachew, Seleshi Bekele, Smkhtin Vladimir, David Molden, and Don Peden. (2012). The Nile River Basin: Water, Agriculture, Governance and Livelihoods. First edit. Rout ledge.

Bailey, T., (1992). Statistical analysis and geographic information systems: a review of the potential and progress in the state of the art. EGIS 92, Proceedings of the Third European Conference on Geographic Information Systems,. Utrwht, EGIS Foundation , pp. 186-203

Baniya.N. (2008). Land Suitability Evaluation Using GIS for Vegetable Crops in Kathmandu Valley, Nepal.A PhD dissertation submitted to Humboldt Universitätzu. Germany: Berlin.

Bégué,J Agnès,G,Damien,S,Arvor,LBeatriz,M Bellon, Julie B Abelleyra, Rodrigo P D Ferraz, Valentine, L, Camille, L, Margareth S, and Santiago R. Verón. 2018. Remote Sensing and Cropping Practices : A Review. Remote Sensing 10 (99): 1 –32.

Bekele,B, Yeshitela,M, Nata,T and Bheemalingswara K, (2012), Preliminary Study on the Impact of Water Quality and Irrigation Practices on Soil Salinity and Crop Production, Gergera Watershed, Atsbi-Wonberta,Tigray,Northern Ethiopia, MEJS, Volume 4 (1):29-46.

Belay,K and Bewket,B.(2013). Traditional Irrigation and Water Management Practices in Highland Ethiopia: Case Study in Dangila Woreda, . Irrigation and Drainage , 62: 435– 448.

Bewket,B and Conway,D. (2007). A Note On Temporal And Spatial Variability Of Rain Fall In Drought Prone Amhara Region Of Ethiopia. International Journal Of Climatology , 27(11),1467-1477.

Boelle.M. (2005). Experiences and Opportunities for Promoting Small-Scale/Micro Irrigation and Rainwater Harvesting for Food Security . IWMI: Ethiopia.

Campbell, J. (1984). Introductory Cartography. Englewood Cliffs, NJ: Prentice HallCA,2007.Water for Food, Water for Life: A comprehensive assessment of water management in Agriculture. Molden, D.J. (Ed.). London, Earth scan, and Colombo: International of Water Management Institute.

Ceballos,M., (2003). Delineation of Suitable Areas for Crops Using a Multi Criteria Evaluation Approach and Land Use/Cover Mapping: A Case Study in Central Mexico. Agricultural Systems. , 77(2): 117-136.

CSA (Central Statistical Agency of Ethiopia). (2016). Statistical Abstract of Ethiopia, Central Statistical Agency, Addis Ababa: Ethiopia.

De Groot RS, Wilson MA,Boumans RMJ (2002).A Typology for The Classification, Description And Valuation of Ecosystem Functions, Goods And Services. Ecol. Econ 41 : 393-408.

Driessen,P ,Konijn,T., (1992) Land-use systems analysis. Wageningen Agricultural University, The Netherlands. 230 p.

Dingman, S.L, (2002). Physical Hydrology, Second Edition Printice, Hall New Jersey. DFID,2004. Guidelines: Predicting and Minimizing Sedimentation In Small Dams, Zimbabwe And Tanzania.

Dula,W., (2010). GIS and Remote Sensing Based Land Suitability Analysis for Agricultural Crops in Mojo Watershed, Upper Awash Sub basin, Ethiopia. M.Sc. thesis, Addis Ababa University.

Eldrandaly , K. (2007). Expert systems, GIS, and spatial decision making: current practices and new trends. Nova Science Publishers, Inc., ISBN: 978-1-60021-688-6, pp. 207-228.

Elachi C., ZylJ.v., (2006). Introduction to the Physics and Techniques of Remote Sensing. 2nd Edition. John Wi-ley & Sons Inc.

Ellis E. (2009) Land-cover, In Encyclopedia of Earth. Eds. CutlerJ. Cleveland. Washington, D.C.

ESRI.(1996).Building applications with map objects. Redlands, Calif. Environmental Systems Research Institute Press.

Eastman, J.J., W.A. Kyem and J. Toledano, (1995). Raster Procedures for Multicriteria/Multi-Objective Decisions, Photo-gram metric Engineering and Remote Sensing. 61(5): 539-547.

FAO. (1976). A framework for land evaluation. FAO Soils Bulletin No. 32.: FAO, Rome.

FAO. (1985). Guidelines Land Evaluation for Irrigated Agriculture. Rome, pp29 FAO Soils Bull 55,.

FAO, 1991. Land use planning applications. Proceedings of the FAO Expert Consultation, 1990.

FAO. (1993). Guidelines: Land Evaluation for Rain-fed Agriculture. FAO, Rome.: FAO Soils Bulletin no. 52,.

FAO (Food and Agriculture Organization), 1995. Planning for Sustainable Use of Land Resources, Towards a New Approach: Land and Water Bulletin, Rome, Italy.

FAO. (1996). Drainage of Irrigated lands. Irrigation water management. Training Manual,. Italy: Rome,.

FAO. (1997). Irrigation potential in Africa: A basin approach FAO Land and Water Bulletin 4.

FAO. (1998). The future of our land Facing the challenge. Guidelines for integrated planning for sustainable management of land resources. FAO, Rome. Land and Water Digital Media Series 8.

FAO. (1999). The Future of Our Land Facing The Challenge. Guidelines For Integrated Planning For Sustainable Management of Land Resources.Fao, Rome. Land And Water , Digital Media Series 8.

FAO (Food and Agriculture Organization of the United Nations), (2001), Irrigation Manual Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation, Volume III, Module 8.

FAO. (2002). Crop Evapotranspiration Guidelines for Computing Crop Water Requirements: Guidelines for Computing Crop Water Requirements (FAO Irrigation and Drainage Paper No.56,).

FAO. (2003). Agriculture, Food and Water a Contribution to the World Water Development Report. Rome: Italy.

FAO. (2006). Hand Book to the Ecology and Integrated Management of Potato. All about Potato. FAO, . Rome,Italy.

FAO. (2007). Irrigation Management Transfer: Worldwide Efforts and Results. Rome: Food and Agriculture Organizations of the United Nations.

FAO. (2015). FAO's Information System on Water and Agriculture. Aqua stat. http://www.fao.org/nr/water/aquastat/didyouknow/index3.stm.Accessed on 2018-04-23.

Fasina , A. S., G. O Awe, and J.O Aruleba, (2008). Irrigation suitability evaluation and cropyield an example with Amaranthus cruentus in Southwestern Nigeria. African Journal of Plant Science Vol. 2 (7), pp. 61 -66, July 2008.

Feizizadeh.N and Blaschke.K. (2001). Land suitability analysis for Tabriz Country, Iran: a multi-criteria evaluation approach using GIS. International Journal of Environmental Planning and Management. , (1-23). Retrieved on June 5, 2012.

Fidelis,N., (2006). Spatial Analysis of Land Suitability To Support Alternative Land Uses At Excelsior Resettlement Project, Oshiko To Region, Namibia

Frew,K, (2003).Geographic Information Systems: Application in Agriculture Training with Arc view. EARO, Melkassa Agricultural Research Center, Nazareth.

Ghasemi,H. Pirbalouti. A, Normohammadi G. H, Kamali. G. H. A, Ayeneh B. And, Porhemmat J,Abdollahik. H.And Golparvara. R., (2008). Integrating Agro-Climatological Variables In Order land Suitability Evaluation For Rapeseed

Sustainable Production By Geographic Informationsystem (GIS) In Southwest Iran. Crop Research, 36: 180-185.

Goodchild, M. F., (2000). The Current Status of GIS and Spatial Analysis. GeographicalSystems, 2, 5-10

Hagos, F., Makombe, G., Namara, R. E., Awulachew, S. B., (2009), Importance of Irrigated Agriculture To The Ethiopian Economy: Capturing The Direct Net Benefits of Irrigation. Colombo, Sri Lanka: International Water Management Institute. 37p. (IWMI Research Report 128).

Haile and kassa. (2015). Irrigation in Ethiopia. Accadamic journal of Agriculture , 3(10): 264-269.

Hailegebriel. (2007). Irrigation Potential Evaluation and Crop Suitability analysis using GIS and Remote Sensing Technique in Beles Subbasin, Beneshangul-Gumez Region.MSc thesis, Addis Ababa University, Department of Earth Sciences.

Henok,M., (2010). Land Suitability and Crop Suitability Analysis Using Remote Sensing and GIS Application, A Case Study in Legambo Woreda, Ethiopia. M.Sc. thesis, Addis Ababa University.

IFAD.(2011). Rural Poverty Report New Realitirs New Challenges New Opportunities For Tomorrows Generation In Ifad (Ed.). (Rome,Italy: Rural Poverty Report (Ed.).

IGBP-IHDP. (1999). Land-Use And Land-Cover Change, Implementation Strategy. Igbp Report 46/Ihdp Report 10.Prepared By Scientific Steering Committee and International Projectoffice Of Lucc.

IWMI. (2015). International Water Management institute in Ethiopia: Addis Ababa.

Jankowski, P., (1995). Integrating Geographical Information Systems and Multiple Criteria Decision-Making Methods. International Journal of Geographical Information Systems, 9: 251- 273.

Janssen,R.andRietveld,P.,(1990). MulticriteriaAnalysis and Geographical Information Systems: an Application to Agricultural Land Use in the Netherlands. In: Scholten H. J. and J. C. H. Stillwell (Eds.), Geographical Information Systems for Urban and Regional Planning. Cluwer AcademicPublishers, Dordrecht, pp. 129–139.

Patrra ,K.C, (2000). Hydrology and Water Resources Engineering, New Delhi India.

Kebede, G (2010) GIS- Based Surface Irrigation Potential Assessment of River Catchments For Irrigation Development In Dale Woreda, Sidama Zone, Khan,D.M.S. N. and Khan, P. M. M. A. (2014). Land Suitability Analysis For Sustainable Agricultural Land Use Planning In Bulandshahr District of Uttar Pradesh. International J. of Scientific And Res. Publications, 4: 1-11.

Murage,S.(2013). Suitability Analysis For Rice Growing Sites Using A Multi-Criteria Evaluation And GIS Approach In Great Mwea Region, Kenya',. Springerplus, Vol. 2, 265-274.

Lillesand, M. T. and W. Ralph Kiefer,J (2004). Remote Sensing and image Interpretation: 5thedition. John Wiley and Sons, Inc.

Makombe,G.,Kelemework,D.Aredo, D., (2007), A Comparative Analysis of Rainfed And Irrigated Agricultural Production In Ethiopia. Irrigation and Drainage Systems 21: 35-44.

Makombe,G.,Namara,R.; Hagos, F.; Awulachew, S. B.; Ayana, M.; Bossio, D., (2011), A Comparative Analysis of The Technical Efficiency of Rain-Fed and Smallholder Irrigation In Ethiopia. Colombo, Sri Lanka: International Water Management Institute. 37p. (IWMI Working Paper 143).

Malczewski J. and C. Rinner, (2005). Exploring Multicriteria Decision Strategies In GIS With Linguistic Quantifiers: A Case Study of Residential Quality Evaluation. Journal of Geographical Systems, 7 (2), Pp. 249–268.

Malczewski J.,T. Chapman, C. Flegel, D. Walters, D. Shrubsole and M.A. Healy, (2003).GIS-Multi-Criteria Evaluation with Ordered Weighted Averaging (OWA): A Case Study of Developing Watershed Management Strategies. Environment andPlanning. 35: 1769–1784.

Malczewsi,J.,(2004). GIS-based Land-Use Suitability Analysis: a Critical Overview:Progress in Planning. Vol.62: 3-65.

Malczewski, J., (2000). Review Article on The Use of Weighted Linear Combination Method In GIS: Common And Best Practice Approaches. Transactions In GIS. 4: 5-22.

Malczewski, J., (2006). GIS-Based Multi-Criteria Decision Analysis: A survey of the literature. International Journal of Geographical Information System. 20(7):703- 726.

Marinoni, O.,(2004). Implementation of The Analytical Hierarchy Process With VBA In Arc GIS. Computers And Geosciences. 30(6):637–646.

Mendoza, G.A., (2006). A GIS Multi-Criteria Decision Analysis In Natural Resource Management: A Critical Review of Methods And New Modeling Paradigms. Science Direct, Forest Ecology And Management 2006(230): 1–22.

Mendoza, G.A., (1997). A GIS-Based Multi-Criteria Approach To Land Use Suitability Assessment And Allocation.Pp.1-7. In: Seventh Symposium On Systems Analysis In Forest Resources, Traverse City, USDA Forest Service.

Mendoza, G.A., E. Santiago and A.R. Ravindran, (2008). A three-phase multi criteria method to the supplier selection problem. International journal of industrial engineering. 15(2): 195-210.

Mengistie, Dereje, and Desale Kidane. (2016). Assessment of the Impact of Small-Scale Irrigation on Household Livelihood Improvement at Gubalafto District, NorthWollo,Ethiopia. Agriculture 6 (27): 1 –22.

Meron, T. (2007). Surface irrigation suitability analysis of Southern Abbay Basin by implementing GIS techniques. MSc thesis Addis Ababa University, Addis Ababa.

MoA (Ministry of Agriculture) Natural Resources Management Directorates, (2011), Small-Scale Irrigation Situation Analysis and Capacity Needs Assessment, Addis Ababa, Ethiopia.

MoFED. (2006). Building on Progress: A plan for Accelerated and Sustained Development to end Poverty Ministry of Finance and Economic Development of Ethiopia. . Ethiopia: Addis Ababa.

MoWIE. (2002). Water sector development program 2002-2016, Volume II: Main Report. Ministry of Water Resources,Federal Democratic Republic of Ethiopia, Addis Ababa, October 2002.

MoWR (Ministry Of Water Resources), 2002. Water Sector Development Program 2002-2016, Volume II: Main Report. Ministry of Water Resources, Federal Democratic Republic of Ethiopia,Addis Ababa, October 2002.

Negash W, and Seleshi B, (2004). GIS based irrigation suitability analysis. Journal of Water Science and Technology. Arbaminch, Ethiopia .V8, 55-61

Openshaw, Stan (1990). Spatial Analysis and Geographical Information Systems: A Review of Progress and Possibilities. In H. Scholten And J. Stillwell (Eds.), Geographical Information Systems For Urban And Regional Planning, Pp. 153-63 (Dordrecht, Kluwer Academic).

Ponjavic, S. and E. Ferhatbegović, (2010). Multi-Criteria Land Use Classification in GIS.pp.445-454. Proceedings of symposium on Multi-Criteria Land Use Classification in GIS for Buildings Construction in Austria. Vienna, Austria, 18- 20 May 2010, REAL CORP.

Ramos -Calzado, P., Gomez-Camacho, J., Perez-Bernal, F. and Pita-Lopez, M.F. (2008) A Novel Approach to Precipitation Series Completion in

Climatological Datasets:Application to Andalusia. International Journal of Climatology, 28, 1525- 1534.

Reshmidevi T., Eldho T.I., Jana R. (2009): A GIS-Integrated Fuzzy Rule-Based Inference System For Land Suitability Evaluation In Agricultural Watersheds. Agricultural Systems, 101: 101–109.

Ritung S, Wahyunto, Agus F, Hidayat, H. (2007). Land Suitability Evaluation with a case map of Aceh Barat District. Indonesian Soil Research Institute and World Agroforestry Centre, Bogor, Indonesia

Rossiter, D.G., (1995). Economic Land Evaluation: why and how, Soil Use and Management. Department of Soil, Crop and Atmospheric Sciences, Cornell University. 2(11):32-140.

Saaty,L.(2008). Decision Making With The Analytic Hierarchy Process. International Journals of Services Sciences, , Vol. 1, No. 1,Pp. 83–98.

Seleshi, B. (2001). Investigation of Water Resources Aimed at Multi Objective Development With Respect to Limited Data Situations The Case of AbayaChamo Basin, Ethiopia. Ph.D Thesis Technische Universitat Dresden InstituteFur Wasserbaw und Technische Hydromechanik D-01062 Dresden

Smith, M. (1992). CROPWAT: A Computer Program for Irrigation Planning and Management.FAO Irrigation and Drainage Paper 46. Food and Agriculture Organization of United Nations, Rome.

SSSA (Soil Science Society of America). (2008) “Glossary of Soil Science Terms.” www.soils.org/publications/soils-glossary/.

Steduto , P, Theodore C,Hsiao, Elias Fereres, and Dirk Raes. (2012). Crop Yield Response to Water. FAO Irrigation and Drainage Paper 66. Food and Agriculture Organization of United Nations, Rome.

Stein , B., Michael, K. ,Colin, L. Susan, O. and Brett, U., (2009). Sustainable Land Management Practices for Grazers. A Book published by Industry and Investment State of New South Wales. Sydney, Australia.

Sultan, D. (2013). Assessment of Irrigation Land Suitability and Development of Map for the Fogera Catchment Using GIS, South Gondar. Asian Journal of Agriculture and Rural Development 3. (1): 7–17.

Sys , C., Van Ranst, E. and Debaveye, J. (1991). Land Evaluation, Part II: Methods in Land Evaluation. Agricultural Publications-No. 7, General Administration for Development Cooperation, Brussels, Belgium.

Triantaphyllou,M and Mann,H.(1995). Using The Analytic Hierarchy Process For Decision Making In Engineering Applications: Some Challenges’.

International Journal of Industrial Engineering Applications And Practice, , Vol. 2, No.1, Pp. 35-44.

USDA(United States Department of Agriculture) (2006). Natural Resources Conservation Service Irrigation National Engineering Handbook Part 623.

Villazón , M.F. and Willems, P.(2010) Filling Gaps and Daily Dis accumulation of Precipitation Data for Rainfall-Runoff Model. BALWOIS 2010, Ohrid, 25-29 May 2010.

Vogel, R. (2008). A software framework for GIS-based multiple criteria evaluation of land suitability. 11 th AGILE International Conference on Geographic Information Science, University of Girona, Spain, p.1.

Walker,R. (2003). Surface Irrigation Simulation, Evaluation and Design Guide and Technical Documentation, SIRMODlll, Biological and Irrigation Engineering Utah State University.

Winchell, M. Srinivasan, R.,Di Luzio, M., and Arnold, J., (2008). ArcSWAT2. Interface for SWAT 2008, User manual.

Wong , K.J., Fung, K.W. and Che, C. (2012) A Comparative Analysis of Soft Computing Techniques Used to Estimate Missing Precipitation Records. 2012 19th ITS Biennial Conference, Bangkok, 18-21 November 2012.

Wood S. K.(1992). Pilot Analysis of Global Ecosystems: Agro ecosystems, a joint study by International Food Policy Research Institute and World Resources Institute, Washington D.C p55.

Worldbank (2006). Ethiopia: Managing Water Resources to Maximize Sustainable Growth. A World Bank Water Resources Assistance Strategy For Ethiopia.

Worqlul, Abeyou W, Jaehak Jeong, Yihun T Dile, Javier Osorio, Petra Schmitter, Thomas Gerik, R Srinivasan, and Neville Clark. (2017). Assessing Potential Land Suitable for Surface Irrigation Using Groundwater in Ethiopia. Applied Geography 85.

Yang Yi .D.H.G, (2003). Application of GIS And Remote Sensing For Assessing Watershed Ponds For Aquaculture Development In Thai Nguyen, Vietnam. School Of Environment, Resources and Development Asian Institute of Technology.

Yazew,E.(2005), Development and management of irrigated lands in Tigray, Ethiopia. PhD thesis, UNESCOIHE Institute for Water Education, Delft, the Netherlands, 265pp.

Yemane,G.(2004).Assessment of Water Balance of Lake Awassa catchment, Ethiopia. MSc thesis, International Institute for Geo-Information Science and Earth observation, Enscheda, Netherlands.

Yu J., Chean Y., Wu J.P. (2009): Cellular automata and GIS based land use suitability simulation for irrigated agriculture. In: 18th World IMACS/MODSIM Congress, Cairns, July 13–17, 2009: 3584–3590.

Yu J., Chen Y., Wu J. (2011): Cellular Automata Based Spatial Multi-Criteria Land Suitability Simulation For Irrigated Agriculture. International Journal of Geographical Information Science, 25: 131–148.

Zhongxin C., Sen Li, Jianqiang R., Gong P., Zhang M., Wang L., (2004). Monitoring and Management of Agriculture with Remote Sensing. In: Liang S. (Ed.), Advances in Land Remote Sensing. Springer, 97–421.

Zhongxin C., Mukherjee C.K., Vinuchandran R., (2006). Applications of Remote Sensing And GIS For Sustain-Able Management Of Shrimp Culture In India. Aqua Cult. Eng, 36, 1–17.

Ziadat,F.(2007). Land Suitability Classification Using Different Sources of Information: Soil Maps And Predicted Soil Attributes In Jordan. Geoderma 1 40: 73-80.

APPENDICES

Appendix 1: Dejen Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	0.8	19.6	109.3	57.9	27.3	124.3	348.0	304.9	214.9	20.8	0.0	0.0	1227.8
1991	2.7	3.4	8.8	11.6	37.1	199.0	276.8	343.6	189.0	18.5	0.0	10.9	1101.4
1992	40.4	32.9	32.8	77.5	69.5	154.3	185.1	230.2	186.2	98.6	27.2	0.0	1134.7
1993	8.8	11.7	35.7	171.9	164.4	171.3	283.7	239.7	212.0	122.8	0.0	0.0	1422.0
1994	0.0	0.0	60.6	14.2	116.8	97.8	401.9	364.0	259.0	0.0	1.4	0.0	1315.7
1995	0.0	0.0	15.2	56.3	87.4	120.8	329.5	388.0	193.1	6.0	4.7	39.1	1240.1
1996	5.2	2.3	86.5	129.5	195.8	152.7	491.7	356.8	98.3	18.3	31.8	7.2	1576.1
1997	54.8	0.0	95.9	173.3	96.1	310.9	376.3	335.0	53.6	200.7	198.7	13.9	1909.2
1998	0.4	13.0	62.1	3.6	188.1	166.7	384.6	472.1	193.3	254.5	0.0	0.0	1738.4
1999	4.9	0.0	0.0	28.8	3.5	161.0	637.4	595.4	128.7	322.5	2.1	5.5	1889.8
2000	0.0	0.0	0.0	187.0	101.9	136.9	484.7	558.8	288.0	158.8	65.8	3.2	1985.1
2001	0.0	9.0	120.8	87.5	83.7	298.0	645.4	361.5	134.3	100.9	2.4	6.1	1849.6
2002	60.9	12.3	77.2	55.1	20.2	168.0	483.4	422.7	200.5	0.0	0.0	8.6	1508.9
2003	0.8	36.0	139.3	64.1	3.3	123.9	273.0	283.3	192.5	0.0	16.1	9.9	1142.2
2004	6.5	19.0	46.0	56.4	12.5	125.2	266.0	249.6	92.3	115.8	19.6	0.0	1008.9
2005	6.0	0.0	69.3	49.4	90.0	151.2	260.8	222.7	139.0	80.5	13.3	0.0	1082.2
2006	7.1	9.2	108.0	124.4	72.3	140.5	336.6	308.2	297.4	46.1	4.4	33.7	1487.9
2007	17.6	68.2	42.8	83.4	177.7	180.7	335.2	261.4	175.5	15.2	0.0	0.0	1357.7
2008	0.0	0.0	0.0	42.6	78.1	307.4	420.9	316.3	278.4	133.3	104.5	0.0	1681.5
2009	0.0	3.0	52.2	66.2	19.8	101.1	331.8	338.5	132.4	113.5	9.9	12.0	1180.4
2010	0.0	4.7	93.3	95.8	174.7	39.6	244.6	296.7	171.2	11.6	28.2	0.0	1160.4
2011	10.2	0.2	113.0	6.3	49.5	54.3	155.9	168.0	121.9	0.2	14.5	0.0	694.0
2012	2.2	0.0	69.5	25.3	6.3	66.2	172.8	118.0	64.7	47.5	1.5	8.1	582.1
2013	1.0	4.0	21.3	7.9	14.1	88.0	247.1	189.6	67.1	47.1	11.8	0.0	699.0
2014	35.5	27.0	16.7	50.6	30.1	55.6	131.2	182.5	156.6	162.3	154.5	173.9	1176.5
2015	39.1	21.9	33.6	38.5	31.9	30.3	33.6	31.6	27.5	35.4	31.3	27.7	382.5
average	11.7	11.4	58.1	67.9	75.1	143.3	328.4	305.4	164.1	82.0	28.6	13.8	1289.8

Appendix 2: D/ Markos Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	4.8	18.9	52.1	70.2	32.9	148.5	325.1	353.3	275.8	11.2	20.7	0.0	1313.5
1991	8.8	18.2	234.3	83.4	88.5	282.4	221.3	311.8	168.0	50.8	32.5	51.0	1551.0
1992	28.6	31.6	31.0	123.9	83.1	144.9	164.9	307.9	168.7	94.6	72.7	5.5	1257.4
1993	8.0	27.4	37.8	179.6	197.6	209.6	305.8	287.5	322.1	165.7	5.5	0.0	1746.6
1994	9.3	5.0	78.8	42.7	139.6	147.6	281.2	301.0	218.1	7.4	13.2	0.5	1244.4
1995	0.0	1.0	20.3	90.4	146.6	126.4	246.1	344.6	151.2	14.4	12.4	95.5	1248.9
1996	27.6	4.6	74.1	108.0	228.0	291.7	252.3	360.5	152.1	33.1	35.2	23.2	1590.4
1997	14.3	0.0	29.6	97.5	118.7	151.0	286.8	338.8	205.8	183.5	85.0	6.7	1517.7
1998	2.9	2.2	21.0	4.4	152.4	91.2	203.2	252.6	270.7	200.8	6.9	0.0	1208.3
1999	72.6	0.0	2.8	43.2	46.8	180.7	252.1	340.3	164.3	210.5	2.5	28.3	1344.1
2000	0.0	0.0	2.9	110.5	29.5	174.9	287.5	211.1	271.0	265.9	32.7	12.3	1398.3
2001	0.0	3.7	58.1	101.2	129.6	154.7	365.2	322.3	170.3	66.9	0.0	2.2	1374.2
2002	57.0	0.0	92.2	75.2	11.2	155.9	276.3	335.5	234.6	3.9	2.2	61.5	1305.5
2003	3.6	57.4	69.6	19.2	5.3	212.0	205.5	351.6	256.8	10.7	0.3	18.8	1210.8
2004	4.1	7.6	13.8	120.1	19.8	195.0	286.6	317.7	205.2	86.1	38.0	23.2	1317.2
2005	2.3	0.6	110.6	47.8	43.7	150.4	314.0	220.5	235.3	90.2	41.5	0.0	1256.9
2006	3.5	20.7	87.8	67.4	104.5	190.9	364.1	281.1	301.5	37.1	30.7	32.3	1521.6
2007	1.7	15.6	77.5	71.0	162.9	188.0	250.6	325.9	269.0	37.9	0.4	0.0	1400.5
2008	0.0	0.0	0.0	15.7	169.9	290.3	250.5	273.9	195.1	71.2	39.1	9.5	1315.2
2009	11.7	21.1	51.9	31.6	16.8	159.3	276.7	452.3	98.5	121.3	10.9	21.8	1273.9
2010	18.7	22.8	35.4	84.7	153.4	151.0	216.4	339.6	307.0	17.5	16.7	5.0	1368.2
2011	2.0	3.1	110.4	68.9	237.8	143.0	231.1	288.3	282.9	7.5	97.3	11.5	1483.8
2012	13.9	0.0	33.1	33.1	23.4	124.2	372.2	250.9	362.4	21.3	30.9	7.1	1272.5
2013	13.0	4.7	16.4	11.8	125.0	161.3	282.8	245.4	194.8	147.3	34.2	0.0	1236.7
2014	9.1	8.6	42.9	138.4	130.1	101.9	274.6	257.1	255.5	100.5	9.2	9.2	1337.1
2015	6.0	14.6	45.5	20.1	244.1	119.1	149.7	237.2	129.4	12.7	65.0	16.0	1059.4
Average	12.4	11.1	55.0	71.5	109.3	171.0	267.0	304.2	225.6	79.6	28.3	17.0	1352.1

Appendix 3: Yetnora Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	1.4	74.3	174.1	119.5	35.3	185.7	505.0	480.1	326.7	17.0	7.6	0.0	1926.7
1991	2.0	25.1	111.5	126.7	132.6	152.6	206.0	242.5	121.2	35.9	0.0	7.4	1163.432
1992	3.3	30.9	22.3	66.3	44.4	115.3	187.0	220.9	111.4	137.1	23.9	39.7	1002.474
1993	1.0	16.7	24.3	161.9	133.7	171.0	371.2	280.6	148.5	121.2	0.0	0.0	1430.107
1994	0.0	6.3	37.7	35.4	126.4	149.2	418.6	338.0	143.7	0.0	1.3	0.0	1256.6
1995	0.0	3.8	19.7	45.3	91.5	99.2	225.2	242.1	65.2	2.3	6.5	44.2	845
1996	5.1	0.0	132.6	91.5	135.8	155.9	125.7	231.1	132.8	128.8	89.4	126.9	1355.573
1997	140.4	6.1	63.6	80.3	92.1	203.0	177.8	184.0	72.7	59.2	54.1	10.2	1143.557
1998	0.0	0.0	75.1	7.9	185.1	95.5	334.4	374.2	126.8	183.0	37.4	0.0	1419.425
1999	4.8	0.0	0.0	33.7	82.1	179.5	390.2	259.9	75.6	277.5	2.2	7.8	1313.259
2000	0.0	0.0	0.0	133.9	32.1	132.4	316.1	324.4	128.1	27.3	131.2	118.5	1343.938
2001	152.2	112.2	120.5	103.3	137.4	209.5	377.2	225.6	132.5	53.3	3.5	4.9	1632.161
2002	36.6	6.4	33.3	43.9	13.3	201.7	403.2	314.2	80.5	0.2	0.0	10.5	1143.8
2003	0.4	30.0	60.1	30.9	0.0	145.2	261.5	222.1	108.9	2.7	9.0	2.3	873.1
2004	14.0	9.7	23.7	66.8	8.2	211.0	230.5	223.3	150.8	74.5	12.3	125.4	1150.243
2005	17.3	0.0	53.6	84.0	58.9	125.1	232.7	161.4	154.2	39.3	32.5	0.0	959.0494
2006	3.1	13.0	114.3	69.1	92.2	125.7	481.4	300.9	267.4	28.8	7.8	35.3	1538.972
2007	10.3	22.5	40.2	72.1	129.8	152.1	287.9	227.9	198.9	16.6	0.0	105.3	1263.577
2008	0.0	0.0	0.0	21.3	101.2	167.7	323.6	180.3	122.9	81.8	69.4	0.0	1068.2
2009	8.7	11.2	37.8	42.5	18.2	46.4	292.5	321.4	99.3	113.9	5.2	26.3	1023.4
2010	3.5	23.3	38.8	81.4	190.1	72.1	258.8	281.3	222.1	19.1	20.5	1.3	1212.3
2011	3.2	0.0	96.8	53.6	178.7	116.2	254.6	262.8	106.6	20.0	92.3	0.0	1184.838
2012	0.0	0.0	79.0	53.0	38.3	153.3	357.5	233.1	176.4	42.5	2.8	0.0	1135.92
2013	3.7	0.6	12.6	31.0	143.8	244.4	317.0	288.7	65.6	42.4	12.0	0.0	1161.8
2014	0.0	45.2	22.4	93.3	129.2	52.8	142.7	191.1	180.4	65.4	24.8	0.0	947.3573
2015	0.0	6.6	0.0	21.2	124.7	182.7	107.9	212.2	94.2	14.8	108.7	22.7	895.7
Average	15.8	17.1	53.6	68.1	94.4	147.9	291.8	262.5	139.0	61.7	29.0	26.5	1207.3

Appendix 4: Motta Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	1.3	32.2	14.4	45.1	20.7	112.6	375.2	178.1	258.8	38.1	1.3	0.0	1077.8
1991	0.9	5.1	99.7	11.5	47.9	60.6	318.7	276.7	232.4	44.8	1.2	19.6	1119.1
1992	0.0	2.3	13.6	67.7	62.3	73.3	184.1	324.4	78.2	122.5	56.4	32.5	1017.3
1993	3.0	13.1	36.7	124.7	143.4	99.5	333.4	155.8	200.5	118.0	12.0	0.0	1240.0
1994	2.1	11.7	10.0	32.3	103.3	102.9	316.8	301.1	150.3	36.2	29.7	7.9	1104.3
1995	0.0	7.0	9.0	22.0	77.8	60.2	355.2	238.0	104.5	70.3	4.1	22.2	970.3
1996	0.3	2.1	66.4	61.4	110.6	203.7	310.9	365.7	164.0	58.4	70.5	9.2	1423.2
1997	0.4	0.0	54.4	58.7	139.9	176.5	272.0	184.4	163.7	188.2	43.0	3.3	1284.5
1998	5.7	1.0	18.2	34.4	119.6	93.4	363.4	368.6	170.7	198.8	49.2	0.9	1423.9
1999	18.8	0.0	0.0	22.6	52.9	109.9	300.4	371.6	157.2	202.7	5.5	26.5	1268.1
2000	3.3	0.0	7.6	111.5	8.0	38.4	243.1	267.8	148.2	209.8	63.0	21.2	1121.9
2001	0.0	15.3	53.2	28.5	79.1	153.0	443.6	327.1	144.3	146.7	37.2	3.6	1431.5
2002	10.8	0.0	30.8	93.0	26.8	127.9	296.7	288.6	186.1	60.9	7.0	18.5	1147.1
2003	0.0	11.4	33.6	8.5	8.8	76.5	339.8	354.1	265.3	52.8	14.7	0.3	1165.8
2004	0.0	7.4	7.0	59.0	14.2	142.0	203.0	269.2	181.3	97.3	23.9	0.0	1004.3
2005	7.9	4.5	50.7	27.9	20.3	138.5	261.3	226.2	204.5	195.6	61.4	0.0	1198.8
2006	0.0	2.2	27.9	76.9	106.3	164.1	366.2	339.0	158.0	80.3	52.7	27.6	1401.2
2007	26.2	12.4	32.4	16.5	116.6	175.5	225.8	295.7	136.4	42.5	0.2	0.0	1080.2
2008	41.7	0.7	0.0	78.9	145.1	94.2	362.4	279.8	209.7	96.5	15.4	0.0	1324.4
2009	0.0	20.4	28.1	30.7	9.0	61.8	317.3	338.6	109.4	158.9	28.4	0.2	1102.8
2010	7.2	0.7	25.3	37.5	64.0	34.1	364.4	450.4	203.4	84.2	22.4	0.2	1293.8
2011	21.8	0.0	48.0	52.4	93.9	69.4	260.9	408.9	197.0	32.1	126.1	0.0	1310.5
2012	2.7	0.0	16.3	3.5	37.2	157.7	355.3	322.5	147.9	50.0	23.6	19.8	1136.5
2013	3.1	0.0	14.5	50.3	77.4	193.0	370.1	381.6	135.6	195.0	54.0	0.0	1474.6
2014	0.2	4.0	86.5	127.1	239.5	93.9	283.7	292.1	176.8	118.3	26.9	7.5	1456.5
2015	0.0	0.0	55.7	3.0	165.9	144.4	194.5	341.1	230.5	60.4	61.5	94.6	1351.6
average	6.1	5.9	32.3	49.4	80.4	113.7	308.4	305.7	173.6	106.1	34.3	12.1	1228.1

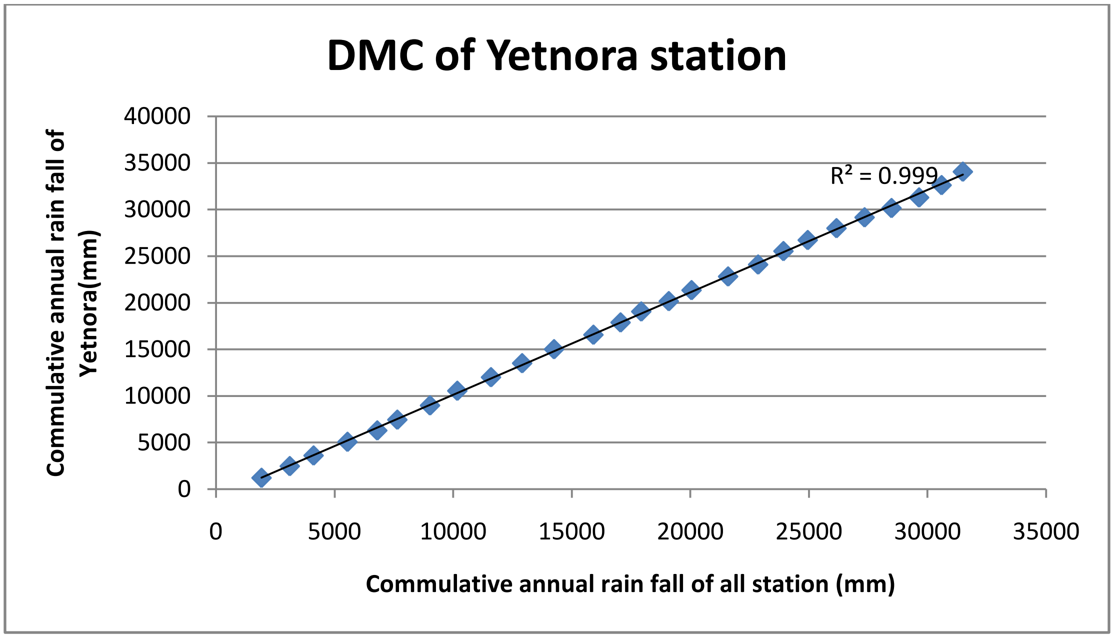
Appendix 5: Monthly average minimum and maximum temperatures, wind speed, relative humidity and sunshine hours.

month	T_{min}(°C)	T_{max}(°C)	Humidity (%)	wind(Km/hr)	Sun hours
Jan	7.7	23.8	50.74	53.72	7.4
Feb	9.2	25.4	41.73	54.02	7.7
Mar	10.8	26.3	49.78	59.02	7.5
Apr	11.2	26.1	49.53	57.32	7.7
May	11.0	25.6	56.77	60.64	7.5
Jun	10.7	23.4	66.88	49.12	6.1
Jul	10.5	19.0	87.57	42.67	4.1
Aug	10.4	18.8	89.31	42.07	5.4
Sep	9.4	21.2	78.40	46.87	7.4
Oct	8.3	23.0	63.93	53.99	8.1
Nov	7.3	23.5	59.45	46.63	7.8
Dec	6.7	23.5	53.29	51.56	7.6
Average	9.4	23.3	62.3	51.5	7.0

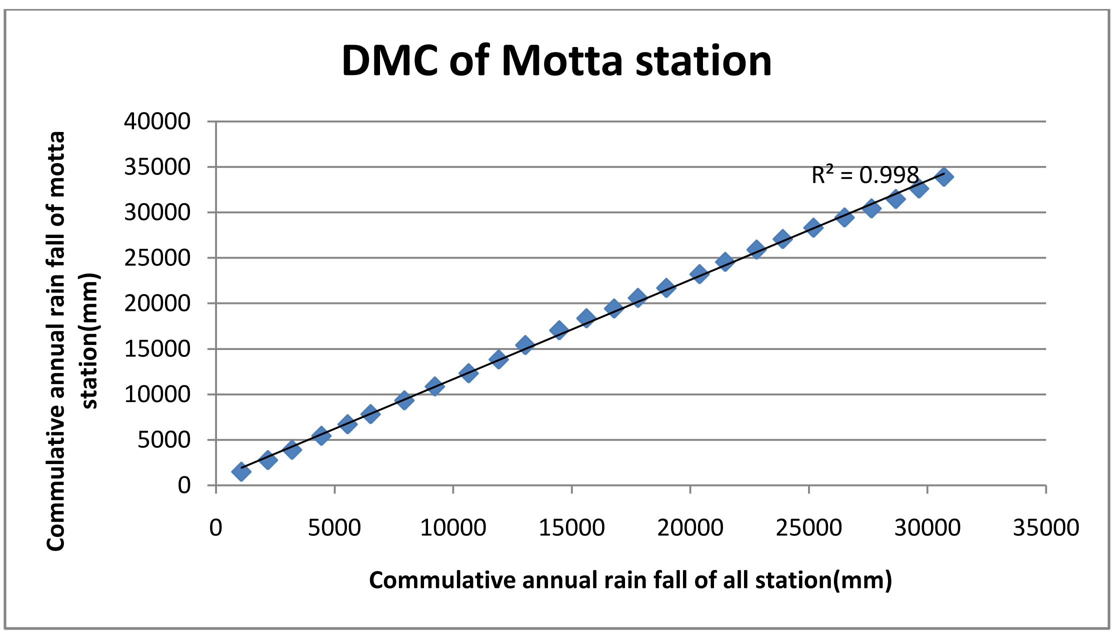
Appendix 6: Mean monthly discharge flow data from Muga River

`	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.493	0.256	0.611	0.481	0.539	0.208	7.531	16.417	9.199	1.489	0.255	0.182
1991	0.134	0.081	0.172	0.070	0.118	0.399	23.215	23.215	9.261	0.962	0.503	0.308
1992	0.247	0.279	0.177	0.720	0.964	0.424	5.869	21.515	11.090	4.685	0.710	0.435
1993	16.314	0.155	0.092	2.244	3.138	2.889	23.687	15.396	13.351	0.310	0.730	0.199
1994	16.476	0.162	0.189	0.144	0.519	1.482	34.564	47.521	15.356	1.493	0.715	0.446
1995	17.554	0.183	0.193	0.674	0.808	0.646	11.520	22.181	8.141	7.035	0.301	0.276
1996	1.403	0.481	0.599	136.903	5.966	13.983	18.352	16.159	11.997	1.327	2.620	14.062
1997	0.360	0.212	0.442	0.840	0.828	3.645	17.877	21.552	2.618	8.032	3.070	1.030
1998	7.760	16.398	18.147	7.593	1.940	2.357	22.159	41.667	12.186	18.602	17.426	15.550
1999	16.725	16.198	13.789	8.042	0.260	0.709	18.201	31.780	5.738	15.719	0.922	0.433
2000	4.684	16.540	16.440	11.487	3.529	1.340	18.951	28.950	7.555	6.435	4.969	0.643
2001	0.357	0.236	0.629	0.476	0.610	5.479	43.514	37.549	8.480	1.910	0.729	0.506
2002	0.523	0.258	1.165	1.058	0.243	0.881	12.098	20.239	4.208	0.798	0.400	0.616
2003	0.265	0.295	1.544	1.458	0.192	1.272	27.922	28.322	13.399	3.324	0.749	0.539
2004	0.244	0.152	0.286	0.787	0.457	1.704	24.401	30.664	6.608	5.704	0.974	0.734
2005	0.241	0.053	0.409	0.240	0.593	0.845	25.424	18.214	14.420	2.169	0.649	0.353
Average	5.236	3.246	3.430	10.826	1.294	2.392	20.955	26.334	9.600	4.999	2.233	2.270

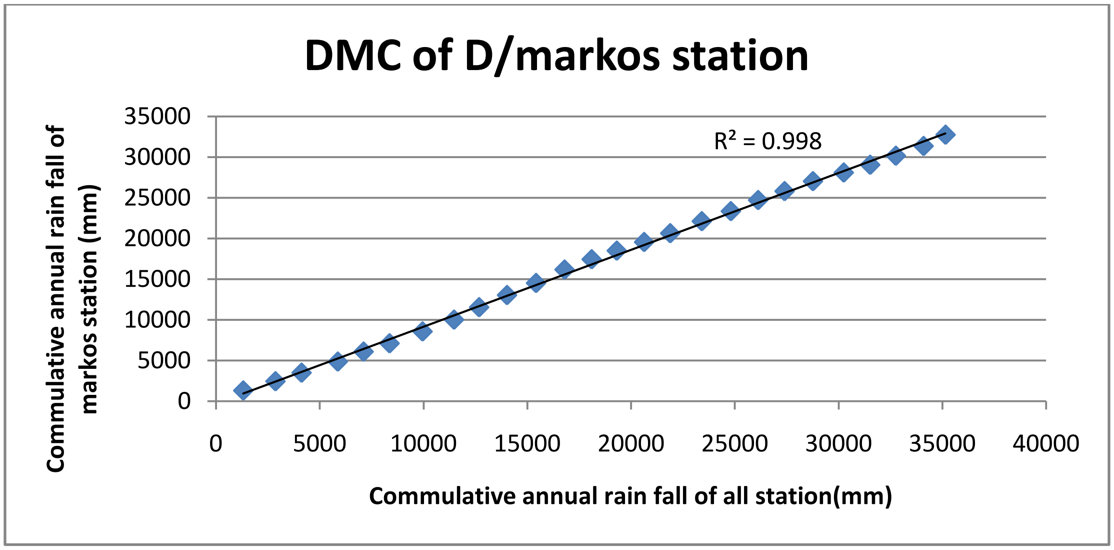
Appendix 7: Double mass curve for Yetnora rain gage station



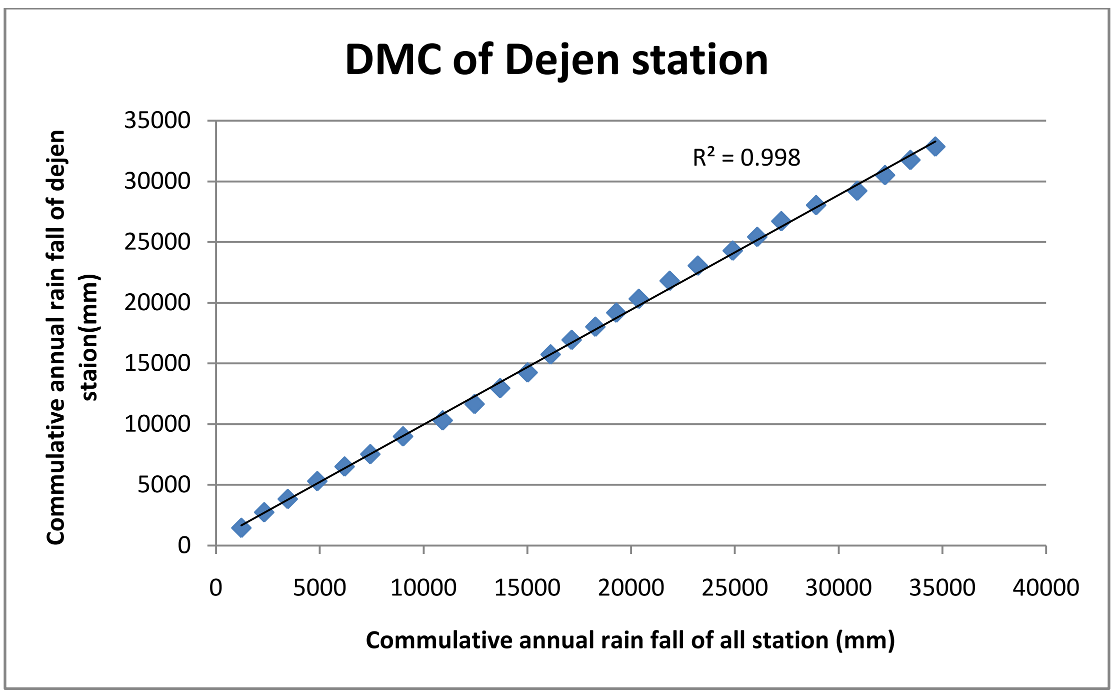
Appendix 8: Double mass curve for Mota rain gage station



Appendix 9: Double mass curve for D/markos station rain gage station



Appendix 10: Double mass curve for Dejen rain gage station



Appendix 11:ETo and climatic data Yetnora Meteorological data for CropWat 8

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day
January	7.7	23.8	51	54	7.4	10.4	1.32
February	9.2	25.4	42	54	7.7	13.1	2.02
March	10.8	26.3	50	59	7.5	16.1	2.94
April	11.2	26.1	50	57	7.7	19.2	3.71
May	11	25.6	57	61	7.5	20.6	4.1
June	10.7	23.4	67	49	6.1	19.1	3.77
July	10.5	19	88	43	4.1	16	2.94
August	10.4	18.8	89	42	5.4	16.6	2.84
September	9.4	21.2	78	47	7.4	16.8	2.75
October	8.3	23	64	54	8.1	14.4	2.2
November	7.3	23.5	59	47	7.8	11.2	1.44
December	6.7	23.5	53	52	7.6	9.7	1.12
Average	9.4	23.3	62	52	7.0	15.3	2.6

Appendix 12: rain fall and effective rain fall

month	Rain	Eff rain
	mm	mm
January	15.8	0
February	17.1	0.3
March	53.6	22.2
April	68.1	30.9
May	94.4	51.5
June	147.9	94.3
July	291.8	209.4
August	262.5	186
September	139	87.2
October	61.7	27
November	29	7.4
December	26.5	5.9
Total	1207.4	722.1

Appendix 13. CWR and IWR estimation for Maize crop.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.3	0.37	3.7	2.2	1.4
Dec	2	Init	0.3	0.34	3.4	2.1	1.2
Dec	3	Deve	0.45	0.54	5.9	1.4	4.5
Jan	1	Deve	0.72	0.9	9	0.1	8.9
Jan	2	Deve	0.97	1.28	12.8	0	12.8
Jan	3	Mid	1.17	1.82	20	0	20
Feb	1	Mid	1.18	2.11	21.1	0	21.1
Feb	2	Mid	1.18	2.39	23.9	0	23.9
Feb	3	Mid	1.18	2.75	22	0.3	21.7
Mar	1	Late	1.14	3.01	30.1	5.4	24.7
Mar	2	Late	0.89	2.63	26.3	8	18.3
Mar	3	Late	0.6	1.92	21.1	8.8	12.4
Apr	1	Late	0.39	1.35	5.4	3.6	0.9
Total					204.7	31.9	171.8

Appendix 14. CWR and IWR estimation for Tomato.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.6	0.73	7.3	2.2	5.1
Dec	2	Init	0.6	0.67	6.7	2.1	4.6
Dec	3	Deve	0.6	0.71	7.8	1.4	6.4
Jan	1	Deve	0.69	0.86	8.6	0.1	8.5
Jan	2	Deve	0.82	1.09	10.9	0	10.9
Jan	3	Deve	0.96	1.5	16.5	0	16.4
Feb	1	Mid	1.1	1.96	19.6	0	19.6
Feb	2	Mid	1.14	2.3	23	0	23
Feb	3	Mid	1.14	2.65	21.2	0.3	20.8
Mar	1	Mid	1.14	3	30	5.4	24.6
Mar	2	Mid	1.14	3.35	33.5	8	25.5
Mar	3	Late	1.11	3.56	39.2	8.8	30.5
Apr	1	Late	1	3.46	34.6	9	25.6
Apr	2	Late	0.88	3.27	32.7	9.7	23
Apr	3	Late	0.8	3.07	12.3	4.9	6.2
Total					303.8	51.9	250.7

Appendix 15. CWR and IWR estimation for potato crop

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.5	0.61	6.1	2.2	3.9
Dec	2	Init	0.5	0.56	5.6	2.1	3.5
Dec	3	Deve	0.54	0.64	7.1	1.4	5.6
Jan	1	Deve	0.74	0.93	9.3	0.1	9.2
Jan	2	Deve	0.96	1.27	12.7	0	12.7
Jan	3	Mid	1.13	1.75	19.3	0	19.3
Feb	1	Mid	1.14	2.03	20.3	0	20.3
Feb	2	Mid	1.14	2.3	23	0	23
Feb	3	Mid	1.14	2.65	21.2	0.3	20.9
Mar	1	Mid	1.14	3	30	5.4	24.6
Mar	2	Late	1.06	3.13	31.3	8	23.3
Mar	3	Late	0.92	2.95	32.5	8.8	23.7
Apr	1	Late	0.79	2.72	24.5	8.1	15.5
Total					242.8	36.4	205.5

Appendix 16. CWR and IWR of maize, tomato and potato crops in the study area

	Month	Jan	Feb	Mar	April	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Eto(mm/month)		1.32	2.02	2.94	3.71	4.10	3.77	2.94	2.84	2.75	2.20	1.44	1.12
Eff RF(mm/month)	Crop	0.00	0.30	22.20	30.90	51.50	94.30	209.40	186.00	87.20	27.00	7.40	5.90
Etc(mm/month)	Maize	41.80	67.00	77.50	5.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.00
	Potato	41.30	64.50	93.80	24.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.80
	Tomato	36.00	63.80	102.70	79.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.80
NIR(mm/month)	Maize	41.80	66.70	55.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.10
	Potato	41.30	64.20	71.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.90
	Tomato	36.00	63.50	80.50	48.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.90
TNIR(Mm3)													
Area(ha) 19470.11	Maize	8.14	12.99	10.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.38
14602.58	Potato	6.03	9.37	10.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.88
14602.58	Tomato	5.26	9.27	11.76	7.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.32
GIR(Mm3) 50% Eff	Maize	16.28	25.97	21.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.76
	Potato	12.06	18.75	20.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.77
	Tomato	10.51	18.55	23.51	14.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.64
GIR(m3/s)	Maize	6.08	10.74	8.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03
	Potato	4.50	7.75	7.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41
	Tomato	3.93	7.67	8.78	5.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.73
	Total annual GIWR=74.76 m^3/s												

Appendix 17. Effective irrigable area within minimum flow for each selected crop

Maize		GIWR (m3/s)	Min flow (m3/s)	Area irrigated with min flow(ha)	Un-irrigated area(ha)
Area	19470.11				
Efficiency	50%				
Month	Day				
Dec	31	1.03	0.26	2457.39	17012.72
Jan	31	6.08	0.24	384.28	19085.83
Feb	28	10.74	0.14	126.89	19343.22
Mar	31	8.04	0.18	217.95	19252.16
Potato	Area	14602.58			
Dec	31	1.41	0.26	1346.34	13256.24
Jan	31	4.50	0.24	389.4	14213.18
Feb	28	7.75	0.14	131.89	14470.69
Mar	31	7.81	0.18	168.28	14434.3
Tomato	Area	14602.58			
Dec	31	1.73	0.26	1097.3	13505.28
Jan	31	3.93	0.24	445.88	14156.7
Feb	28	7.67	0.14	133.67	14468.91
Mar	31	8.78	0.18	149.68	14452.9
Apr	24	5.31	0.20	275.00	14327.5