

**ASSESSMENT OF SURFACE IRRIGATION POTENTIAL OF GUDER
SUB-BASIN, ABAY RIVER BASIN, ETHIOPIA**

M.Sc. Thesis

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**ASSESSMENT OF SURFACE IRRIGATION POTENTIAL OF GUDER SUB-BASIN,
ABAY RIVER BASIN, ETHIOPIA**

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BIOGRAPHICAL SKETCH

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ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
ALOS	Advanced Land Observing Satellite
AOI	Area of Interest
AQUASTAT	Aqua Statistics
ASF	Alaska Satellite Facility
BMC	Billion Meter Cubic
CEC	Cation Exchange Capacity
CEST	Central European Summer Time
CI	Consistency Index
CNES	Centre National d'Études Spatiales
CR	Consistency Relationship
CWR	Crop Water Requirement
DEM	Digital Elevation Model
DFID	Department for International Development
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resource Data Analysis System
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FDC	Flow Duration Curve
GCP	Ground Control Point
GeoTIFF	Geo-referenced Tagged Image File Format
GILES	Geographic Information and Land Evaluation System
GIS	Geographic Information System
GLCN	Global Land Cover Network
GMES	Global Monitoring for Environment and Security
GPS	Global Positioning System
IFAD	International Fund for Agricultural Development

ISO	International Organization for Standardization
IWMI	International Water Management Institute
IWR	Irrigation Water Requirement
KMZ	Keyhole Markup Language Zip file
LSA	Land Suitability Assessment
LULC	Land Use Land Cover
LUPRD	Land Use Planning and Regulatory Department
MCE	Multi Criteria Evaluation
MOFED	Ministry of Finance and Economic Development
MoWR	Ministry of Water Resources
NASA	National Aeronautics and Space Administration
NED	National Elevation Dataset
NGA	National Geospatial intelligence Agency
NMSA	National Meteorological Services Agency
OLI	Operating Land Images
OWWDSE	Oromia Water Works Design and Supervision Enterprise
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
RI	Random Index
RS	Remote Sensing
RTC	Radiometric Terrain Correction
SPOT	Système Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
T°c	Temperature
TIRS	Thermal Infrared Sensor
WGS	World Geodetic System
WOA	Weighted Overlay Analysis
WRB	World Reference Base
XML	Extensible Markup Language

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Assessment of Surface Irrigation Potential of Guder Sub-Basin, Abay River Basin, Ethiopia

ABSTRACT

Assessing available land resources for irrigation is important for planning their use. Irrigation land suitability assessment has an important role in the utilization of scarce physical land resources. The study aimed at the surface irrigation potential and land suitability assessment for using GIS tools. By delineating the boundary of the study area, irrigation suitability of each physical land was classified based on the FAO guideline for land evaluation into S1, S2, S3, and N suitability classes independently, where potentially irrigable land was identified by weighted overlay analysis of factors of suitability. The main suitability factors used to identify the existing and potential irrigable land were slope, soil, land use/cover, and distance from water supply (sources). Surface water availability and land potentially suitable for irrigation development were considered. Surface water potential was examined by analyzing long-term daily historical river discharges. Analytical Hierarchy Process with the integration of GIS-based multicriteria decision making an approach using DEM and Sentinel 2A satellite data was utilized to evaluate land suitability for Surface irrigation in Guder sub-basin. A pairwise comparison matrix is used to establish the weights. About, 0.3 % area is classified in the class as highly suitable, 47.6 % as moderately suitable, 49.8% in marginally suitable, and 2.4 % in unsuitable for Surface Irrigation. The total command area which can be irrigated in upper, middle, and Lower Guder Catchment are calculated and found to be 122,515.3 ha, 130,027.06 ha, and 67,491.25 ha respectively. The result after overlay analysis in Arc Map indicated that approximately 317,748.71 ha (47.9%) of the Guder sub-basin is suitable highly to moderately for surface irrigation. The potential of surface water was evaluated concerning the water requirements of dominant crops in the study area. In the Upper Guder 13,272.72 ha could be irrigated with the available river flow for the maximum gross water demand. Similarly, it is 50,571.43 ha and 11,639.43 ha for Middle and Lower Guder watersheds respectively. Among the total potential suitable land in Guder sub basin the river flow can irrigate 75,483.58 ha (23.9%) area. Thus, the irrigation potential can be met by storing water during rainy season flows.

Keywords: Analytical Hierarchy Process, Irrigation, Land Suitability, Multi-Criteria Evaluation

1. INTRODUCTION

1.1. Background

Most of the Ethiopia population lives in highland areas, where about 85% is rural and dependent on low input and low output rainfed agriculture with limited use of irrigation technologies. Considering the current population growth rate and food insecurity, irrigation development is expected to play an important role in stimulating economic growth and rural development by increasing and stabilizing agricultural production and productivity in Ethiopia (MoWR, 2002; MoFED, 2006). Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity. In the agricultural development strategy of the country, irrigation development is crucial to improve smallholder livelihood (Tesfaye, 2015).

Appropriate management and selection of applicable irrigation methods is a prerequisite for wise utilization of scarce physical resources, land, and water. To ensure adequate management and design of a particular irrigation system, a well-developed and suitable database is quite important. Thus, it should be able to deal with spatially and temporally varying factors affecting the system (Dagnenet, 2008).

Ethiopia comprises 112 million hectares of land. Cultivable land area estimates vary between 30 to 70 Mha. Currently, high estimates show that only 15 Mha of land is under cultivation. For the existing cultivated area, the estimate is that only about 4 to 5 percent is irrigated, with existing equipped irrigation schemes covering about 640,000 ha. This means that a significant portion of cultivated land in Ethiopia is currently not irrigated (Seleshi, 2010).

Land suitability analysis (LSA) is a method to encounter inherent and potential capabilities and suitability for different objectives (FAO, 1976). Land assessment measures the degree of land usefulness for potential land use by land requirements and qualities (FAO, 1976). The multi-criterion evaluation (MCE) method is mostly applied for land suitability analysis. Further, the Analytic hierarchy process (AHP) is extensively utilized for multi-criterion decision making of land suitability for the various field. It determines the weight of importance for different land-use based on pairwise comparisons of various parameters according to their relative significance (Miller *et al.*, 1998). The analytic hierarchy process was firstly developed by (Saaty, 1980), establish a hierarchical model for solving complex problems of land management with best

alternatives (Malczewski, 2006). As a multi-criterion decision-making method, the analytic hierarchy process has been used widely for solving an extensive variety of problems based on complex parameters across various levels where the interaction among parameters is common characteristics (Tiwari, *et al.*, 1999). The weighted overlay analysis method (WOA) along with the analytic hierarchy process provides a very assuring outcome for the site suitability assessment of agricultural land use.

The method can be useful to the multi-level hierarchical structure of various constraints and criteria (Triantaphyllou and Mann, 1995). It has steps to analyze the relative influence of weights on each parameter, before obtaining the final score (Borouhaki and Malczewski, 2008; Bunruamkaewand Murayam, 2011). The analytical hierarchy process is one of the auspicious methods utilized for agricultural land suitability assessment based on individual parameters through quantitative assessment (Chen *et al.*, 2010a, b; Akinci *et al.*, 2013; Khahro *et al.*, 2014). Pairwise comparison is also used to calculate the overall score of individual elements or criteria. Integration of GIS and analytical hierarchy process helps to decision support system by the generation of suitability maps (Khahro *et al.*, 2014).

In this study, Irrigation land suitability in the Guder sub-basin was analyzed using AHP and GIS-based weighted overlay analysis (WOA) techniques. Multiple criteria Evaluation for Irrigation land suitability mapping were derived based on literature reviews, field investigations, and following FAO guidelines for irrigation land evaluation

1.2. Statement of Problems

The population is increasing and becoming beyond the carrying capacity of the available land. Because of an absence of an alternative source of livelihood, the people encroach into the forest land, cultivate the fragile steeply slope, resulting in land degradation, forest and grazing land are diminishing.

Ample water resource potential characterizes the Guder sub-basin. Currently, with the increased population, land shortage, and demand for food crops, farmers are in need to expand the irrigation fields. If the water resource potential is estimated and developed and well improved, prominent changes could happen through the use of small-scale irrigation for farming activities.

In the sub-basin different problems arise from the community such as the lack of alternative income source due to dependence on seasonal rainfall for crop production as well as an absence of integrated watershed management and unavailable planned land use for the sub-basin which leads to the use of land to expand to very steep slopes and marginal land.

The study area, Guder sub-basin lacks information on irrigation land and water resources in sufficient detail for further irrigation development. The study was aimed at assessing the land and water resources potential of the sub-basin for irrigation development and generating a suitability map of these resources using a geographic information system.

1.3. Objectives of the Study

1.3.1. General objective

The main objective of the study was the assessment of surface irrigation potential and land suitability for the Guder sub-basin and to prepare an irrigation land suitability map of the subbasin.

1.3.2. Specific objectives

The specific objectives of the study are:

- To identify potential land areas suitable for surface irrigation using a GIS tool
- To identify irrigation water potential for surface irrigation
- To develop a suitability map of the sub-basin for surface irrigation.

2. LITERATURE REVIEW

2.1. Irrigation Potential of River Basins

In Ethiopia, under the prevalent rain-fed agricultural production system, the progressive degradation of the natural resource base, especially in highly vulnerable areas of the highlands coupled with climate variability has aggravated the incidence of poverty and food insecurity. Water resources management for agriculture includes both support for sustainable production in rain-fed agriculture and irrigation (Awulachew *et al.*, 2005).

The area which can potentially be irrigated depends on the physical resources, soil, and water, combined with irrigation water requirements as determined by the cropping patterns and climate (FAO, 1986). Ethiopian plateaus are the source of most rivers (Abay, Awash, Tekeze, Mereb, Baro, Gilo, Akobo, and Omo rivers) that flows west and southwest. Ethiopia comprises 112 million hectares (Mha) of land; out of this land cultivable area is estimated to vary between 30 to 70 Mha. Currently, high estimates show that only 15 Mha of land is under cultivation and over 3.73 Mha of farmlands could be potentially developed by irrigation is estimated to be about 160,000ha, including the area under traditional irrigation. However, the total estimated irrigable land potential in Ethiopia is 5.3 Mha assuming the use of existing technologies, including 1.6 Mha through rainwater harvesting and groundwater.

Irrigated agriculture has realized only 4.3% of the total of its estimated potential. This means that a significant portion of cultivated land in Ethiopia is currently not irrigated. In terms of output, irrigated agriculture accounts for approximately 3% of total food crop production (MoWR, 2009, and IWMI, 2010).

Ethiopia is said to have an estimated irrigation potential of 3.5 million hectares of irrigation land (Awulachew *et al.*, 2007). Accordingly, 39 significant irrigation projects are planned to be implemented during the PASDEP period. To just mention a few of the major projects, these include the World Bank projects around Tana (100,000 ha); Anger Negesso Project in Oromia (49,563 ha); Humera project in Tigray (42,965 ha); Kessem Tendaho in Afar (90,000 ha); Upper Beles in Benishangul Gumz (53,000 ha); and Ilo-Uen Buldoho (32,000 ha) in Somali (MOFED 2006; MoWR, 2006). The total estimated area of irrigated agriculture in the country is about in 2005/2006 was 625,819 ha, out of which 483, 472 is from the traditional irrigation, 56,032 ha is

from modern small scale, 86,612 ha is from modern medium and large-scale schemes. The total and modern irrigated area accounts for about 17 and 5 percent of the potential respectively

2.2. Irrigation Potential in Ethiopia

The estimates of the irrigation potential of Ethiopia vary from one source to the other, due to lack of standard or agreed criteria for estimating irrigation potential in the country. The earlier the report, for example from the (World Bank, 1973) showed the irrigation potential at a lowest of 1.0 and 1.5 million hectares, and a highest of 4.3 million hectares. There have also been different estimates of the irrigation potential in Ethiopia. According to the Ministry of Agriculture (MoA, 1986), the total irrigable land in the country measures 2.3 million hectares. The International Fund for Agricultural Development (IFAD, 1987), on the other hand, gives a figure 2.8 million ha. A total of 3.7 million ha had been identified as potentially irrigable land by (MoWR, 2002). Most of these figures are derived by adding up the irrigation potential of the country's twelve river basins (Sileshi *et al*, 2007)

Abbay River Basin

Abbay river basin has a catchment area of 199,812 km², covering parts of Amhara, Oromia, and Benishangul-Gumuz regional states. It has the major sub-basins of Anger, Beles, Dabus, Debre Markos, Didesa, Dindir/Rahid, Fincha, Guder, Jemma, Lake Tana, Mota, and Muger. The major river in the basin is the Blue Nile (Abay) river, which rises in Lake Tana flowing about 1,450 km long, and merges with the White Nile to form the Nile proper. The river basin has the lowest elevation of 500 m. and the highest elevation of 4261 m. The total mean annual flow from the river basin is estimated to be 54.8 BMC.

The Abay river basin is well known as the source of the Nile, a land of dramatic gorges and mountains. Abay is the most important river basin in Ethiopia. It accounts for 20 percent of Ethiopia's land area, for about 50 percent of its total average annual runoff which emanates from the Ethiopian highlands, for 25 percent of its population and over 40 percent of its agricultural production. The rivers of the Abay basin contribute on average about 62 percent of the Nile at Aswan; together with the contribution of Baro Akobo and Tekeze rivers, Ethiopia accounts for at least 86 percent of the runoff at Aswan.

According to MoWR data, it is identified that the Abay river basin has a potential of 211 irrigation projects, of which 90 are small-scale, 69 are medium-scale and 52 are large-scale. A total of 815,581 hectares of potentially irrigable land is estimated, out of which 45,856 ha are for small scale, 130,395 hectares for medium-scale, and 639,330 hectares for large-scale development.

2.3. Irrigation Land Suitability Evaluation Factors

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

Land evaluation is primarily the analysis of data about the land its soils, climate, and vegetation in terms of realistic alternatives for improving the use of that land. For irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, to the distance from available water sources, and the terrain conditions concerning methods of irrigation considered (FAO, 2007). In addition to these factors, land cover/land use types are considered as limiting factors in evaluating the suitability of land for irrigation (Hailegebriel, 2007; Meron, 2007).

As extensively discussed in FAO land evaluation guidelines (FAO, 1976, 1983, 1985), the suitability of these factors for surface irrigation method and the given land utilization types can be expressed corresponding to the following suitability classes.

2.3.1. Order S – suitability classification

The classes under this order are:

- S1 (highly suitable) - land having no significant limitation to a sustained application of a given use.
- S2 (moderately suitable) - land having limitation which in the aggregate are moderately severe for a sustained application of a given use.
- S3 (marginally suitable) - land having limitation which in the aggregate are severe for a sustained application of a given use and will reduce productivity or benefits.

2.3.2. Order N – suitability classification

- N1 (temporarily not suitable) - land having limitations that may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.
- N2 (Permanently not suitable) - land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land of given land use. The factors considered for surface irrigation land suitability evaluation are narrated separately in subsequent subsections

2.3.2.1. Slope

The slope is the incline or gradient of a surface and is commonly expressed as a percent. Slope is important for soil formation and management because it influences runoff, drainage, erosion and choice of irrigation types. The slope gradient of the land has a 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 (FAO, 1999).

2.3.2.2. Soils

The assessment of soils for irrigation involves using permanent properties 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.

2.3.2.3. Land Use/Land Cover

Land cover and land use are often used interchangeably. However, they are quite different. The (GLCN, 2006) defines land cover as the observed (bio) physical cover, as seen from the ground or through remote sensing, including vegetation (natural or planted) and human construction (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock or sand surfaces also count as land cover.

However, the definition of land use establishes a direct link between land cover and the actions of people in their environment. Thus, a land-use can be defined as a series of activities undertaken to produce one or more goods or services. Given land use may take place on one, or more than one, pieces of land, and several land uses may occur on the same piece of land. Definitions of land cover or land use in this way provide a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation. Therefore, matching of existing land cover/use with topographic and soil characteristics is used to evaluate land suitability for irrigation with land suitability classes and present possible lands for new agricultural production (Jaruntorn, *et al.*, 2004).

The land use land cover of the Guder sub-basin essentially follows the divide between highland and lowland. The high land around the Ambo and Guder mountainous areas were once dominantly covered with forests. However, these sub-humid tropical forests have been reduced to remnants, having been converted to cultivation and grazing. Almost the entire highland area is now under farmland (BCEOM, 1998).

2.3.2.4. Water Availability

It is important to make sure that there will be no lack of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle (FAO, 2001). Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the year which it is available (FAO, 1985). Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use. Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source is near the center of the irrigated area to minimize the size of the delivery channels and pipelines. Therefore, distance from water sources to command area, nearness to rivers is useful to reduce the conveyance system (irrigation canal length) and thereby develop the irrigation system economical (Sileshi, 2000).

2.4. Overview of GIS Technology

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

GIS is a computer-assisted system capture, storage, retrieval, analysis, and display of spatial data, within a particular organization. Information derived through remote sensing along with non-remote sensing methods are integrated within GIS and specific management, and developmental plans are arrived finally. The information in a GIS is presented in two basic forms: as maps and as tables to produce information that is needed by a user (Aronoff, 1993).

The main purpose of GIS is to process spatial information. The data structure can be conceptualized as a set of “floating maps” with common registration, allowing the user to “look” down and across the stack of maps. All GIS packages contain hardware and software for data input, storage, processing, and display of computerized maps. The processing functions of these systems can be broadly grouped into three functional areas, computer mapping, spatial database management, and cartographic modeling (Goodchild *et al.*, 1993). In Ethiopia, the Land Use Planning and Regulatory Department (LUPRD) of the Ministry of Agriculture developed custom-oriented Geographic Information and Land Evaluation System (GILES) software for the application of land evaluation, land capability, and suitability classification and land use-planning purposes with special reference to the highlands of the country (Saymen, 2005).

The information within GIS consists of two elements: spatial data represented by points (e.g., well locations), lines (e.g., streams, road networks), and polygons (e.g., soil delineations), and attribute data or information that describe the characteristics of the spatial features. The spatial data are referenced to a geographic coordinate system and are stored either in a vector or raster format.

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

2.4.1. Mapping

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

2.4.2. Weighted Overlay Analysis

The weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding an optimal site for irrigation requires weighting of factors such as land cover, slope, soil, and distance from water supply (Yang Yi, 2003). To prioritize the influence of these factor values, weighted overlay analysis uses an evaluation scale from 1 to 9. For example, a value of 1 represents the least suitable factor in evaluation while a value of 9 represents the most suitable factor in evaluation. Weighted overlay only accepts integer rasters as input, such as a raster of land cover/use, soil types, slope, and Euclidean distance output to find suitable land for irrigation (Janssen and Rietveld, 1990). Euclidean distance is the straight line from the center of the source cell to the center of each of the surrounding cells.

2.4.3. Watershed Delineation

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

2.5. GIS as a Tool for Irrigation Potential Assessment

In the past, several studies have been made to assess the irrigation potential and water resources by using the GIS tool (FAO, 1987; FAO, 1997; Melaku, 2003; Negash, 2004; Hailegebriel, 2007; Meron, 2007).

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

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

Food and Agricultural Organization (FAO, 1997) has studied the irrigation potential of Africa taking into consideration the above limitations. It concentrated mainly on quantitative assessment based on physical criteria (land and water) but relied heavily on information collected from the countries. A river basin approach had been used to insure consistency at river and basin levels. Geographic Information System (GIS) facilities were extensively used for this purpose. In this study, a physical approach to irrigation potential was understood as setting the global limit for irrigation development.

(Melaku, 2003) carried out a study on the assessment of irrigation potential at the Raxo dam area (Portugal) for the strategic planning by using Remote Sensing (RS) and Geographic Information System (GIS). This study considered only the amount of available water in a dam and topographic factor (slope) in identifying potential irrigable sites on the downstream side of the dam. Another study was conducted by (Hailegebriel, 2007) using a similar technique in Beles sub-basin while

considering different factors such as soil, slope, land use, and water resource availability in evaluating surface irrigation suitability.

(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 of perennial rivers in the basin to identify potentially irrigable land. (Meron, 2007) and (Kebede, 2010) also done their study on surface irrigation suitability potential assessment on southern Abay and dale woreda Sidama zone respectively using GIS and remote sensing technology.

2.6. Application of Remote Sensing

Remote Sensing refers to the technique of obtaining information about an object or feature through the analysis of data acquired by a device that is not in contact with the object or feature under investigation (Lillesand and Kiefer, 1994). This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. In much of remote sensing, the process involves an interaction between the incident radiation and the targets of interest. Remote Sensing technology produces an authentic source of information for surveying, identifying, classifying, mapping, monitoring, and planning of natural resources and disaster mitigation, preparedness, and management as a whole.

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

2.7. Review of Commonly Used GIS and Remote Sensing Data

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

2.7.1. Satellite imagery

Remotely sensed satellite data are familiar to GIS users. The utility of different remote sensing data from different satellites have been demonstrated in many fields such as agriculture, cartography, civil engineering, environmental monitoring, forestry, geography, water resources management, land resources analysis, and land use planning. The use of satellite images in any of the fields mentioned above, demands the knowledge of the different bands that each sensor system onboard satellites use to take the imagery and how these bands of the electromagnetic spectrum interact with land surface features and with that of the atmosphere (Lemlem, 2007). All types of satellites vary with their sensors, flight height, bands, spectral and or spatial resolutions etc.

The spatial resolution of a satellite image relates to the ground pixel size. For example, a spatial resolution of 30 meters means that each pixel in the satellite image corresponds to a ground pixel of 900 square meters. The pixel value, also called the brightness value, represents light energy reflected or emitted from the Earth's surface (Lillesand and Kiefer, 2000). The measurement of light energy is based on spectral bands from a continuum of wavelengths known as the electromagnetic spectrum. Panchromatic images are comprised of a single spectral band, whereas multispectral images are comprised of multiple bands.

As there are many satellites in space providing remote sensing data, their application will vary with their way of data acquisition. The most popular satellites providing high-resolution image for free were the Sentinel at 10 m.

Sentinel-2A satellite sensor was successfully launched on June 23, 2015, at 03:51:58 am CEST from a Vega launcher from the spaceport in Kourou, French Guiana. Sentinel-2A satellite is the first optical Earth observation satellite in the European Copernicus program and was developed and built under the industrial leadership of Airbus Defense and Space for the European Space Agency (ESA).

Sentinel-2A satellite was built by Airbus Defense and Space which adds color to the Copernicus program through a multispectral instrument that provides unique image quality. Copernicus is the new name of the European Commission's Earth Observation Programme, previously known as GMES (Global Monitoring for Environment and Security).

The mission is dedicated to the full and systematic coverage of land surface including major islands globally to provide cloud-free products typically every 15 to 30 days over Europe and Africa. Sentinel-2A satellite image data support generic land cover, land use, and change detection maps and maps of geophysical variables for leaf area index, leaf chlorophyll content, and leaf water content.

The span of 13 spectral bands, from the visible and the near-infrared to the shortwave infrared at different spatial resolutions ranging from 10 to 60 meters on the ground, takes global land monitoring to an unprecedented level. The four bands at 10-meter resolution ensure continuity with missions such as SPOT-5 or Landsat-8 and address user requirements, in particular, for basic land-cover classification. The six bands at 20-meter resolution satisfy requirements for enhanced land-cover classification and the retrieval of geophysical parameters. Bands at 60 meters are dedicated mainly to atmospheric corrections and cirrus-cloud screening.

Sentinel-2A satellite is the first civil optical Earth observation mission of its kind to include three bands in the 'red edge', which provide key information on the vegetation state.

Sentinel-2A satellite will be able to see very early changes in plant health due to its high temporal, spatial resolution, and 3 red edge bands. This is particularly useful for the end-users and policymakers for agriculture applications and to detect early signs of food shortages in developing countries. The images, archived in the United States and at Landsat receiving stations around the world, are a unique resource for global change research and applications in agriculture,

cartography, geology, forestry, regional planning, surveillance and education, and can be viewed through the U.S. Geological Survey (USGS) 'Earth Explorer' website.

2.7.2. Digital elevation model (DEM)

A digital elevation model (DEM) is the digital representation of the land surface elevation with respect to a given reference datum. DEM is frequently used to refer to any digital representation of a topographic surface and is the simplest form of digital representation of topography. DEMs are used to determine terrain attributes such as elevation, slope, and aspect at any location.

Alaska Satellite Facility (ASF) has produced DEM products at both 12.5-m and 30-m resolutions for the different world areas. The creation of radiometric terrain corrected (RTC) products is a project of the Alaska Satellite Facility that makes SAR data accessible to a broader community of users. The project corrects synthetic aperture radar (SAR) geometry and radiometry and presents the data in the GIS-friendly GeoTIFF format.

The product package includes the following contents: Radiometric Terrain Corrected GeoTIFF file for each polarization available which pixel values are gamma nought power in 32-bit floating-point format and spacing is 12.5 m for high-resolution (RT1) and 30 m for low-resolution (RT2) products, Incidence Angle GeoTIFF, indicating the angle in radians for each pixel and pixel spacing is the same as the RTC GeoTIFF in the package, Layover/Shadow GeoTIFF, indicating where processing was impacted by layover or shadow of spacing is the same as the RTC GeoTIFF in the package, the DEM used for RTC processing in GeoTIFF format where best resolution SRTM or NED source DEM available with geoid correction applied and Pixel spacing is the same as the RTC GeoTIFF in the package and Browse image in GeoJPEG format 1000 x 1000 pixels, Color images available when multiple polarizations are available (FBD and PLR products) Metadata in ISO 19115 format (XML file) KMZ file with 30-m overlay.

Synthetic aperture radar (SAR), used to create the majority of the imagery available in the ASF archive, is one of the power tools of remote sensing. Synthetic aperture radar (SAR) bounces a microwave radar signal off the Earth's surface to detect physical properties.

Most DEMs are geoid-based and require a correction before they can be used for terrain correction. The DEM included in an ASF RTC product was converted from the orthometric height of the source DEM to ellipsoid height using the ASF Map Ready geoid adjust tool.

This tool applies a geoid correction so that the resulting DEM relates to the ellipsoid. An online tool is available that computes the height of the geoid above the WGS_84 ellipsoid, and will show the amount of correction that was applied to the source DEM used in creating an RTC product.

The quality of an ALOS PALSAR RTC product is directly related to the quality of the digital elevation model (DEMs) used in the radiometric terrain correction (RTC) process.

Digital Elevation Models (DEM) is a commonly used digital elevation source and an important part of using for watershed characterization. Many agencies provide DEM data with 90-m, 30-m and 10-m resolutions. The point elevation data are very useful as an input to the GIS. This data is used to yield important derivative products such as slope, aspect, flow accumulation, flow direction and curvature in process of watershed delineation. ALOS PALSAR Radiometric Terrain Correction (<https://asf.alaska.edu>).

3. MATERIALS AND METHODS

3.1. Description of the study area

Guder sub-basin which has a drainage area of 6683.82 square kilometers is situated in the Northwest of Ethiopia; in the Southeastern part of the Blue Nile Basin approximately between 7°30' to 9°30' N latitude and 37°00' to 39°00'E longitude. The Guder River originates from the mountainous area south of the towns of Ambo and Guder at an elevation of 3000 m.a.s.l. The river flows from the south to the north and has its outlet to the Abay River. The Guder sub-basin borders with the Muger sub-basin to the east, the Awash Basin to the south, and the Fincha sub-Basin to the west.

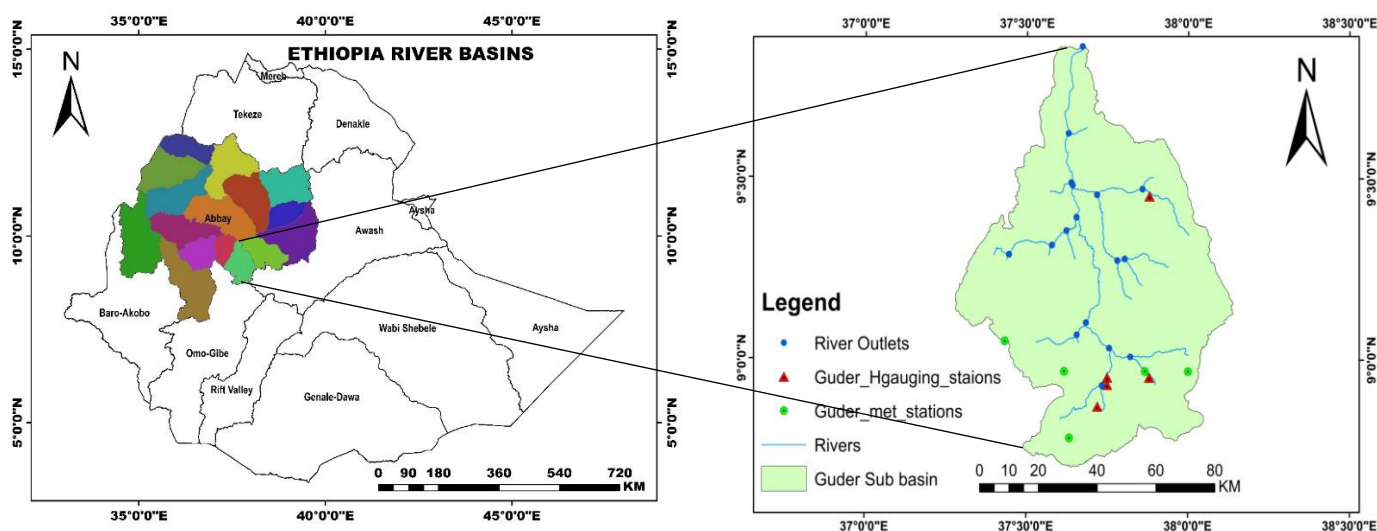


Figure 1. Description of the study area

3.1.1. Topography

The elevation of Guder sub-basin varies from 916 to 3302 m.a.s.l. The higher elevation ranges are located on the mountainous area in the South of the town of Ambo and Guder.

3.1.2. Climate

The climate of Ethiopia can be classified in different ways including the Traditional, Koppen's, Thornthwaite's, Rainfall regimes, and Agro-climatic zone classification systems. The most commonly used classification systems are the traditional and the agro-ecological zones. According to the traditional classification system, this mainly relies on altitude and temperature; there are

five climatic zones namely: Wurch (cold climate at more than 3000 Mts. altitude), Dega (temperate like climate-highlands with 2500-3000 Mts. altitude), Woina Dega (warm at 1500-2500 Mts. altitude), Kola (hot and arid type, less than 1500m in altitude), and Berha (hot and hyper-arid type) climate (NMSA, 2001).

Guder sub-basin, despite being near the equator, has a comparatively mild climate because of its high elevation (1500-3000 m.a.s.l). The annual climate may be divided into a rainy and dry season. The rainy season may be divided into a major rainy season (Kiremt) and minor rainy seasons (Belg & Tsedey). During the Kiremt season from June through August above 75% of the total rainfall occurs and in the Belg season from March to May small rainfall occurs. The dry seasons (Bega) occur in December to February and Tsedey covers from September through November. There is a high diurnal variation in temperature.

The monthly rainfall distributions of the study area indicate that July and August are the wettest months of the year in all the selected stations. The mean monthly rainfall of the Ambo, Asgori, Gedo, Guder, and Tikur Enchini stations for the period of 1999-2018 is shown in Figure 2.

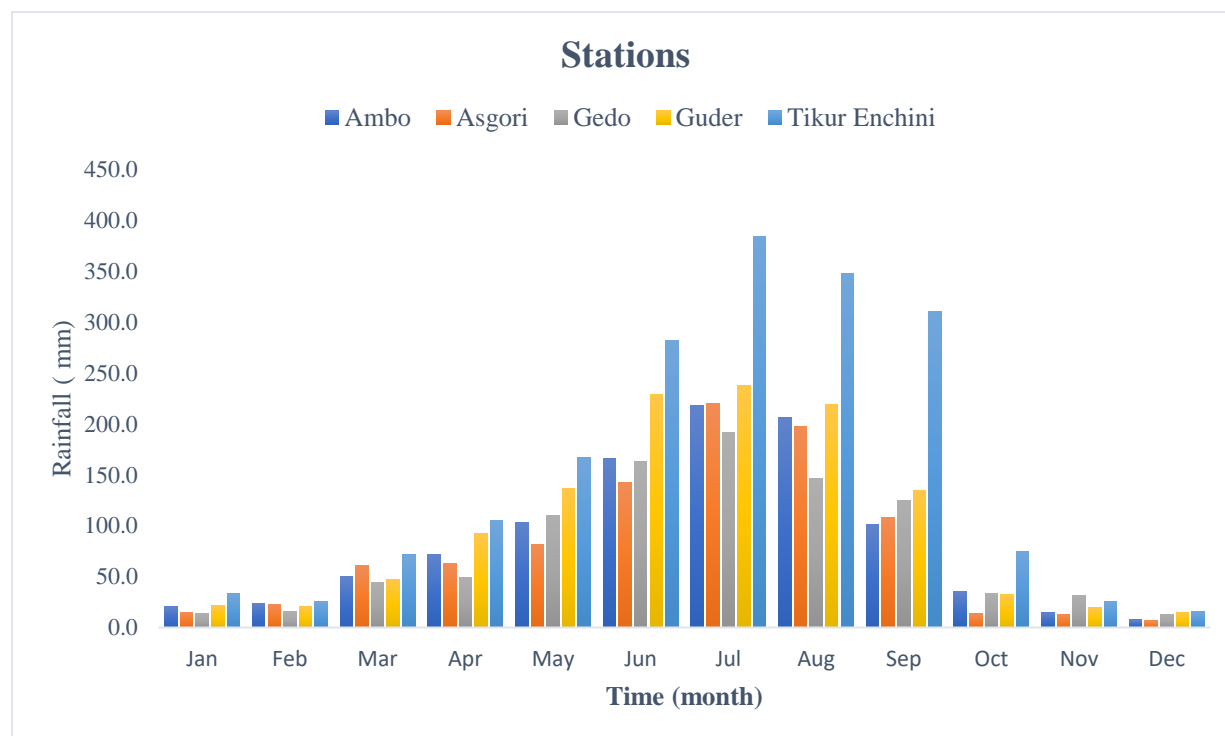


Figure 2. Mean monthly rainfall of five rain gauge stations for the period of (1999-2018)

3.1.3. Geology and Soil

The geology of the area is characterized by the exposure of different rocks from the oldest to the youngest superficial deposits. Guder sub-basin contains Precambrian metamorphic and intrusive, Paleozoic sediments, sedimentary rocks, Cenozoic Volcanic, and Quaternary deposits. According to the age order from older to younger, the local geology of the project area comprises Precambrian rocks, Paleozoic and Mesozoic sedimentary rocks, Tertiary volcanic rocks, Quaternary Volcanic, and Quaternary sediment deposit. The Precambrian basement rocks the older rocks formed by strong pressure (metamorphic) found at the base of geologic structure. It includes the high-grade metamorphic rocks (Biotite, Quartz, and Granite), Mafic Ultramafic rocks, and Granite intrusive rocks. On the contrary, Quaternary sediment deposits are the youngest layer which includes Alluvial Deposits mainly occupies the vast plain alongside the river plains, graben, and marshy areas, but rarely, covers the base of gently sloping hills and also Eluvial deposits mostly found on the plateau and occupying flat-lying and gentle topography is represented by red to reddish-brown soils that are developed from the surrounding parent rocks (OWWDSE, 2018).

Corresponding to the variation in landscape and other soil-forming factors such as climate and vegetation, the soils of the Guder sub-basin are also highly variable. The major soil types in the area include Gleyic Luvisols, Cambic Luvisols, Aluandic Andosols, Rhodic Nitisols, Calcic Vertisols, Chromic Luvisols, Dystric Nitisols, and Pellic Vertisols, Vertic Cambisols, Chromic Cambisols, Eutric Leptosols, and Lithic Leptosols. These soils have various productivity limiting characteristics such as acidity, depth, and permeability (OWWDSE, 2018).

3.1.4. Agronomy

Agriculture is the dominant economic sector in the Guder sub-basin. Traditional and backward practices dominate farming activities in the Guder sub-basin. The type of production prevails the long period low productive practice. There is low utilization of modern inputs. Moreover, subsistence production characterizes the agricultural production of the area.

The main cropping season is the most dominant system in the study area when crops are entirely grown under rainfed conditions. Cultivation is largely confined to the periods during or immediately following the small rains and the big rains.

Crops are planted during or immediately following the rains (June-September) to permit maturing and harvesting in the dry season (October-January). Major rainfed crops grown in the sub-basin are teff, wheat, barley, maize, sorghum, faba beans, field peas, linseed, oats, chickpeas, and lentils, etc.

Major vegetable crops produced in the sub-basin include potato, head cabbage, onion, tomato, shallot, red/green pepper, garlic, beetroot, carrot, taro, sweet potato, etc. perennials like sugarcane and fruits like mango, avocado, guava, etc are in the crop grown under rainfed conditions.

Irrigation during the dry season starts with land preparation soon after harvesting the crops grown on residual moisture in December. Planting dates can be staggered from January to March depending on crop type. Maize and vegetables (tomato, potato, onion, shallot, garlic, head cabbage, and beetroot) are planted with irrigation water during the season. (OWWDSE, 2018).

3.2. Data Collection

To achieve the objectives of the study, different data inputs were collected and downloaded from different sources such as DEM, Satellite Image downloaded from Alaska satellite facility and United State Geological Survey (USGS) respectively, Soil data obtained from Oromia Water Works Design & Supervision Enterprise (OWWDSE) and Streamflow data from Ministry of Water, Irrigation and Energy. The materials and data used to assess surface water potential and land suitability and mapping of the study area are Software (ArcGIS 10.4, ERDAS Imagine 2014), Satellite images, Meteorological data, Soil data, streamflow data, DEM (Digital Elevation Model).

3.2.1. Meteorological Data

The meteorological data required for this study were collected from the Ethiopian National Meteorological Services Agency (NMSA) at the Addis Ababa office. The meteorological variables collected vary from station to station depending on the class of the stations. The daily meteorological data collected were precipitation, maximum and minimum temperature, relative humidity, wind speed, and sunshine hours at Ambo, Gedo and Tikur enchini stations.

Table 1. List of the station name, location, and meteorological variables

No	Station Name	Latitude (degree)	Longitude (degree)	Elevation (m)	Rainfall Mm	Max T°c	Min T°c	Start Year	End year
1	Ambo	8.98	37.84	2068	✓	✓	✓	1999	2018
3	Gedo	9.02	37.46	2520	✓	✓	✓	1999	2018
5	Tikur E.	8.84	37.67	2467	✓	✓	✓	1999	2018

The only station which has data for relative humidity, sunshine hours, and wind speed is Ambo with a short period of record. All stations listed above contain daily rainfall and temperature data for at least twenty years and for the other stations these data were acquired from weather data.

3.2.2. Hydrological Data

In the Guder Sub-basin, there are some flow gauging stations located on upper Guder relatively small tributaries and/or near the headwaters of the main river that have a relatively long record of daily streamflow data. These streamflow data from 1994-2013 collected at the Three gauging stations from the Ethiopian Ministry of Water and Energy hydrology department at Addis Ababa office at Indris (near guder), Guder (at guder), and Duber (near Duber)

Table 2. Hydrological gauging stations of rivers

Station number	River	Site	Latitude	Longitude	Installed date	Drainage area (Km ²)
113005	Guder	@ Guder	8°57'N	37°45'E	15-2-59	524
113038	Indris	@ Guder	8°56'N	37°45'E	1-3-86	111
113047	Duber	Nr. Duber	9°28'N	37°53'E	-	225.2

Table 3. Data sources and details

Parameters	Data type	Data sources	Details of data	Period
Slope	Spatial data	ALOSPALSAR	12.5m x12.5m	2008
Soil	Spatial data	OWWDSE	0.5 - 2 Km units	2018
LULC	Spatial data	Sentinel 2A image	10 x 10 m	01/02/2019
Distance from water sources	Spatial data	ALOSPALSAR	12.5m x 12.5m	2008

3.2.3. Soil Properties

Soil is a major factor in the suitability of land for sustained irrigation. Its primary influence is on the productive capacity, but it also influences production and development costs. Soil texture, soil drainage, soil depth, and soil type are the major physical properties of soil that are very important for the evaluation of the irrigation potential of the basin. They affect the root growth of a plant, infiltration of water into the soil, and the production of crops. In this study, soil depth, soil texture, and soil drainage are some properties taken as factors to assess general soil suitability for irrigation potential of the sub-basin. The soil properties used here were first standardized according to FAO guidelines and then used for land suitability assessment.

3.2.4. Slope

The slope is the incline or gradient of a surface and is commonly expressed in percent. The slope is important for soil formation and management because it influences runoff, drainage, erosion, and the choice of crops.

The slope gradient of the land has a great influence on the length of the irrigation run, crop adaptability, erosion control practices, and irrigation method. With surface irrigation, the following adverse effects occur as the gradient increases: erosion hazard increases, water control becomes more difficult, the practical length of irrigation runs decreases, and crop selection becomes more limited. Slope also orders the irrigation method used. These factors intensify as the gradient increases. Steep gradients usually result in lower productivity and higher costs of production.

Slope map were created from raster digital elevation model of 12.5 m spatial resolution. The Slope derived from the DEM was classified based on the classification system by (FAO, 1990) for suitability assessment.

According to FAO standard guidelines for the evaluation of slope gradient, slopes, which are less than 2%, are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended (FAO, 1999).

3.2.5. Water Resources

Guder river is one of the main rivers found in the country. It flows in the center of the Guder sub-basin which originates from a mountainous area south of Ambo and Guder towns. The Guder river flows from the south to the north and has its outlet to the Abay River. Some of the major tributaries of the Guder sub-basin include the upper side of the watershed which collects surface runoff from Huluka, Fatto, and Indris in the middle part of the watershed which collects surface runoff from debris, and in the downstream part, Duber contributes the main Guder River.

Daily river flow data from 1994 to 2013 of the Guder main river and four Guder tributary rivers were obtained from the Ethiopian Ministry of Water, Irrigation, and Energy. The data was checked for gross errors, and missed recordings were filled using the Multiple imputation method. The data were required to quantify the amount of water available for surface irrigation during the dry season.

3.3. Methodology

This study consists of two parts, First, the land most suitable for surface irrigation was determined, and then the river water available during the dry season is quantified. Land suitability was determined by assigning weights to the factors that likely affect the irrigation potential of a certain land area. Factors considered are land features (soil properties, land use, and slope) and proximity to a perennial river. Second, the amount of water available during the dry season (October to May) was determined by analyzing long term discharge records for the Guder main rivers in the Guder sub-basin.

3.3.1. Data Pre-Processing and Checking

Collected data can contain errors due to failures of the measuring device or the recorder. Therefore, before using the data for a specific purpose, the data have to be checked and errors have to be corrected. To make use of the streamflow and rainfall data for research, their consistency should be checked.

The double mass curve is used to check the consistency of streamflow and rainfall data by comparing data for a single station with that of a pattern composed of the data from several other stations in the study area.

Rainfall and river flow missed data were filled using a tool called XLSTAT using Multiple imputation methods with self-iteration of each station up to several times. Multiple imputation is a strategy of replacing each missing value with a set of 'm' plausible values drawn from their predictive distribution. The multiply imputed datasets can be analyzed by complete data methods and the results from these analyses are combined and overall estimates are produced. This method avoids the problems of single imputation, can relieve the distortion of the sample variance, and produces unbiased estimates. (Farhangfar, A., *et al*, 2007).

3.4. Multi-Criteria Decision Evaluation

Multi-Criteria Evaluation is a set of procedures designed to facilitate decision-making. The basic purpose is to investigate several choice possibilities in the light of multiple criteria and conflicting objectives. Decision theory is concerned with the logic by which one arrives at a choice between alternatives. But those alternatives are varying from problem to problem.

They might be alternative actions, alternative hypotheses about a phenomenon, alternative objects to include in a set. In the present study multi-criterion, site suitability modeling was developed to establish appropriate and potential locations for irrigation development based on a group of constraints and criteria. Depending on their significance and importance in agriculture four different constraints and criteria were selected. The identification of different criteria depends on the maximum limitation method that influences the use of land for irrigation which includes soil properties, slope, land use /land cover and distance from water, etc.

Moreover, weights for each selected criterion were estimated using Analytical Hierarchy Process, and after that weighted overlay, the analysis method was adopted to establish the suitability map. (Table 3) represents the data used, types, and sources for the irrigation site suitability.

3.4.1. Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach introduced by (Saaty 1977, 1994). The AHP has attracted the interest of many researchers mainly because of the effective mathematical properties of the method (Triantaphyllou and Mann, 1995). One of the most widely known and used multi-criteria analysis approaches, the AHP method enables users to determine the weights of the parameters in the solution of a multi-criteria problem. In the AHP method, a hierarchical model consisting of objectives, criteria, sub-criteria, and alternatives is used for every problem (Saaty, 1990). After the problem is set on a hierarchical structure, the weights of the criteria forming the hierarchy are calculated (Ozturk and Batuk, 2010). To evaluate the criteria included in a level compared with other criteria included in the next hierarchy level, scoring is made with the utilization of the preference scale (Table 4) suggested by (Saaty, 1980), and a pairwise comparison matrix is created (Saaty, 1980, 2004).

The pairwise comparison matrix consists of $n(n - 1)/2$ comparisons for n number of elements (Malczewski, 1999; Ozturk and Batuk, 2010). Solving a problem using AHP is carried out using the weights or priorities of the criteria subjected to pairwise comparison. Weights or priorities are determined by normalizing the pairwise comparison matrix. For this normalization, a “normalized pairwise comparison matrix” is obtained by dividing the column elements of the matrix by the sum of each column. The row elements in the obtained matrix are summed, and the total value is divided by the number of elements in the row. In this manner, a priority vector or weight vector is obtained (Tombus, 2005). Weights are within the range of 0-1, and their sum is equal to 1 (Malczewski, 1999; Ozturk and Batuk, 2010).

While performing pairwise comparisons of criteria in the AHP method, a certain level of inconsistency may occur. Therefore, the logical consistency of pairwise comparisons must be checked (Ozturk and Batuk, 2010). To measure the consistency of pairwise comparison judgments, the consistency ratio proposed by (Saaty, 1980) is used. A consistency ratio is calculated for the pairwise comparison matrix. The upper limit proposed by Saaty for this ratio is 0.10. In a case where the consistency ratio calculated for the judgments is below 0.10, it is considered that the judgments exhibit a sufficient degree of consistency and that the assessment can be continued. If the consistency ratio is above 0.10, then the judgments are considered inconsistent. In this case,

the quality of the judgments needs to be improved. The consistency rate can be reduced by reviewing the judgments (Ozturk and Batuk, 2006).

Table 4. The fundamental scale for pairwise comparison (Saaty, 1980).

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	Activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent Judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

3.5. Multi-Criteria Evaluation

The following are the procedures, which were used for developing a land suitability map for surface Irrigation potential in the study area.

3.5.1. Establishing the Factors

A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore most commonly measured on a continuous scale.

For the evaluation of physical land suitability of the sub-basin for irrigation, sets of factors that influence the capability of land for surface irrigation in the study area were first established.

The following factors, which were discussed before, were considered for the assessment of land suitability for irrigation:

- Slope gradients
- Soil properties (soil depth, soil drainage, and soil texture)
- Land use/Land cover and
- Distance from water sources

3.5.2. Standardization of Factors

The selected criteria maps are initially in different units. For executing WOA for land suitability, the criteria maps need to be converted into a similar scale through standardization techniques. Standardization techniques convert the measurements in each criteria map into a uniform measurement scale so that the resulting maps lose their dimension along with their measurement unit (Reshmidevi *et al.*, 2009; Zabihi *et al.*, 2015). After all the criteria maps are standardized, the weights of each criteria map can be calculated using AHP. Ratings were given for all factors on a 9-point continuous scale. For example, if one feels that slope gradient is very strongly more important than distance from water sources in determining physical land suitability for surface irrigation, one will enter a 7 on this scale. If the inverse is the case (Distance from water source 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.

Table 5. Pairwise comparison matrix for multi-criteria decision problems

Criteria	Slope	Distance from water sources	Soil	LULC
Slope	1	2	2	3
Distance from water sources	1/2	1	3	4
Soil	1/2	1/3	1	2
LULC	1/3	1/4	1/2	1

3.5.3. Calculation of Weight for each Factor

The analytic hierarchy process is one of the most significant multicriteria decision-making techniques. The process is applied to a set of criteria or sub-criteria to establish a hierarchical structure by giving the weight of each criterion an incomplete decision-making process (Kiker *et al.*, 2005).

The weight value analyzes the relative significance of individual criterion and hence to be chosen deliberately. The analytic hierarchy process gives a structural ground for quantifying the strong comparison of design criteria and elements in a pairwise technique and thus decreases the complexity of the decision-making process (Miller *et al.*, 1998; Saaty, 1977).

The process determines the weight values by pairwise comparison technique by relative significance of criterion, taken two at a time (Miller *et al.*, 1998). Using the pairwise comparison matrix, the analytic hierarchy process calculates the weights for the individual criterion by taking the eigenvalue corresponding to the highest eigenvector of the completed matrix and normalizing the sum of the factors to unity (Saaty 1980; Malczewski 1999; Feizizadeh *et al.*, 2014).

Table 6. The synthesized matrix for multi-criteria decision making

Criteria	Slope	Distance from water sources	Soil	LULC	Criteria weight
Slope	0.4286	0.5581	0.3077	0.300	0.3986
Distance from water sources	0.2143	0.2791	0.4615	0.400	0.3387
Soil	0.2143	0.0930	0.1538	0.200	0.1653
LULC	0.1429	0.0698	0.0769	0.100	0.0974

Max eigen value (λ_{max}) = 4.192074

$n = 4$

$$\text{Consistency Index(CI)} = \frac{(\lambda_{max} - n)}{n - 1} = 0.064025 \quad (1)$$

Random Index = 0.90

$$\text{Consistency Ratio (CR)} = \text{CI/RI} = 0.071139 < 0.1 \text{ (acceptable)} \quad (2)$$

Using the analytic hierarchy process explained above the pairwise comparison matrix was calculated using the scale of 1-9 where 9 indicates extreme significance and 1 indicates the equal significance of in-between criterion of the matrix shown in Table 4 (Saaty 1980; Malczewski 1999; Feizizadeh *et al.* 2014).

The comparison matrix mainly has the criteria of reciprocity which is mathematically expressed as, $n(n-1)/2$ for n number of components in pairwise comparison matrix (Saaty, 1980; Akinci *et al.*, 2013).

After the computation of the pairwise matrix, relative weights/eigenvectors are calculated using Saaty's method (Saaty, 1980) (Tables 5, 6). Moreover, the analytic hierarchy process also identifies and calculates the inconsistencies of decision-makers which is one of the significant characteristics (Saaty, 1980; Feizizadeh *et al.*, 2014; Garcia *et al.*, 2014). The efficiency criteria of the analytic

hierarchy process are estimated by consistency relationship (CR) which is measured by (Eq. 2). It represents the CR where CI indicates consistency index and RI indicates the random index. Consistency relationship facilitates the determination of possible events and measures logical inconsistencies of the decision-maker/judgments (Cengiz and Akbulak, 2009; Chen *et al.*, 2010a). It represents the likelihood where the matrix judgments were formed randomly (Park *et al.*, 2011; Saaty, 1977). The CR mainly depends on the Consistency Index and Random Index.

Table 7. Random Consistency Index (RI) (Saaty, 1980).

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

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

Equation 3 indicates the Consistency Index (CI) when λ_{max} is the principle or highest eigenvector of the computed matrix and n denotes the order of the matrix. Random Index (RI) is the mean value of the consistency index depending on the computed matrix order given by (Saaty, 1977) that has shown in (Table 7). If the value of CR > 0.10, then the weight values of the matrix indicate inconsistencies and the method (AHP) may not give a meaningful result (Saaty, 1980). In the present study, the calculated CR was 0.0654 which is under acceptable limits and the computed weight values are converted into a percentage for weighted overlay analysis (WOA) in GIS.

3.6. Computing Irrigation Water Requirements

To estimate irrigation water requirements of some selected crops in the potential irrigable sites, the definition of the area of influence of the climatic stations using Arc GIS inside and around the sub-basin were performed. To obtain a spatial coverage of climate data over the study area, each station was assigned to an area of influence using the Thiessen polygons method (FAO, 1997). This method assigns an area of 'nearest vicinity' to each climate station. (Fig. 3), indicates the density of the stations over the study area. From (Fig. 3), Three climatic stations such as Ambo, Gedo, and Tikur Enchini were taken to calculate the irrigation water requirement of the identified irrigable area. Ambo station has full climatic data; other stations do not have complete climatic records. Therefore, recorded data of these stations from the Weather data has been taken for the creation of database. Then based on the cropping pattern of the study area, obtained from Woreda's

agricultural offices, three crops such as potato, maize, and onion, were selected to estimate the water demand on a monthly basis.

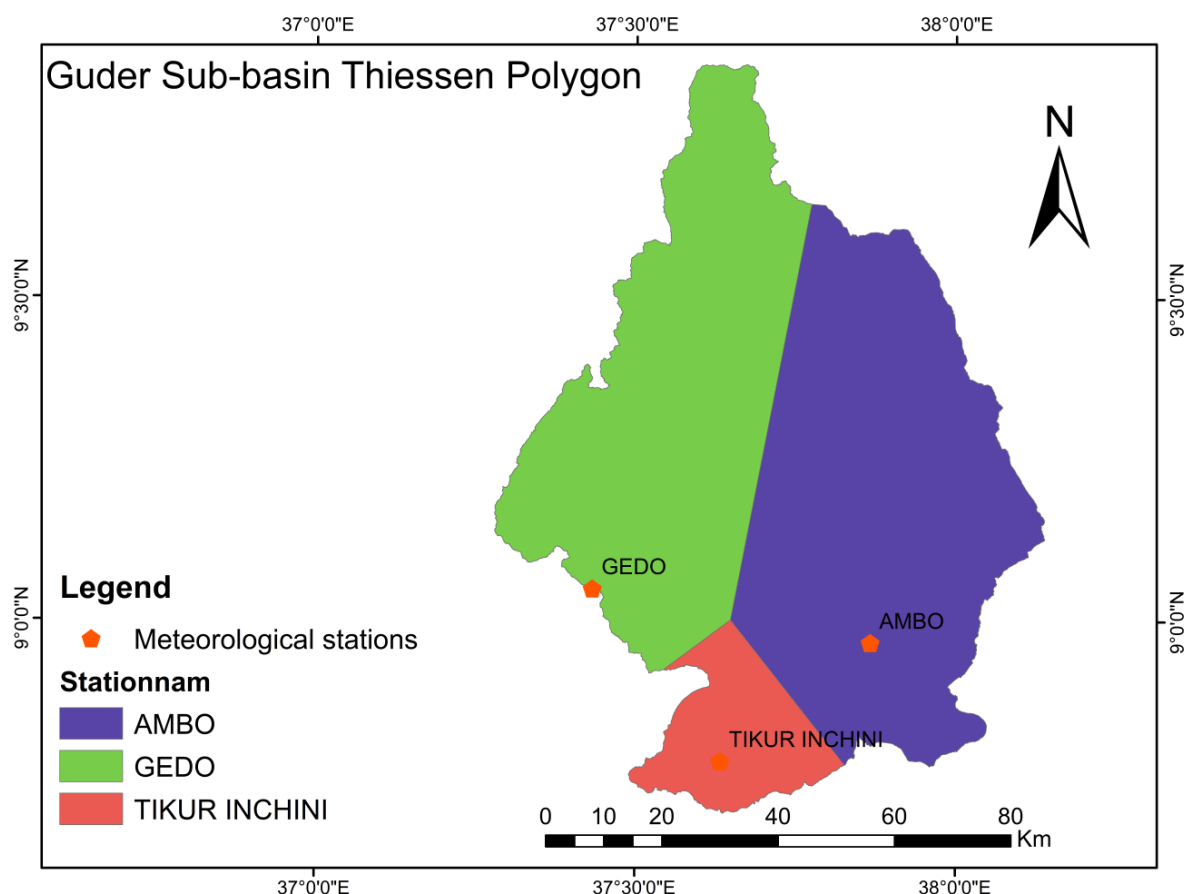


Figure 3. Thiessen polygons showing the area of influence of climatic stations in the study area. Planting dates for the crops were chosen in such a way that the planting dates coincided with the local cropping calendar at the nearby meteorological stations.

Then, ETo and other climatic data were derived from the computation for crop water requirement estimation. The respective crop coefficients for these crops were selected based on (FAO, 1998). Then, Crop water requirement and irrigation water requirement is calculated by using CROPWAT model with irrigation efficiency of 60% and time step of 10 days for different crops grown in the study area.

3.7. Estimation Methods for CWR and IWR

To find out the crop water requirements (CWR) and irrigation water requirements (IWR) through the CROPWAT model, the following steps and information is required.

A decade or monthly climate data that is minimum and maximum air temperature, relative humidity, sunshine duration, and wind speed is required for the model. Reference crop evapotranspiration (ET_o) equation based on the Penman-Monteith method were estimated from

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.4u_2)} \quad (4)$$

Whereas,

ET _o	= reference evapotranspiration [mm day ⁻¹]
R _n	= net radiation at the crop surface [MJ m ⁻² day ⁻¹]
G	= soil heat flux density [MJ m ⁻² day ⁻¹],
T	= mean daily air temperature at 2 m height [°C]
u ₂	= wind speed at 2 m height [m s ⁻¹]
e _s	= saturation vapour pressure [kPa]
e _a	= actual vapour pressure [kPa]
e _s -e _a	= saturation vapour pressure deficit [kPa]
Δ	= slope vapour pressure curve [kPa °C ⁻¹]
γ	= psychrometric constant [kPa °C ⁻¹]

Rainfall data is required to calculate effective rainfall, for this study Dependable rainfall (80% probability exceedance) method has been chosen for the calculation of effective rainfall. This method which is developed by FAO can be used more for designing purpose to estimate dependable rainfall.

$$ER = 0.6TR - 10 \quad (5)$$

This equation is valid where (TR < 70mm)

$$ER = 0.8TR - 24 \quad (6)$$

Equation 6, is valid when (TR > 70 mm)

ER = Effective Rainfall

TR = Total Rainfall

A cropping pattern consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction), and the area planted and also a set of typical crop coefficient data files are provided in the program.

CWR and IWR compute due to the following formula, on the account of the CROPWAT model.

$$\text{CWR} = \text{ET}_o * K_c \quad (7)$$

$$\text{IWR} = (\text{ET}_o * K_c) - \text{ER} \quad (8)$$

$$\text{GIWR} = \frac{1}{E} (\text{FWS} * A_{\text{crop}}) \quad (9)$$

Where: E – water conveyance efficiency

GIWR – Gross irrigation requirement (m³/month)

FWS – Field water supply (l/s/ha)

A_{crop} – the potential irrigable area to be cultivated with selected crop (ha)

After the data is entered, CROPWAT 8.0 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.

3.8. Watershed Delineation

The watershed delineation was performed using 12.5 m resolution DEM data using the Arc SWAT model watershed delineation function. First, the SWAT project set up was created. The watershed delineation process consists of five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition, and calculation of sub-basin parameters. After the DEM setup is completed and the location of the outlet is specified on the DEM, the model automatically calculates the flow direction and flow accumulation. Subsequently, stream networks, sub-basins and topographic parameters were calculated using the respective tools.

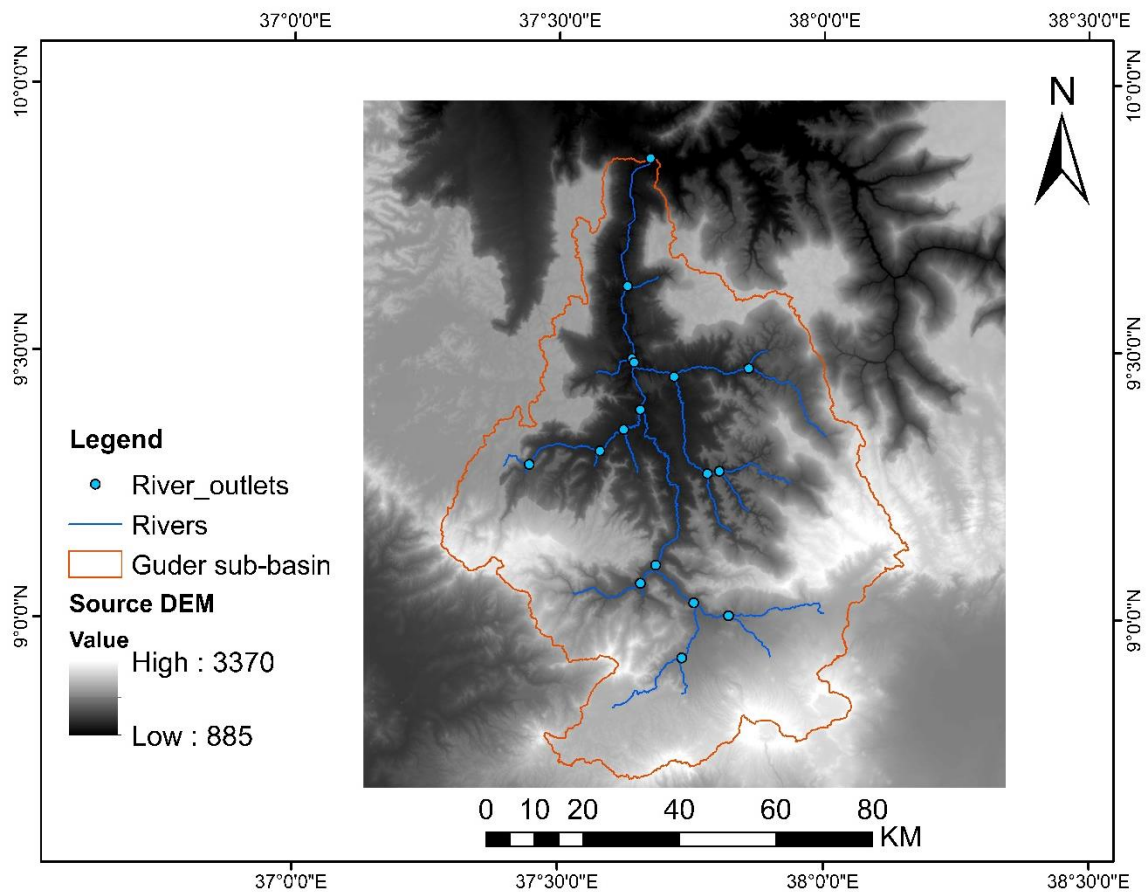


Figure 4. Guder sub-basin source digital elevation model

The stream definition and the size of Sub-basin were carefully determined by selecting the threshold area or minimum drainage area required to form the origin of the streams. Using a threshold value suggested by the user (10,000 hectares), the Guder sub-basin was delineated into 11 sub-basins having an estimated total area of 6683.82 km² (Fig. 5). Guder river which is the main river in Ethiopia reaches Abay river from its many tributaries in south passing through the center of the Guder sub basin.

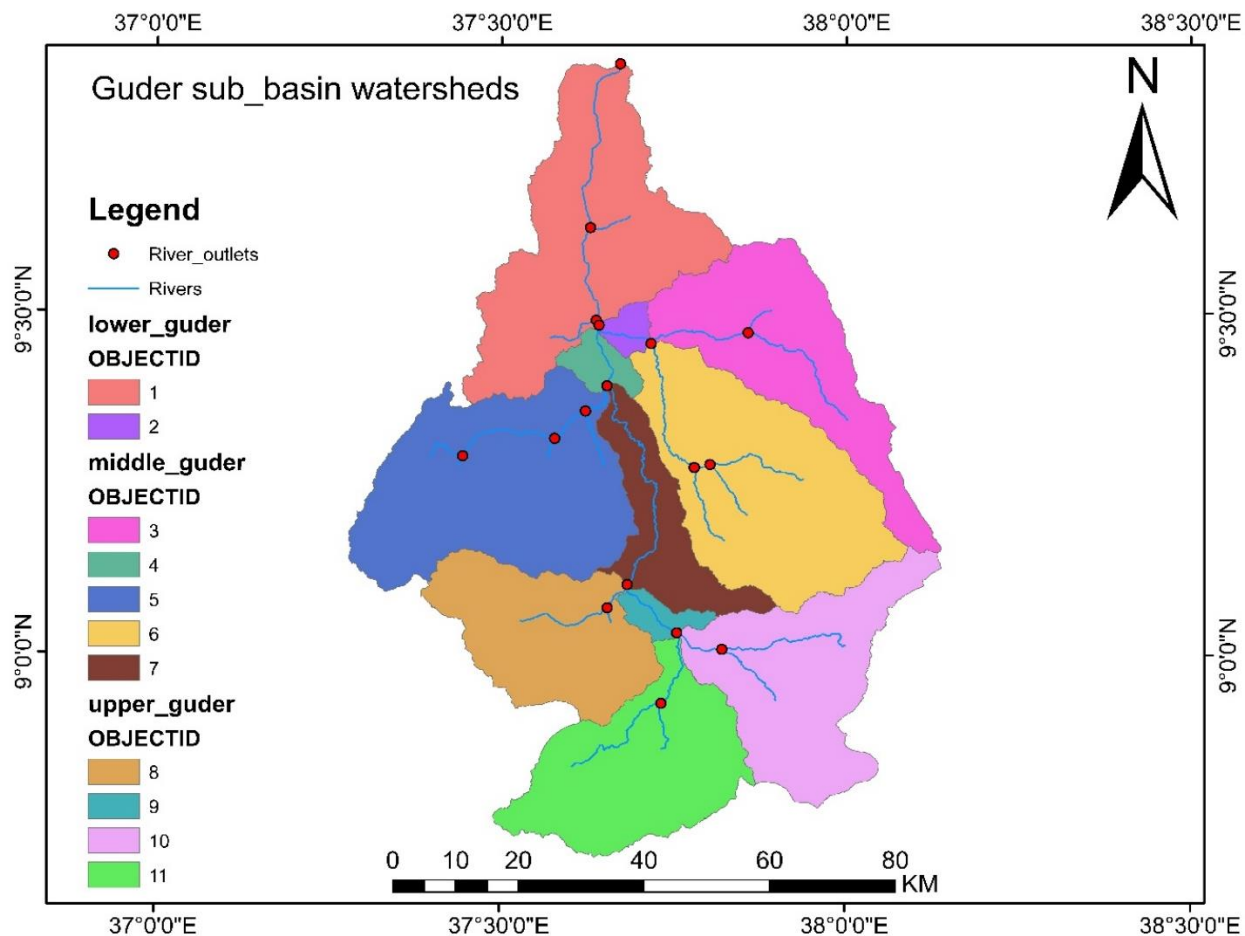


Figure 5. Guder sub-basin watersheds

During the watershed delineation process, the topographic parameters (elevation, slope) of the watershed were also generated from the DEM data. Accordingly, the elevation of the watershed ranges from 916 to 3303 m above mean sea level, the highest elevation is at the south of Ambo and Guder Towns and the lowest at the watershed outlet, Guder river.

3.9. Identifying Potential Irrigable Sites

Identification of suitable sites for irrigation was carried out by considering the slope, soil, land cover/use, and distance between water supply and the potential command area as factors. The individual suitability of each factor was first analyzed and finally weighted to get potential irrigable sites.

3.9.1. Slope Suitability Analysis

Slope map of the sub-basin was derived from AIO SPALSAR-DEM of 12.5 m spatial resolution using the “Spatial Analyst of Slope” tool in ArcGIS and it is classified based on the classification system of (FAO, 1999) using the “Reclassification” tool into suitability classes and finally, slope suitability map was developed and the classified raster data layers is then used for the overlaying analysis. Using data management tools in Arc Toolbox, a generalization of the feature (vector) data layers was performed to make a clearer slope suitability map.

Table 8. Slope suitability classification for surface irrigation

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

Source: FAO (1996)

3.9.2. Soil Suitability Assessment

To assess soil suitability for irrigation, Soil data from OWWDSE were used and it is available in shape file format. The following soil suitability rating was used based on the FAO guidelines for land evaluation (FAO, 1976, 1979, 1990, 1991) and (FAO, 1997) land and water bulletin.

Table 9. Soil suitability factor rating

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

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

3.9.3. Land Use /Land Cover

Land use/cover of the study area is also the factor, which was used to evaluate the land suitability for irrigation. Land use/Land cover classifications were generated through image classification of Sentinel-2A satellite imagery of the study area, which was taken by Sentinel-2A satellites having different band ranges and 10 m spatial resolution using ERDAS Imagine 2014 software.

3.9.3.1. Image Pre-Processing

The classification process and analysis of LULC classes were done by using Sentinel 2A satellite images. The sentinel images were downloaded from United States Geological Survey (USGS) Earth Explorer. The selection of the Sentinel satellite image dates influences the quality of the image especially for those with limited or low cloud cover. Each sentinel image was geo-referenced to the WGS_84 datum and Universal Transverse Mercator Zone 37 North coordinate system.

An intensive pre-processing such as atmospheric correction, mosaic, and layer-stacking were carried out to Ortho-rectify the satellite images. The image was then processed in ERDAS IMAGINE 2014 software. The satellite image of selected band was layer stacked in ERDAS software within interpreter main icon utilities with layer stacked function. Then, the layer stacked satellite image of the study area image was extracted by subset & chip tool under raster tab of ERDAS Imagine software.

3.9.3.2. Image Classification

For this study, only supervised classification was performed. Supervised classification is where the user develops the spectral signatures of known categories, such as urban, forest, *etc.* and then the software assigns each pixel in the image to the cover type to which its signature is most comparable. The supervised classification is applied after a defined area of interest (AOI) which is also called training sites. More than one training site were used to represent a particular class. The training sites were selected in agreement with the Sentinel image and Google Earth. The basic sequence operation followed on supervised classification are;

- Defining of Training Sites
- Extraction of Signatures
- Classification of the Image (Supervised classification)



Figure 6. A true band RGB (321) of Guder sub-basin Sentinel 2A image of 2019

3.9.3.3. Accuracy Assessment

One of the most important final steps in the classification process is accuracy assessment. Accuracy assessment aims to quantitatively assess how effectively the pixels were sampled into the correct land cover classes.

To validate and crosscheck the result of the sentinel image classification with known ground truth data, accuracy assessment was checked for the area of interest (AOI) of the classified images by calculating the error matrix, kappa coefficient in ERDAS software.

$$Kappa(K) = \frac{Po - Pe}{1 - Pe} \quad (10)$$

Where,

Po = is the proportion of correctly classified classes

Pe = is the proportion of correctly classified classes expected by chance

The columns of the confusion matrix show to which classes the pixels are in the validation set belong (ground truth) and the rows show to which classes the image pixels have been assigned in the image. The diagonal shows the pixels that are classified correctly.

From this error matrix, a number of accuracy measures such as overall accuracy, user's and producer's accuracy is determined.

The overall accuracy is used to indicate the accuracy of the whole classification (i.e., number of correctly classified pixels divided by the total number of pixels in the error matrix), whereas the other two measures indicate the accuracy of individual classes. User's accuracy is regarded as the probability that a pixel classified on the map actually represents that class on the ground or reference data, whereas producer's accuracy represents the probability that a pixel on reference data has been correctly classified. Pixels that are not assigned to the proper class do not occur in the diagonal and indicate the confusion between the different land-cover classes in the class assignment.

The accuracy assessment of the classified map is the comparison of the classified image and the sampling points from the Google Earth Imageries and existing land cover maps. In this study, the assessment was carried out using the Google Earth Image for 2019 together with previous knowledge of the area were used as reference data to generate testing data set. A total of 90 testing sample points was selected randomly for the year 2019 which is shown in (Appendix H, Fig.16).

3.9.3.4. Compilation of Final Land Use/Cover Map

Classified images require post-processing to generalize classes for export to image maps and vector GIS. The classification result can be used for further analysis, which is usually done with GIS-software like ArcGIS. To avoid processing problems, it is advised to export imagine files with "img" format to ArcGIS raster format. The classified images have a vector layer for each selected class. Due to the higher spatial resolution of the Sentinel images, countless very small polygons are created in the classified images. To produce the final land use/cover map, it is necessary to filter these classes so that incorrectly classified class numbers are included in the correct class numbers. This process was performed within ERDAS software using Recode tool under the thematic tab.

3.9.4. Distance from Water Sources

To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from watershed outlets were calculated using DEM of 12.5 m \times 12.5 m cell size and reclassified. Then, the reclassified distance was used for weighted overlay analysis together with other factors.

3.9.4.1. Weighing of Irrigation Suitability Factors to Find Potential Irrigable Sites

First, the irrigation suitability of each factor was assessed and their suitability map layer of each criterion was developed separately. Using tools from spatial analyst toolsets, an overlay analysis was done to get the final suitability map.

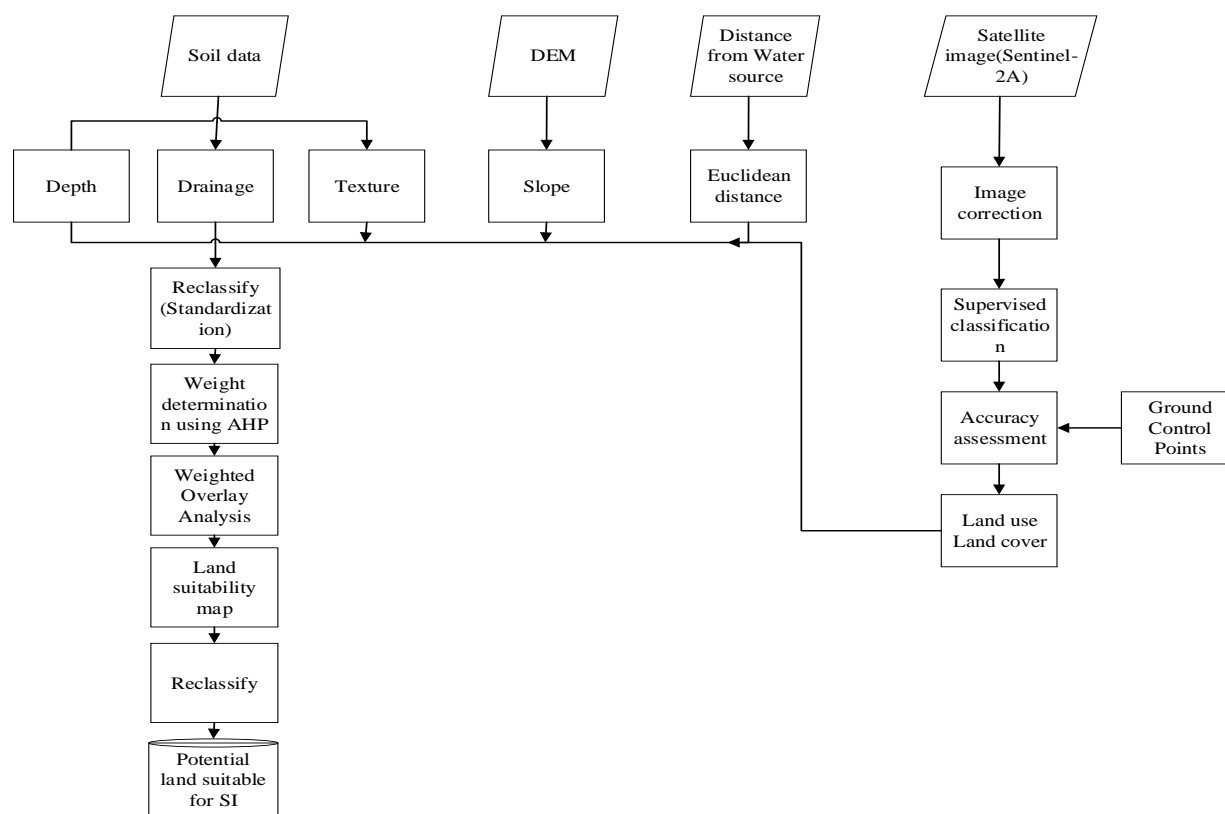


Figure 7. Flow diagram for generating land suitability for surface irrigation

4. RESULTS AND DISCUSSIONS

4.1. Hydro-meteorological Data Consistency Results

4.1.1. Testing Rainfall Data for Consistency

The accumulated rainfall at each rain gauge station was tested for consistency with the average accumulated rainfall of the other four rain gauge stations using the Double Mass Curve method. The mean annual cumulative rainfall of twenty years of each station was drawn in the y-axis and the mean annual cumulative rainfall of the group of the station was drawn on the x-axis to check the consistency of each rainfall station using a double mass curve. The results illustrated two stations (Ambo and Gedo) have a small breakpoint at different years where the Tikur Enchini station have no significant change in slope and is consistent. Therefore, the stations which show a change in slope on the graph were corrected and used for this study. Finally, a single straight sloped line for the three rain gauge stations which indicates the rainfall data were consistent is obtained as shown in (Fig. 8) and Appendix F (Fig 1-5).

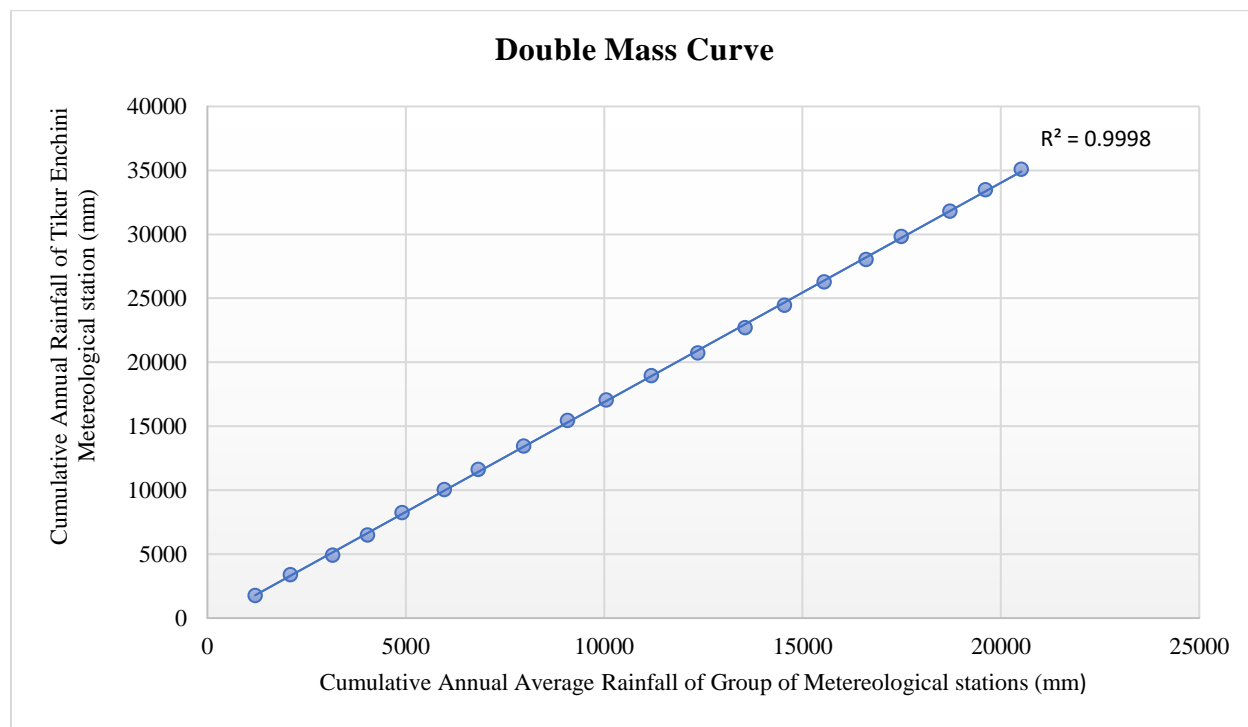


Figure 8. Precipitation data consistency check (DMC) for Tikur Enchini station

4.1.2. Stream Flow Data Consistency

The streamflow data consistency check was done for all hydrological gauging stations using a double mass curve which was used for surface water irrigation potential estimation. The mean annual cumulative streamflow data of each station is drawn in the y-axis and the mean annual cumulative streamflow data of the group of stations were drawn in the x-axis. Hence, the streamflow data of the stations were found to be inconsistent and the break-in slope for each station was corrected using double mass curve analysis and used for further analysis.

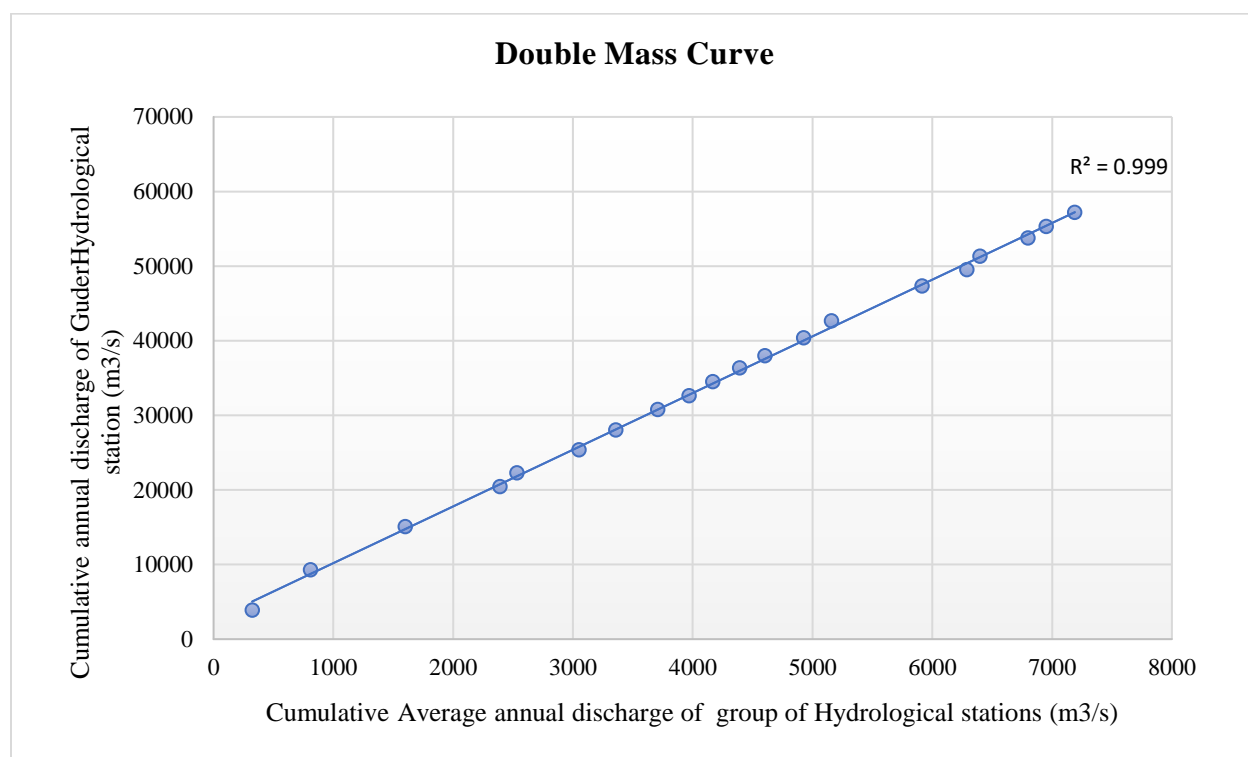


Figure 9. Streamflow data consistency check for Guder hydrological station

4.2. Irrigation Suitability Evaluation

The analysis results of Irrigation land suitability evaluation factors are presented in the following sections.

4.2.1. Slope Suitability

The slope of a given area plays an important role in irrigation activities in general and especially in the case of surface irrigation. Slope defines whether an area is workable at all or not, is an erosion hazard too.

Thus, the study of the slope is an important factor for the land suitability assessment for surface irrigation. Using FAO guidelines factor rating, the sub-basin was reclassified into four classes (i.e., S1, S2, S3, and N) according to its characteristics of the slope for the selection of the land for suitability of surface irrigation.

The slope suitability of the basin for the development of surface irrigation is shown in (Fig.10) and the area coverage of the suitability classes was presented in (Table 10).

The result obtained after the evaluation of the Guder sub-basin indicates that 9.16 % of the sub-basin area was less than 2%, 11.4 % of the sub-basin was between 2-5% and 23.4 % of the total sub-basin area found 5-8% and 55.4% of the sub-basin is greater than 8%. This indicates that 43.96% of the study area is found to be suitable in terms of slope for surface irrigation.

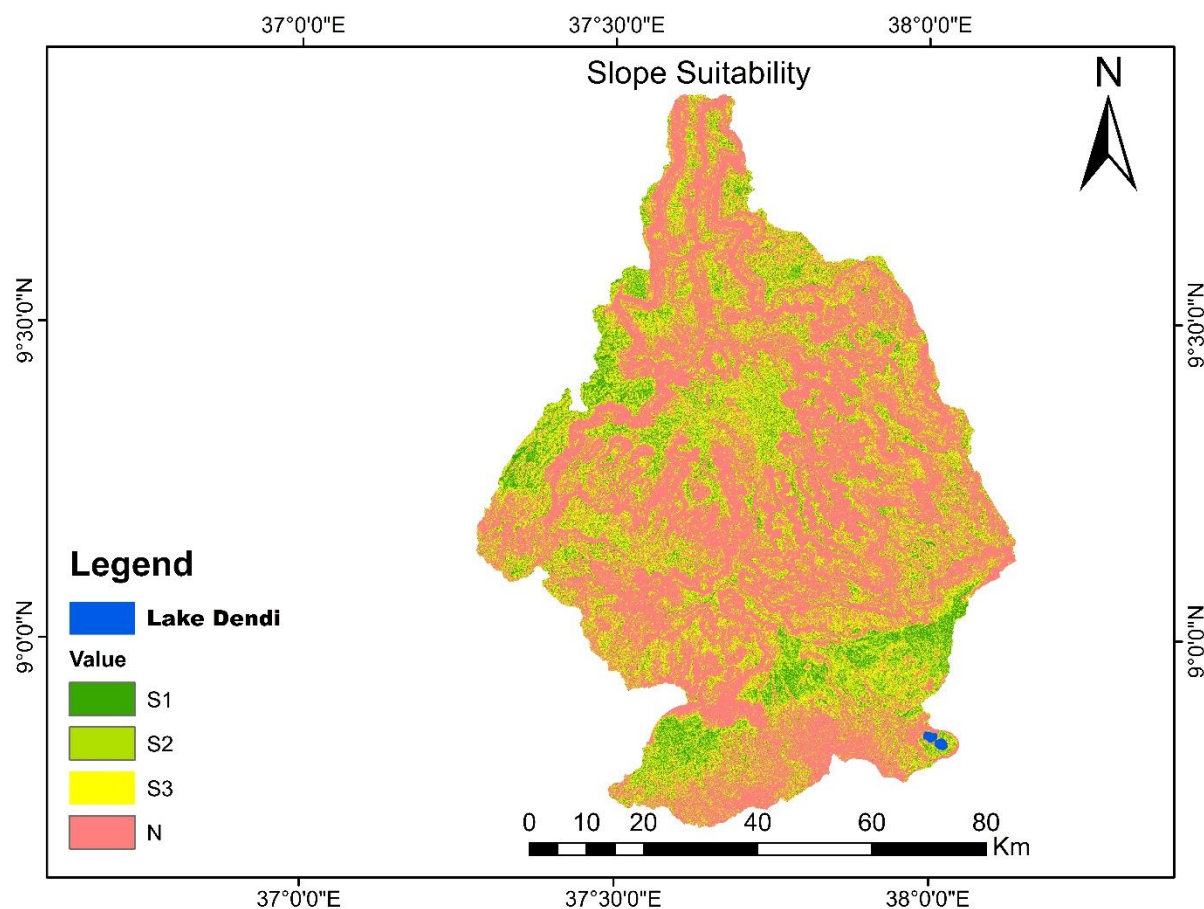


Figure 10. Slope suitability of Guder sub-basin

Table 10. Slope suitability range of the study area for surface irrigation

Slope range (%)	Area (ha)	Percent of total area (%)	Suitability classes
0 – 2	61,236.36	9.16	Highly suitable
2 – 5	76,319.84	11.4	Moderately suitable
5 – 8	156,100.53	23.4	Marginally suitable
>8	374,725.05	56.0	Not Suitable
	668,381.78	100.0	

4.2.2. Soil Suitability

Soil is a major factor in the suitability of land for surface irrigation. Its primary influence is on the productive capacity, but it also influences production and development costs. Soil texture, soil drainage, soil depth, and soil type are the major physical properties of soil that are very important for the evaluation of the irrigation potential of the sub-basin. They affect the root growth of a plant, infiltration of water into the soil, and the production of crops.

The soil map of the study area was derived from Oromia Water Works Design and Supervision Enterprise soil spatial data. There were six (6) Major soil groups in the sub-basin. i.e., Andosols, Cambisols, Leptosols, Luvisols, Nitosols, and Vertisols.

Based on their particle size, soils are divided into three major soil texture types. These include clay, silt, and sandy soils. These major types have mixtures like silt-clay, clay-loam, sandy loam, etc. Clay, clay loam, and silty clay loam are classified as fine-textured soils while sandy clay loam, loam, and silt loam are classified as medium textured soils and the others like sandy soils are classified as coarser-textured soils.

Coarse textured soils, generally, rich in sand tend to warm and drain rapidly and have good aeration, but do not hold water or nutrients well. The fine-textured or heavy soils, rich in clay and silt contents, are slow to warm but hold a large amount of water and nutrients, they tend to drain poorly and can be more compact, the great problem with aeration and they are often more difficult to work. Medium textured soils with mixtures of sand; silt and clay (L, SL, and SiL) combine the best features of the coarse and fine particles and tend to give higher productivity.

Most of the soil textures of the study area are clay loam, silty clay loam, clay and sandy loam from which clay loam is dominantly observed on the topsoil and clay are predominant in the subsoil of

the area. The clay type of the soil under the sub-basin influences permeability, chiefly by its swelling and shrinking qualities with changes in soil moisture. The soils of the sub-basin evaluated under the study area, which was fine-textured, have higher soil moisture.

The Vertisols have heavy clay subsoil and although there is some variability of subsoil texture in the Cambisols including occasional sandy lenses heavy textures predominate.

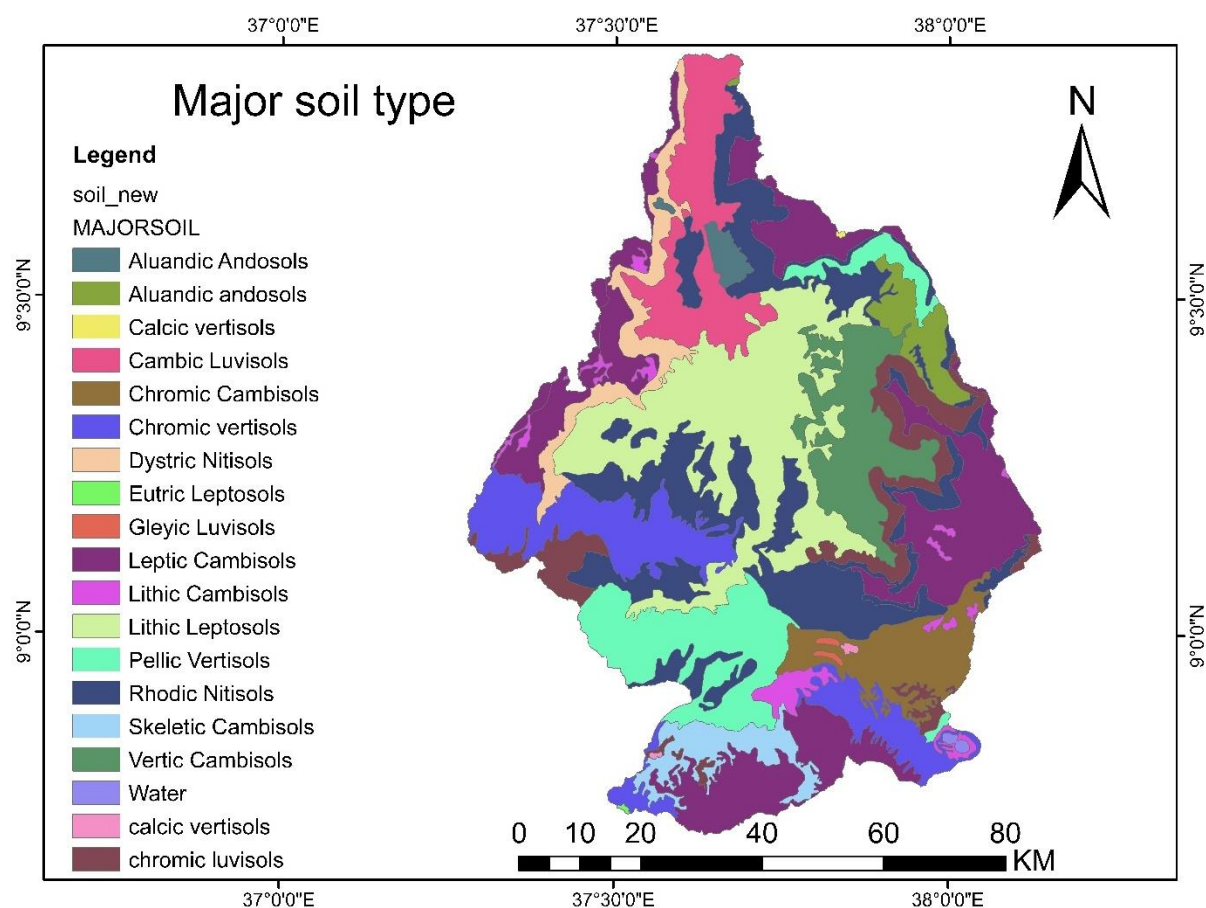


Figure 11. Major soil types of Guder sub-basin

Soil depth was considered as one of the factors that determine the selection of surface irrigation potential suitable land in the study area. The soil depth of the Guder sub-basin was varied from place to place. It was ranging from less than 25 centimeters to greater than 150 centimeters. Rating factor was given for the value of soil depth and weighting them to evaluate the suitability of surface irrigation potential of the study area. Accordingly, soil that has a depth greater than 100 cm were classified as highly suitable (S1) and the depth of soil which ranges from 80 – 100 cm it is

moderately suitable (S2) and for the range of 50 – 80 cm were classified as Marginally suitable(S3) and soil depth which are less than 50 cm were classified as Not suitable(N).

Among sixteen soil series identified in the study area, Gleyic Luvisols, Cambic Luvisols, Aluandic Andosols, Rhodic Nitisols, Calcic Vertisols, Chromic Luvisols, Dystric Nitisols, and Pellic Vertisols were found to be very deep, Vertic Cambisols were deep and Chromic Cambisols were moderately deep while Eutric Leptosols and Lithic Leptosols were shallow in soil depth (<25 cm).

Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. In an irrigation system, consideration must be given to additional facilities to permit adequate removal of the excess water and salts added from irrigation water. 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, imperfectly drained, poorly drained, and very poorly drained (FAO,1991).

Therefore, the soil drainage properties of the study area were available as Excessive/well, moderately drained, imperfectly drained, and poorly drained. Soils of the study area range from imperfectly drained to poorly drained for Vertisols and well-drained for Luvisols and Cambisols to Excessively drained for Leptosols soil types which vary depending on their varying properties affecting drainage such as water transmission, soil depth, soil chemistry, slope gradient, etc.

Andosols accommodate dark soils of volcanic landscapes that develop in glass-rich volcanic ejecta under almost any climate except under hyper-arid climate conditions (WRB, 2014). However, Andosols of the study area was produced from acidic rocks of tuff and pumice weathering parent materials. These Andosols of the area are developed in the environment of undulating to mountainous landscape mostly humid and per-humid regions with a wide range of vegetation types. Andosols occur in volcanic regions all over the sub-basin. In the sub-basin, major occurrences of Andosols are found along with the moderate to high gradient hilly and mountains of the west to southwest ambo districts.

The total area of Andosols is estimated to 8600.43 ha or about 1.28 percent of the total sub-basin area. Soils with at least the beginnings of horizon differentiation in the subsoil with evidence of changes in structure, color, clay content, or carbonate content are classified as Cambisols. Cambisols combine soils with at least an incipient subsurface soil formation. Cambisols developed

from acidic and basic parent materials or rocks. Cambisols of the sub-basin are used as intensively cultivated land. Cambisols with high base saturation in the sub-basin are among the most productive soils of the area. More acid Cambisols, although less fertile, are used for mixed arable farming and as grazing and forest land. Even Cambisols on steep slopes of an area is used for cultivation rather than kept under forest; this is particularly true for Cambisols in highlands parts of an area.

Cambisols on irrigated alluvial plains in the sub-basin are used intensively for the production of food and oil crops. Cambisols in undulating or hilly terrain were planted with a variety of annual or perennial crops and are used as grazing land. Cambisols in the humid area is typically poor in nutrients but are still richer than associated Nitisols, Leptosols and they have a greater CEC. Cambisols account for an area of 214,007.89 ha which covers 31.75 % of the total area of sub-basin.

Leptosols comprise very thin soils over continuous rock and soils that are extremely rich in coarse fragments. Leptosols are particularly common in mountainous regions. Leptosols have no profile development and have a continuous rock at <25 cm to the surface or and are extremely gravelly. Leptosols are the third most extensive next to Nitisols in the sub-basin, extending over about 151,337.63 ha which covers 22.45 % of the total area of the sub-basin. Elsewhere, Leptosols can be found on rocks that are resistant to weathering or where erosion has kept pace with soil formation or has removed the top of the soil profile.

Leptosols of the sub-basin has a resource potential for wet-season grazing and as forest land. Leptosols to which the calcic qualifier applies are used for grazing whereas acid Leptosols are commonly under forest coverage. The excessive internal drainage and the very shallow depth of Leptosols of an area cause drought even in a humid environment.

Luvisols are soils with a pedogenetic clay differentiation especially clay migration between topsoil with a lower and a subsoil with higher clay content, high-activity clays, and a high base saturation at subsurface layers. Profile development of Luvisols shows that pedogenetic differentiation of clay content, with a lower content in the topsoil and a higher content in the subsoil without marked leaching of base cations or advanced weathering of high-activity clays. Luvisols covers 38,182.65 ha this occupies 5.66 % of the total area of the sub-basin.

Luvissols occur mainly on young land surfaces. Most Luvissols are fertile soils and suitable for a wide range of agricultural uses. Luvissols with a high silt content are susceptible to structural deterioration when tilled when wet or with heavy machinery. Luvissols on steep slopes of the sub-basin require erosion control measures. In places, the dense subsoil causes temporarily reducing conditions with static properties.

Nitisols are very deep, well-drained, red soils with diffuse horizon boundaries and a subsurface horizon with a greater 30 percent clay and moderate to strong angular blocky structure and shiny aggregate faces. Weathering is relatively advanced but Nitisols are far more productive than most other red soils. They originate from weathering products ranging from acidic to basic parent materials with large proportions of volcanic landforms gneiss. Nitisols are predominantly found on the level to hilly land and high Plateau of the sub-basin.

Nitisols are the second most extended soil in the area which covers about 173,411.0 ha and occupies 25.73 % of the total area of the sub-basin. Nitisols are among the most productive soils of the sub-basin. The deep and porous solum and the stable soil structure of Nitisols permit deep rooting and make these soils quite resistant to erosion. The good workability of Nitisols, their good internal drainage, and fair water-holding properties are complemented by chemical fertility that compares favorably with those of most other soils of the sub-basin. Nitisols have relatively high contents of weathering minerals, and surface soils may contain several percent of organic matter, in particular under forest or tree crops.

Vertisols are churning heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years.

They are originated from unconsolidated parent materials that have swelling clays produced by Geoformation from weathering basalt and tuffs as well as from limestone's produced in valley and gorge landscapes of the sub-basin. They developed under physiographic units of valley, depressions, and level to undulating areas, mainly in warm to sub-humid and humid climates with an alternation of distinct wet and dry seasons of the area.

Table 11. Soil suitability classification for irrigation

Major Soil	Soil Depth	Drainage	Salinity (EC)	Soil Texture	Alkalinity (ESP)	Soil type	Area(ha)	Percent of Area (ha)	Irrigation Suitability
Andosols	>150	E	0.1	SL	4.78	Aluandic Andosols	19305.16	2.888	S2
Vertisols	>150	I	0.2	C	0.52	Calcic Vertisols	685.67	0.103	S2
Luvisols	>150	W	0.1	CL	1.26	Cambic Luvisols	42926.07	6.422	S1
Cambisols	50-100	W	0.2	SiCL	1.83	Chromic Cambisols	31131.68	4.658	S2
Luvisols	>150	W	0.1	SiCL	5.72	Chromic Luvisols	37040.78	5.542	S1
Vertisols	>150	I	0.1	C	1.59	Chromic Vertisols	59817.79	8.950	S2
Nitisols	>150	W	0	C	0.74	Dystric Nitisols	22347.80	3.344	S1
Leptosols	<25	E	0.1	CL	0.84	Eutric Leptosols	166.89	0.025	N
Luvisols	>150	M	0.1	CL	2.82	Gleyic Luvisols	828.88	0.124	S2
Cambisols	25-50	W	0.1	CL	0.12	Leptic Cambisols	118248.59	17.692	N
Cambisols	25-50	M	0	SL	4.02	Lithic Cambisols	11375.63	1.702	S3
Leptosols	<25	E	0.1	SL	8.39	Lithic Leptosols	98293.96	14.706	N
Vertisols	>150	P	0	C	1.28	Pellic Vertisols	55101.71	8.244	S1
Nitisols	>150	W	0	CL	2.58	Rhodic Nitisols	111876.76	16.738	S1
Cambisols	25-50	W	0.2	C	0.81	Skeletal Cambisols	17616.59	2.636	S3
Cambisols	100-150	M	0.1	C	2.04	Vertic Cambisols	40833.70	6.109	S2
Water	N	N	N	N	N	N	784.11	0.117	N
							668,381.78	100	

SiCL=Silty clay loam, SL=Sandy Loam, CL = Clay Loam, C=Clay E = Excessive, W = Well, I = Imperfect, M = Moderate, P = Perfect, N = None

Vertisols covers 115,605.17 ha which accounts 17.3 % of the total area of the sub basin. Vertisols are often found in lower landscape positions of Abay river basins and lower river terraces that are periodically wet in their natural state.

The heavy soil texture and domination of expanding clay minerals result in a narrow soil moisture range between moisture stress and water excess. The consistency of Vertisols when the soil is wet and when the soil is dry also influences on agronomical management of Vertisols. For example, tillage is hindered by stickiness when the soil is wet and hardness when it is dry.

The exposure of Vertisols to waterlogging may be the single most important factor that reduces the actual growing period. Vertisols are also characterized by very low infiltration rates which are used for water harvesting during the rainy season (excess water during rainy seasons is stored at low infiltration area of Vertisols and is used for post rainy seasons).

4.2.3. Land Use/Cover Evaluation

In the Guder sub-basin, about Nine (9) dominant land use/cover classes have been identified. Supervised classification using Sentinel 2A of 2019 satellite image shows that Nine land use/cover classes were identified as shown in (Fig. 12).

Accuracy assessment which quantitatively assesses how effectively the pixels were sampled into the correct land cover classes was done using a random sampling of reference class with a classified image of Sentinel 2A image. A total of 90 points were created in the classified image of the study area. The accuracy assessment cell array reference column was filled according to the best guess of each reference point. (Table 12) shows the relationship between ground truth data and the corresponding classified data obtained through an error matrix report. The overall classification accuracy, the number of correct points divided by a total number of points is 86%. Kappa coefficient is 0.84. The Kappa coefficient of 0.84 of the land cover classification in the study area represents a strong agreement according to (Rahman *et.al.*, 2006).

Table 12. Accuracy assessment

Class Names	WB	BLTUP	OSHRB	GRLND	BSHLND	WDLND	DSHRBLND	ECULT	MCULT	Classified Totals	Users Accuracy
Water body	10	0	0	0	0	0	0	0	0	10	100.00%
Built up	0	7	0	0	0	0	0	0	3	10	70.00%
Open shrubland	0	0	9	0	0	0	1	0	0	10	90.00%
Grassland	0	0	0	7	0	3	0	0	0	10	70.00%
Bushland	0	0	0	0	9	0	0	1	0	10	90.00%
Woodland	0	0	1	0	0	8	0	0	1	10	80.00%
Dense shrubland	0	0	0	0	0	0	9	1	0	10	90.00%
Dominantly cultiv	0	0	0	0	0	0	0	8	2	10	80.00%
Moderately cultiv	0	0	0	0	0	0	0	0	10	10	90.00%
Reference Totals	10	7	10	7	9	11	10	10	16	90	
Producers										Overall	
Accuracy	100.0%	100.0%	90.0%	100.0%	100.0%	72.7%	90.0%	80.0%	62.5%	Accuracy	86%

As it is shown in (Table 13), the study area largely comprises Moderately cultivated land which is about 51.24 % of the total area coverage of the Guder sub-basin. The second-largest proportion of the study area is covered by Dominantly cultivated land which is 23.54 % of the area coverage. Next to these proportions, the Guder sub-basin area is covered by Dense Shrubland which is 11.47 % of total area coverage, 1.87 % was of the land covered by bushland and 9.97 % of the basin is covered by Forest. Grassland covers 0.79 % of the total area coverage of the sub-basin. Open shrubland of the land covers 0.7% of the total area coverage. The rest proportion of the basin area which was about 0.29 % is covered by Built-up and 0.11% by Water. The majority of the sub-basin is covered by Moderately cultivated land.

Table 13. Area coverage of land cover/use classes of Guder sub-basin

Class names	Area(ha)	Percentage area
Moderately cultivated	342,493.76	51.24
Dominantly cultivated	157,336.93	23.54
Dense shrubland	76,656.43	11.47
Bushland	12,490.58	1.87
Forest	66,636.46	9.97
Open shrubland	4,678.61	0.70
Grassland	5,324.58	0.79
Built Up	2,001.46	0.29
Water bodies	760.18	0.11
	668,378.99	100

4.2.3.1. Moderately Cultivated

A moderately cultivated land can be defined as where the cultivated portion of land is estimated to be in the range of 40% to 60% of the total land. As it is shown above in (Table 13) and (Fig.12) the moderately cultivated land covers about 342,493.76 hectares of land, which is 51.24 % of the total study area. This land mapping unit includes rain-fed land on which the farmers especially in the sub-basin mainly cultivate grains like sorghum, maize, wheat, etc. livestock grazing, and perennial crop cultivation. The farmers are using this type of land for annual crops during the rainy season. About forty percent of this type of land is fallow or has natural vegetation used for livestock grazing.

4.2.3.2. Dominantly Cultivated

This type of land use can be defined as the land that is cultivated portion of a mappable unit of land which is estimated to be more than 80% of total land, it is classified as Dominantly cultivated

land. As it is shown above (Table 13), dominantly cultivated land covers about 157,336.93 hectares of land, which is 23.54 % of the total area of the Guder sub-basin. This is the second-largest land cover class in the sub-basin in size. A large proportion of the land in this map unit is put under annual crop during the rainy season and cereal crops are grown and all the land was opened up for cropping and very scattered tree vegetation was visible.

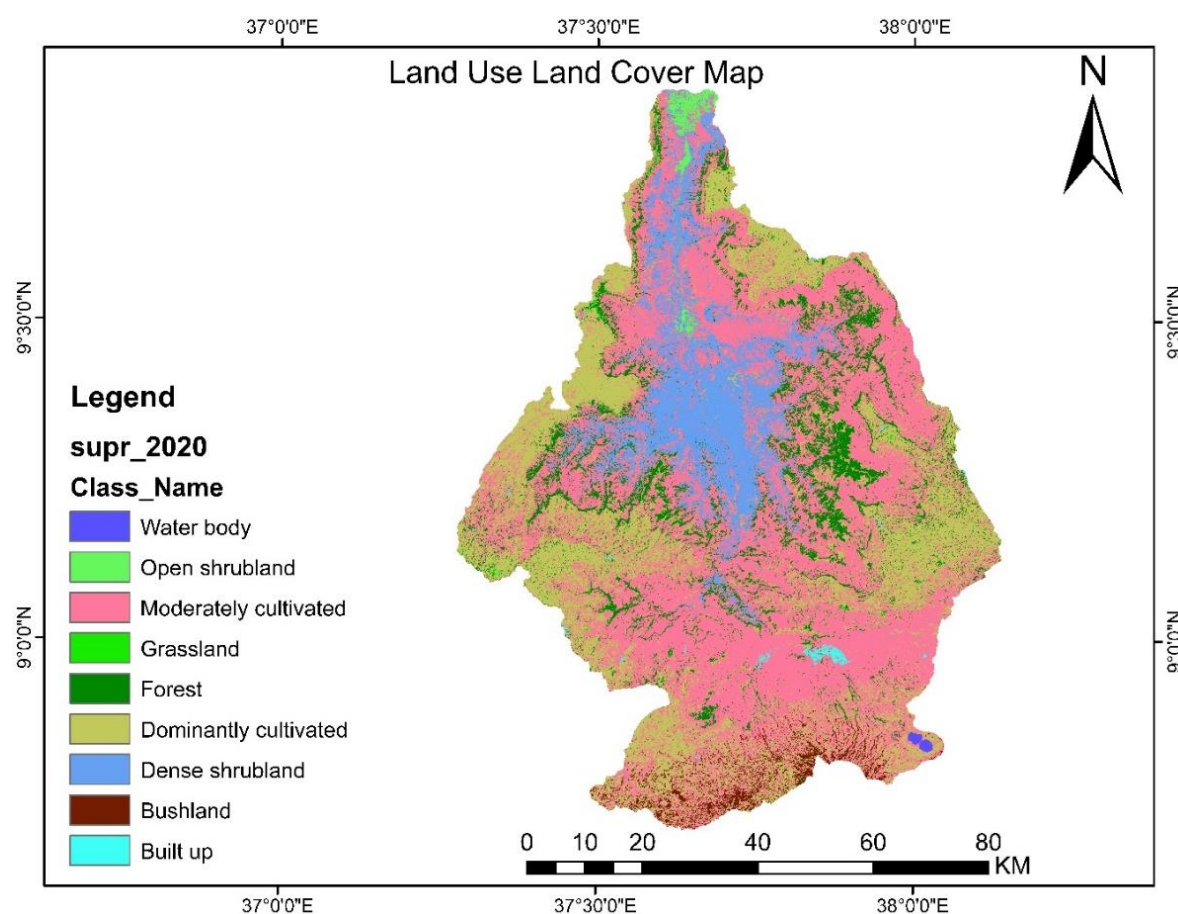


Figure 12. Supervised classification of Land cover/use map of Guder sub-basin

4.2.3.3. Dense Shrubland

This unit is predominantly found in lowland areas of the Sub-basin. In this mapping unit, the woody species are estimated to cover a canopy of 41-80%, which characterizes this class as dense shrubland. This unit accounts for 76,656.43 ha which is 11.47 % of the total area of the sub-basin.

4.2.3.4. Open Shrubland

Generally, shrubland is characterized by the occurrence of shrubs of 0.7-6 m height; trees may occupy 10% of the canopy cover (FAO, 1984). Shrubland has been also defined as a continuous

stand of shrubs with a crown density of between 20 -100 %. Open shrublands have between 99 and 400 shrub stems per hectare. Scattered trees within the shrub layer are classified according to three categories of stem density: densely scattered between 80 and 149 stems per hectare, moderately scattered trees between 40 and 79 stems per hectare, and sparsely scattered less than 39 stems per hectare (WBISPP, 2004b).

In the Guder sub-basin, the total area covered by open shrublands is estimated to be 4,678.61 hectares of land. The open shrubland constitutes about 0.7% of the total sub-basin area. Many of these shrublands are grazed extensively by livestock and provide wildlife habitat. And as its use is not limited for irrigation this land cover is classified into highly suitable for irrigation.

4.2.3.5. Bushland

This land use and land cover category is a multistorey cover type comprising of trees and shrubs mixed with approximate heights of 2 to 10m, some emergent may be higher. The crown cover of woody species is 41 to 80%. Together the bushlands and woodlands occupy the intermediate ecological zones between the humid and semi-arid zones. This land cover type accounts for about 12,490.58 hectares which is 1.87 % of the total sub-basin area. This land unit is used for livestock grazing and browsing. Since it has severe limitation for irrigation, bushland is classified into marginally suitable land for irrigation.

4.2.3.6. Forest

This land unit can be defined as multistoried and interlaced with an upper canopy of 10m or higher. The crown cover of woody species exceeds 80% of the land unit. This type of land cover as indicated above in (Table 13) covers 66,636.46 hectares which is 9.97 % of the total area coverage of the sub-basin. Since forests have significant limitation for irrigation it is classified into not suitable unit of land.

4.2.3.7. Grassland

Grasslands are characterized as lands dominated by grasses rather than large shrubs or trees. grassland can be defined as the land with almost no woody species and the crown cover of the unit is almost zero. Grazing was practiced over the patches of the narrower plain, which for most of the year have been practically bearing with very low-density coverage of grass. Since it has no significant limitation, this land cover unit is classified into moderately suitable for irrigation. The predominant land using activity was the pastoral type.

As indicated above in (Table 13) grassland covers 5,324.58 hectares which is 0.79 % of the total area coverage of the sub-basin.

4.2.3.8. Built-up

Land covered by buildings and other man-made structures residential, commercial services, industrial area, mixed urban or built-up lands, as indicated above in (Table 13) built up covers 2127.64, hectares which is 0.29 % of the total area coverage of the sub-basin. This type of land unit is limited for irrigation development and is classified as not suitable.

4.2.3.9. Water Bodies

The water body is any significant accumulation of water, generally on a planet's surface. The term most often refers to oceans, seas, and lakes, but it includes smaller pools of water such as ponds, wetlands, or more rarely, puddles. A body of water does not have to be still or contained; rivers, streams, canals, and other geographical features where water moves from one place to another are also considered bodies of water (Langbein, W.B.; Iseri, Kathleen T., 1995) As indicated above in (Table 13) water bodies covers 760.18 ha which is 0.11 % of the total area coverage of the sub-basin. Due to its limitation for irrigation, this unit is classified as not suitable.

4.2.4. Distance from Water Sources

The land unit close to the water supply (rivers), straight-line (Euclidean) distance from watershed outlets calculated from DEM (12.5m) resolution were classified and reclassified to obtain the suitability classes. Therefore, based on the four classes of land suitability evaluation 97.21 % of the distance from outlets were classified as highly to marginally suitable for the development of irrigation system. However, the distance of the land unit from the water source of about 2.78% was found as not suitable. The area coverage of each class is presented in (Table 14).

Table 14. Euclidean distance

S.No	Euclidean distance		Percentage area
	Suitability class	Area(ha)	
1	S1	295,571.79	44.22
2	S2	241,867.81	36.19
3	S3	112,309.20	16.8
4	N	18,632.97	2.78
	Total	668,381.78	100

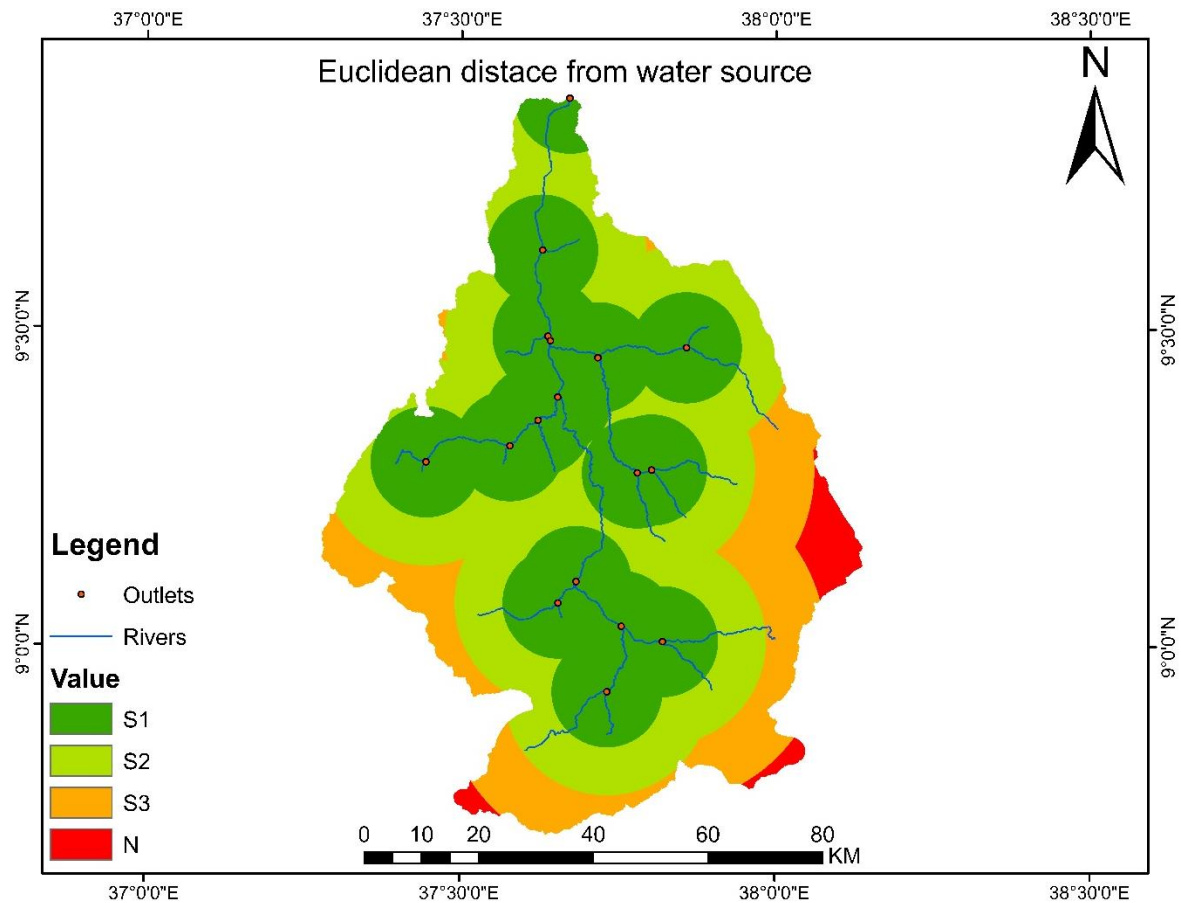


Figure 13. Distance from the watershed outlet (Euclidean distance)

4.3. Site suitability Model for Irrigation using weighted Overlay Analysis

The weighted overlay analysis is an effective method to resolve spatial complexity in suitability analysis and site selection based on general measurement of dissimilar and diverse impacts (Girvan *et al.*, 2003; Kuria *et al.*, 2011).

Analytic hierarchy process is applied to determine the influential factors in the hierarchy of selected dissimilar inputs to weighted overlay analysis (Parimala and Lopez, 2012). Moreover, all created thematic layers were combined in GIS to applied the weighted overlay techniques (Girvan *et al.*, 2003).

Land suitability for irrigation development has been found using weighted overlay techniques based on the analytic hierarchy process and multi-criterion decision-making process. Selected raster layers were overlaid by recognizing their cell values to the same scale, giving a weight value to individual criterion, and integrating the weight cell values (Eq. 11).

The cell values of each raster layer are also multiplied by their weight value (Mojid *et al.*, 2009; Cengiz and Akbulak, 2009) using a weighted overlay of spatial Analyst tools in ArcGIS 10.4.

$$LS = \sum_{i=1}^n W_i X_i \quad (11)$$

Where, LS indicates the total land suitability score, W_i denotes the weight of the selected land suitability criteria, X_i indicates the assigned sub-criteria score of i land suitability criteria, and n denotes the total number of land capability criteria (Cengiz and Akbulak, 2009).

Then output raster map was calculated (Eq. 11) and allotted scores were averagely converted into four classes i.e., 9, 7, 4 and 1. Finally, these classes were reclassified into the four suitability levels i.e., highly suitable, moderately suitable, marginally suitable, and not suitable according to the classification of Food and Agriculture Organization classifications (FAO, 1976).

4.4. Potential Suitable Land for Irrigation

Potentially irrigable land was obtained by creating irrigation suitability model analysis which involved weighting of values of all data sets such as soil, slope, land use/land cover, and distance from the water source. (Fig.14) shows the identified potential irrigable lands below the reservoir or diversion sites among the main and tributary rivers of Guder sub-basin.

Based on the interpretation of physical characteristics of the parameters, the qualitative land evaluation for irrigation suitability implies that the majority of the upper part of the study area was identified as mostly moderately suitable for surface irrigation for soil, slope, land cover, and distance from the water supply. The potential storage structure sites were identified considering the potential command areas found below the rivers.

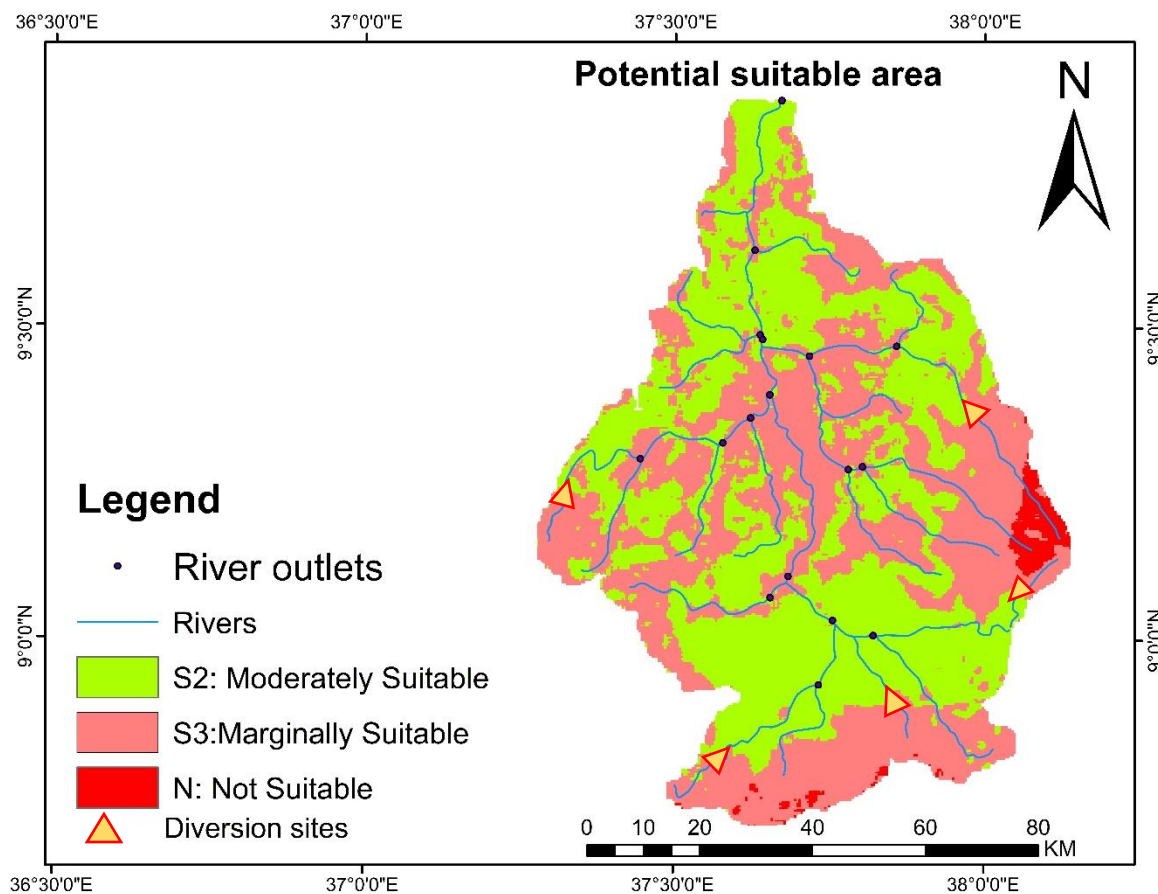


Figure 14. Potential irrigable land of Guder sub-basin

Table 15, represents identified areas and its percentage to the total area with different suitability levels. From the total area, it was observed that 2,113.56 ha (0.3%) was highly suitable (S1) which were not shown on the map due to smaller polygons, 315,635.14 ha (47.6%) was found to be moderately suitable (S2), 330,244.45 ha (49.8 %) was identified as marginally suitable (S3), and 15,708.98 ha (2.4%) was not suitable for potential surface irrigation.

Table 15. Areal distribution of suitability classes

Suitability Class	Area (ha)	Area (%)
S1	2,113.56	0.3
S2	315,635.15	47.6
S3	330,244.45	49.8
N	15,708.98	2.4
Total	663,702.14	100

4.5. Gross Irrigation Water Requirements

Gross irrigation water requirements of commonly grown crops in the study area i.e., Maize, Onion, and Potato at the identified potential irrigable sites under surface irrigation methods were estimated using ETo. The ETo for the Ambo station was 4.18 mm/day. It varies from 2.87 to 5.21 mm/day. The maximum ETo was in February and the minimum was recorded in the month of August.

Similarly, the ETo for the Gedo station was 4.16 mm/day. It varies from 2.8 to 4.93 mm/day. The maximum ETo was in February and April and the minimum was recorded in the month of July. And the ETo for the Gedo station was 4.12 mm/day. It varies from 2.51 to 5.16 mm/day. The maximum ETo was in February and the minimum was recorded in the month of July.

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

4.6. Surface Water Potential of River Catchments

The gross crop irrigation water requirement for selected crops is estimated and subsequent gross monthly volume is obtained. As the potentially irrigable sites are located downstream of the possible diversion sites, Accounting 1/3 (one third) of the river flow for downstream ecological balance; the gross volume of irrigation requirement is compared with available river flow for each month.

Irrigation water requirement, gross irrigation water requirements were calculated for three crops commonly grown in the study area over identified potential suitable area. The potential suitable area identified after overlay analysis was 122,515.3ha in Upper Guder watershed, 130,027.66 ha in middle Guder watershed and 67,491.25 ha in lower Guder watershed all under moderately suitable class.

The net scheme irrigation water requirement was varying from 0.5 to 4.7 mm/day over percent of irrigated total area. The irrigation requirement or duty of crop for the actual irrigated area ranges from 0.19 l/s/ha in October and 0.55 l/s/ha in December as shown in (Table 18) with the maximum

irrigation water requirement of 0.55 l/s/ha and the available mean monthly flow in the corresponding month was 7.3 m³/s for upper Guder watershed (Table 16). Similarly, the maximum duty for middle and lower Guder watersheds were also obtained as 0.7 l/s/ha in April. The available mean monthly flow in the respective month was 35.4 m³/s (Table 16) and 0.61 l/s/ha in April, the available mean monthly flow in the respective month was 7.1 m³/s (Table 16) respectively. Therefore, the amount mentioned above is required from the rivers to meet the demand of crop for water per hectare of land in each watershed.

In the upper guder watershed the irrigable area was obtained for the maximum crop demand in the month of December as 13,272.72 ha which means 10.8 % of potential suitable land. Similarly In the middle guder watershed the irrigable area was obtained for the maximum crop demand in the month of April as 50,571.43 ha, which means 38.9 % of potential suitable land. The irrigable land in the lower guder for the available river flow was obtained for the maximum crop demand in April as 11,639.43 ha, which means 17.25 % of potential suitable land in the corresponding watershed.

The analysis shows that middle guder watershed has bigger surface water potential compared to the other watersheds and upper guder has the smaller water potential. It is visible that stream flow availability during periods of crop growth were not sufficient and irrigation development using storage structures has been most important because when artificial storage structure is considered, there is huge potential for irrigation development on the area.

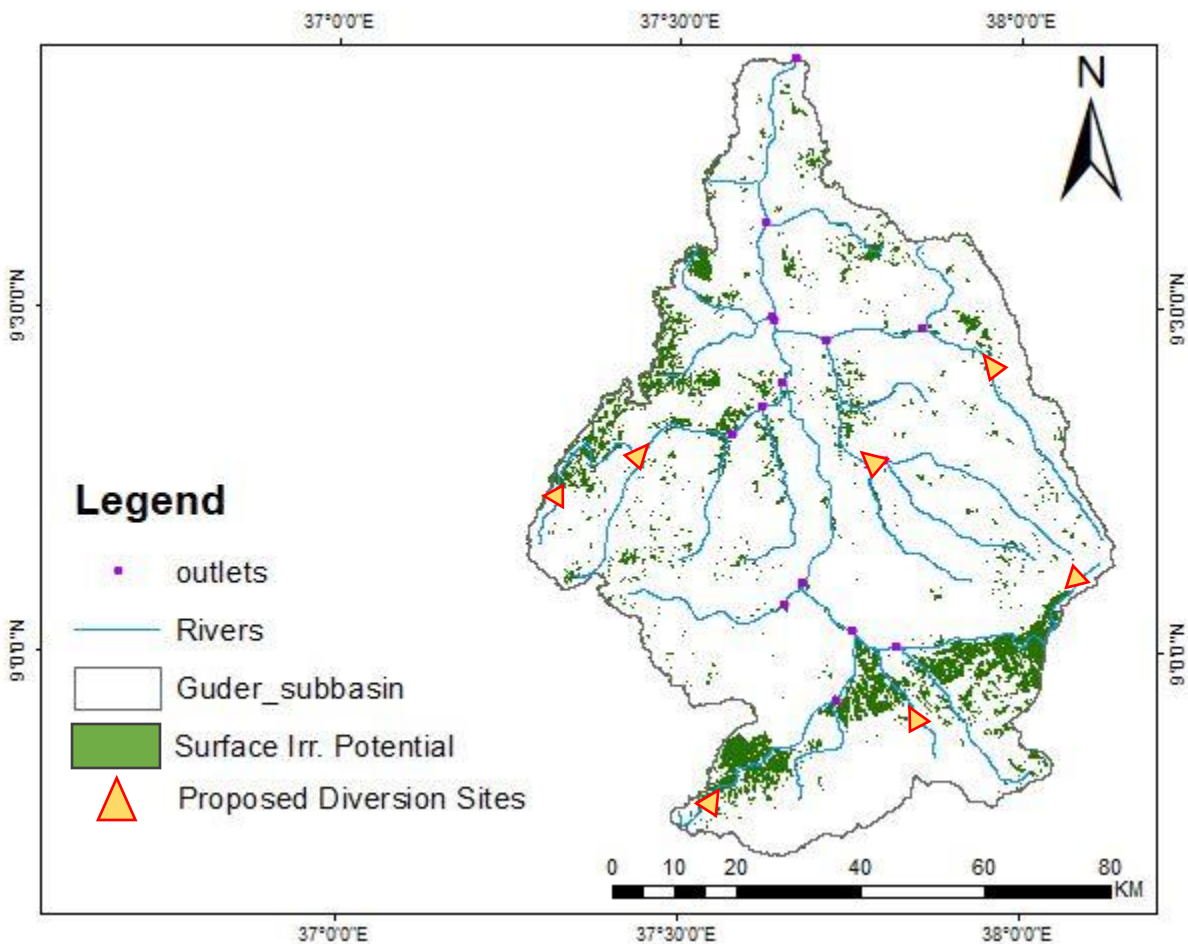


Figure 15. Surface Irrigation Potential of Guder Sub-basin

The available stream flow magnitude (Table 16) at proposed diversion sites was compared to gross crop water requirement for selected crops (Table 17-19). Accordingly, among 317,748.71 ha (47.9%) of potentially identified suitable area in the watershed, 75,483.58 ha (23.9 %) of the watershed area can be irrigated using the available streams in the catchment taking into account the downstream environmental requirements. The proposed diversion point that could maximize the irrigable area is also indicated in (Figure 15).

Table 16. Mean monthly discharges and total annual flow of rivers catchments in m³/s

River Name	watershed	Mean monthly flow												Annual Flow
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Fatto	upper	5.8	4.5	5.2	5.2	8.3	55.0	271.9	358.3	242.9	51.1	13.0	7.2	85.7
Guder	middle	27.1	17.5	30.0	35.4	63.1	338.9	1057.2	1381.0	1025.5	351.2	84.9	35.4	370.6
Duber	lower	6.6	6.6	7.4	7.1	6.9	14.1	196.6	347.0	87.7	9.0	6.3	6.7	58.5

Table 17. Scheme water requirement of upper guder watershed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Potato	155	124.8	0	0	0	0	0	0	0	50	101.7	145.7
2. Onion	157.5	140.6	58.4	0	0	0	0	0	0	50	113.7	153.2
3. Maize	98.5	126.5	169.5	71.5	107.8	0	0	0	0	0	0	0
Net scheme irr.req.in mm/day	4.7	4.6	1.7	0.5	0.7	0	0	0	0	1.3	2.8	3.8
in mm/month	144.4	129.9	51.4	14.3	21.6	0	0	0	0	40	85	118.8
in l/s/h	0.54	0.54	0.19	0.06	0.08	0	0	0	0	0.15	0.33	0.44
Irrigated area (%of total area)	100	100	50	20	20	0	0	0	0	80	80	80
Irr.req. for actual area (l/s/ha)	0.54	0.54	0.38	0.28	0.4	0	0	0	0	0.19	0.41	0.55

Table 18. Scheme water requirement of Guder guder watershed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Potato	167.6	131.1	0	0	0	0	0	0	0	54.7	109.6	157.9
2. Onion	170.4	147.9	63.5	0	0	0	0	0	0	54.7	122.3	165.9
3. Maize	107.3	133.6	187.1	180.9	115.8	0	0	0	0	0	0	0
Net scheme irr.req. in mm/day	5	4.9	1.8	1.2	0.7	0	0	0	0	1.4	3	4.2
in mm/month	156.4	136.6	56.5	36.2	23.2	0	0	0	0	43.8	91.5	128.7
in l/s/h	0.58	0.56	0.21	0.14	0.09	0	0	0	0	0.16	0.35	0.48
Irrigated area (% of total area)	100	100	50	20	20	0	0	0	0	80	80	80
Irr.req. for actual area (l/s/h)	0.58	0.56	0.42	0.7	0.43	0	0	0	0	0.2	0.44	0.6

Table 19. Scheme water requirement of Lower guder watershed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Potato	145.1	112.3	0	0	0	0	0	0	0	49.3	97.3	135.7
2. Onion	147.6	127.1	53.9	0	0	0	0	0	0	49.3	107.8	142.2
3. Maize	95.8	117.1	160.4	157.4	109	0	0	0	0	0	0	0
Net scheme irr.req. in mm/day	4.4	4.2	1.6	1	0.7	0	0	0	0	1.3	2.7	3.6
in mm/month	136	117.7	48.2	31.5	21.8	0	0	0	0	39.4	81	110.5
in l/s/h	0.51	0.49	0.18	0.12	0.08	0	0	0	0	0.15	0.31	0.41
Irrigated area (% of total area)	100	100	50	20	20	0	0	0	0	80	80	80
Irr.req. for actual area (l/s/h)	0.51	0.49	0.36	0.61	0.41	0	0	0	0	0.18	0.39	0.52

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary and Conclusion

The Irrigation suitability study was conducted for the Guder sub-basin which is located in the Abay basin Oromia regional state. The total area coverage of the watershed obtained through watershed delineation is 6683.82 km². The study was carried out to evaluate and estimate suitable irrigable land and water resource in the sub-basin and develop the suitability map.

In this study, the surface irrigation potential of the sub-basin was mapped based on factors, which affect the suitability of land for surface irrigation, such as Distance f command area from the water source, slope, land use, and soil. Land suitability for irrigation has been extracted using weighted overlay analysis techniques based on Multi-Criteria Decision Making and Analytical Hierarchy Process. Selected raster maps were overlaid by converting their cell values to a common scale, assigning a weight to each criterion, and adding the weighted cell values together. The cell values of each input raster layer are multiplied by their weight and the final land suitable for irrigation is found. The result after overlay analysis in Arc Map indicated that approximately 317,748.71 ha (47.9%) of the Guder sub-basin is suitable highly to moderately for surface irrigation.

Potentially irrigable land was obtained by creating irrigation suitability model analysis which involved weighting of values of all data sets such as soil, slope, land cover, and distance from the water supply. Surface irrigation land suitability shows that 40.29 % of soil is highly suitable, 22.83 % of soil is moderately suitable, and 4.34 % of soil is marginally suitable and 32.42 % is not suitable. Also, 9.16 % of the slope in the study area is highly suitable, whereas 11.4 % is moderately suitable and 23.4 % is marginally suitable for a surface irrigation system. In terms of land cover/use forests, water bodies, built-up, and bushland of the study area were restricted from irrigation development. 97.21 % of the distance from outlets were classified as highly to marginally suitable for the development of irrigation system. However, the distance of the land unit from the water source of about 2.78% was found as not suitable.

Highly suitable lands have no significant limitations for surface irrigation development. Moderately suitable lands are also suitable for surface irrigation but proper management required.

Marginally suitable lands show medium suitability with requirements of conservation structures, additional inputs to land and protection.

The surface water irrigation potential was assessed for the potential suitable areas in the watersheds and the result shows that the river flow in middle guder has huge potential for surface irrigation. The total command area which can be irrigated in the upper guder for the maximum gross water requirement with the available flow was 50,571.43 ha (38.9 %) of total potential suitable area. The upper guder watershed has the second potential for surface irrigation for the available river flow. The total command area which can be irrigated with the available flow in the guder sub basin was 75,483.58 ha (23.9 %) of the potential suitable area. The result shows that Guder sub basin has huge suitable land for surface irrigation but the potential of river flow was not sufficient to irrigate the suitable land in the dry season without storing water in the rainy season.

5.2. Recommendation

Based on the Land suitability and surface water potential assessment of this study the following points are recommended.

- In this study the land suitability for surface irrigation was carried out by considering only four Factors (i.e., distance from water sources, soil, slope, and land use/cover). However, the effects of other factors such as water quality, environmental, economic, and social terms should be assessed to get sound and good results. These factors were not used in the land evaluations for this study due to insufficient environmental and socio-economic data.
- Based on the land evaluation, the physical land quality of the Guder sub-basin has great potential for Surface irrigation. But irrigation cannot be carried out only based on the physical qualities of the land. The chemical properties of soils are also very necessary for irrigation. Therefore, future studies should include the evaluation of chemical properties of the soil such as PH, soil fertility, etc.
- Any future expansion and planning of surface irrigation in the study area may involve a Storage reservoir across the river to store runoff during the rainy season as the only river water flow does not meet the crop water demand.
- The analysis of land suitability considered highly and moderately suitable land for surface irrigation but marginally suitable land should be used under high level management.

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7. APPENDICES

Appendix A: Hydro-meteorological Data (Hydrological Data)

Appendix Table 1. Guder River monthly flow (m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
1994	27.120	17.426	25.333	18.972	37.172	178.352	1179.293	1288.235	964.719	121.443	39.607	25.227	326.908
1995	19.090	14.789	14.773	30.320	44.925	92.972	630.129	1370.715	879.549	129.605	36.191	26.650	274.142
1996	28.617	15.807	75.921	64.893	208.932	883.833	1223.854	1420.136	794.850	301.804	61.197	33.333	426.098
1997	31.972	18.313	19.423	46.251	40.936	326.919	1117.497	1147.958	548.770	271.806	112.131	68.046	312.502
1998	41.801	21.529	40.061	18.543	30.377	209.372	1013.574	1408.726	1001.827	699.119	93.418	32.932	384.273
1999	24.719	12.558	14.609	9.854	45.437	326.542	1029.188	1378.356	976.028	727.992	94.528	43.303	390.260
2000	30.016	19.565	17.297	42.789	65.053	287.543	664.735	1277.199	1384.888	666.879	180.879	37.504	389.529
2001	37.244	23.299	74.945	57.129	100.831	839.715	1273.184	1150.418	933.299	371.341	74.308	37.408	414.427
2002	34.437	21.284	24.575	38.312	85.293	185.067	1078.525	1069.455	663.291	126.531	35.870	30.325	282.747
2003	27.511	19.630	40.950	46.278	20.786	113.708	935.912	1272.406	1027.948	242.140	44.646	33.123	318.753
2004	26.756	18.355	21.147	42.682	33.936	145.974	762.362	1149.480	1059.567	504.900	44.456	25.925	319.628
2005	22.452	8.833	22.435	32.818	67.928	223.492	933.313	1220.022	870.225	338.247	53.388	21.835	317.916
2006	15.042	9.592	48.201	57.567	47.644	398.512	1216.472	2296.391	1193.807	298.952	60.004	39.383	473.464
2007	26.177	24.786	19.970	20.817	89.274	411.477	1335.841	1473.223	1659.277	370.543	35.367	20.739	457.291
2008	15.339	13.184	10.300	14.443	71.873	751.062	1754.010	1588.448	1650.752	133.975	300.380	31.187	527.913
2009	25.848	20.528	10.054	25.476	19.265	47.361	767.044	1585.416	799.739	313.590	91.384	59.867	313.798
Mean	27.1	17.5	30.0	35.4	63.1	338.9	1057.2	1381.0	1025.5	351.2	84.9	35.4	370.600
STDEV	7.0	4.5	20.2	16.2	44.5	255.2	276.4	279.4	303.6	195.5	66.8	12.4	71.8

Appendix Table 2. Fatto River monthly flow (m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
													Average
1998	9.908	3.628	7.001	2.792	5.790	40.768	195.236	287.639	181.779	70.255	11.978	5.162	68.495
1999	4.336	2.680	2.525	1.595	7.703	39.552	163.432	227.670	175.438	95.531	12.416	5.539	61.535
2000	2.987	1.936	1.177	4.358	6.361	37.459	183.311	289.124	216.603	98.226	14.906	6.271	71.893
2001	3.462	2.232	5.559	5.141	5.121	160.940	242.006	293.104	253.092	25.540	6.982	3.816	83.916
2002	3.780	2.398	2.562	2.926	4.068	15.810	214.438	224.043	103.281	12.785	3.869	3.220	49.432
2003	2.819	1.943	2.940	5.242	1.695	10.895	254.855	319.440	228.876	30.266	5.166	3.641	72.315
2004	3.000	2.294	3.377	3.066	2.240	10.470	139.783	291.587	280.133	62.255	8.596	4.252	67.588
2005	3.347	2.015	3.460	3.957	3.349	6.424	138.261	349.350	337.343	96.048	8.745	5.893	79.849
2006	2.277	3.358	3.880	6.160	5.769	83.415	339.367	544.428	284.000	25.221	7.492	5.453	109.235
2007	5.200	5.745	3.622	2.822	7.218	55.426	415.001	335.616	259.060	60.309	7.928	4.894	96.903
2008	2.737	2.919	2.676	2.534	12.312	101.901	491.071	497.631	271.471	41.183	56.381	15.891	124.892
2009	11.976	11.084	9.813	8.340	9.047	25.875	195.200	432.000	254.220	80.076	20.184	16.215	89.503
2010	14.078	12.832	14.914	13.981	24.798	90.467	389.947	356.061	406.791	41.915	20.914	15.978	116.890
2011	14.857	10.763	12.974	11.067	8.021	129.659	481.273	445.284	125.211	14.662	7.639	5.185	105.550
2012	3.926	3.208	2.922	3.669	2.627	14.876	262.956	443.400	307.707	34.114	7.426	5.080	90.993
2013	3.478	2.657	3.785	5.319	26.273	55.455	244.181	396.858	201.277	29.892	6.650	8.129	81.996
Mean	5.8	4.5	5.2	5.2	8.3	55.0	271.9	358.3	242.9	51.1	13.0	7.2	85.7
STDEV	4.2	3.5	3.9	3.2	7.0	44.8	112.6	90.6	74.4	28.6	12.2	4.4	20.3

Appendix Table 3. Duber River monthly flow (m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
													Average
1997	4.122	8.624	7.168	7.251	3.927	2.961	191.908	207.074	15.957	2.364	2.256	2.136	37.979
1998	3.844	3.395	2.112	2.375	2.472	1.992	133.629	328.922	119.591	7.186	1.808	1.783	50.759
1999	1.830	1.776	1.896	2.040	2.424	2.525	144.229	405.348	59.175	8.943	1.672	1.760	52.802
2000	1.790	1.740	2.232	2.076	2.016	1.800	100.915	371.132	43.827	3.687	0.673	0.740	44.386
2001	0.632	0.295	0.312	0.152	0.139	1.643	270.656	268.683	91.294	11.559	7.840	7.817	55.085
2002	8.435	7.924	8.773	8.490	8.773	8.342	191.596	378.902	118.072	22.234	19.430	19.840	66.734
2003	19.444	17.700	19.620	19.200	19.840	33.564	241.013	374.616	76.813	11.816	11.815	16.226	71.806
2004	12.337	12.309	15.098	15.158	16.494	25.116	126.286	328.019	76.452	7.270	7.335	9.682	54.296
2005	10.075	8.628	10.153	9.650	10.385	25.066	150.056	207.948	75.312	11.190	7.050	7.873	44.449
2006	9.053	8.972	13.945	11.699	9.083	9.177	285.038	373.607	136.740	1.598	0.302	0.217	71.619
2007	0.217	0.196	0.217	0.210	0.217	49.545	169.890	501.549	160.078	10.687	5.521	6.693	75.418
2008	6.888	7.151	7.705	7.050	7.285	7.817	354.478	417.818	79.518	9.049	10.170	5.583	76.709
Mean	6.6	6.6	7.4	7.1	6.9	14.1	196.6	347.0	87.7	9.0	6.3	6.7	58.5
STDEV	5.4	5.1	6.1	5.8	6.1	15.0	73.0	82.2	38.7	5.2	5.4	5.9	12.8

Appendix B: Meteorological data (Rainfall data)

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

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	8.4	0.1	39.5	20.1	99.2	108.4	195.9	132.9	95.9	119.9	1.3	0.0	821.6
2000	0.0	0.0	9.3	51.5	93.7	121.2	186.4	191.6	131.2	83.7	20.7	14.8	904.1
2001	0.0	12.5	60.5	70.4	177.9	148.5	197.9	243.1	110.5	41.8	5.4	11.0	1079.5
2002	78.7	16.9	55.6	56.3	39.5	178.0	176.9	149.7	40.3	3.0	0.0	17.2	812.2
2003	41.7	100.0	54.8	154.1	9.4	209.0	134.2	142.7	76.0	9.3	1.0	0.0	932.2
2004	39.2	16.6	35.0	108.7	26.8	137.1	203.6	215.0	138.9	19.0	0.0	8.9	948.8
2005	25.2	0.0	86.8	47.5	58.1	166.3	158.0	187.1	98.4	19.0	10.2	0.0	856.6
2006	0.0	4.7	150.7	72.3	157.7	109.9	196.8	298.6	76.5	17.9	18.8	0.0	1103.9
2007	49.3	54.3	40.2	38.9	131.6	275.2	232.6	218.3	111.7	11.0	0.0	0.0	1163.1
2008	0.0	0.0	1.0	18.7	157.3	161.8	308.0	260.2	84.0	64.8	101.8	2.7	1160.3
2009	26.9	23.1	28.7	61.2	47.5	96.4	285.7	271.9	65.3	56.1	1.7	41.9	1006.4
2010	22.4	48.4	76.3	33.5	126.7	166.4	315.7	235.1	116.0	0.0	22.6	24.5	1187.6
2011	55.9	7.0	90.0	120.0	185.8	358.7	456.4	387.1	224.2	0.0	0.0	0.0	1885.1
2012	0.3	0.0	38.6	56.5	23.1	142.5	283.1	167.7	173.1	53.2	0.0	18.0	956.1
2013	0.0	3.9	18.6	88.0	119.8	158.8	226.3	172.3	73.4	94.9	4.0	0.0	960.0
2014	2.8	18.2	61.5	44.8	202.9	138.8	130.1	134.2	91.3	28.2	8.9	4.4	866.1
2015	4.3	6.1	40.1	54.4	81.9	166.7	184.7	166.7	103.9	0.0	27.9	2.1	838.8
2016	37.0	29.1	21.1	104.4	97.1	113.7	185.7	156.4	66.2	37.0	0.0	4.5	852.2
2017	0.0	9.2	13.4	27.5	218.9	89.0	152.3	140.9	129.6	7.6	17.6	0.0	806.0
2018	13.4	130.3	72.1	200.0	13.6	267.2	151.6	261.5	25.2	38.9	44.8	0.0	1218.5
Mean	20.3	24.0	49.7	71.4	103.4	165.7	218.1	206.7	101.6	35.3	14.3	7.5	
Depend	0	0.02	19.1	34.58	29.34	110.66	153.44	144.11	67.62	3.92	0	0	

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

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	18.9	0.0	10.0	29.3	57.5	82.2	175.9	64.7	59.8	53.5	10.9	2.8	565.5
2000	0.0	0.0	5.8	36.7	64.2	61.8	74.6	43.1	75.6	82.6	26.7	0.0	471.1
2001	14.2	26.7	130.8	87.3	140.5	134.4	292.5	392.0	255.5	58.0	7.0	4.0	1542.9
2002	45.0	0.0	64.5	13.5	77.8	163.5	229.5	109.0	103.4	0.0	11.5	14.0	831.7
2003	18.0	26.5	74.0	38.0	3.0	196.0	158.6	84.9	195.5	0.0	14.9	38.6	848.0
2004	14.0	7.7	56.9	29.6	41.8	126.0	101.5	145.7	61.9	27.9	8.3	29.6	650.9
2005	13.8	0.0	64.0	41.5	64.1	114.9	205.1	132.8	132.4	5.5	31.9	5.7	811.7
2006	4.5	51.5	89.6	92.9	141.9	205.0	139.6	383.8	83.2	60.3	58.3	33.6	1344.2
2007	27.1	37.7	26.4	36.6	215.9	250.2	239.3	90.2	131.3	7.8	0.0	0.0	1062.5
2008	3.2	0.0	0.0	59.2	302.0	252.6	208.7	184.1	113.9	54.1	158.5	10.5	1346.8
2009	40.2	5.9	18.1	55.2	37.9	117.2	214.9	126.7	64.4	59.5	0.0	24.8	764.8
2010	29.4	38.7	25.7	33.0	128.7	209.5	280.6	115.3	49.0	0.0	51.6	31.1	992.6
2011	6.8	0.0	25.3	18.9	125.9	113.5	90.7	99.5	66.5	0.0	65.5	0.0	612.6
2012	0.0	0.0	63.9	16.5	25.3	133.7	223.0	138.9	187.8	0.0	22.9	18.8	830.8
2013	17.0	9.5	9.8	66.8	146.6	156.7	266.0	100.3	82.8	49.7	7.6	0.0	912.8
2014	9.5	20.5	27.4	82.2	84.8	132.2	174.3	126.0	128.6	74.1	10.7	0.0	870.3
2015	0.0	15.0	77.3	0.0	109.1	141.2	131.8	101.0	160.9	37.3	49.4	23.8	846.8
2016	2.1	0.0	17.2	57.0	40.9	251.6	195.7	0.0	224.0	1.0	0.0	16.8	806.4
2017	0.0	27.6	49.7	80.6	107.6	157.5	181.7	181.1	165.3	48.2	19.6	0.0	1018.9
2018	5.6	38.1	49.7	99.0	281.4	269.4	242.0	304.9	158.1	56.5	82.0	5.5	1592.2
Mean	13.5	15.3	44.3	48.7	109.8	163.5	191.3	146.2	125.0	33.8	31.9	13.0	
Dep.Rf	0.42	0	11.44	20.98	41.08	115.36	133.36	85.96	64.82	0	7.12	0	

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

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	6.9	7.6	3.0	18.8	136.2	283.2	309.3	314.0	346.9	169.2	0.0	3.3	1598.4
2000	55.5	0.0	17.4	146.9	204.9	255.3	224.6	346.0	259.5	123.6	43.4	21.4	1698.5
2001	5.9	37.0	152.8	86.9	169.0	250.7	425.7	315.3	403.1	83.5	0.0	31.9	1961.8
2002	47.0	21.7	66.1	179.6	107.0	295.7	504.7	352.7	217.2	0.0	0.0	18.4	1810.1
2003	58.9	19.7	88.4	248.4	101.9	329.3	383.5	254.8	180.1	50.6	1.8	29.6	1747.0
2004	42.3	29.9	90.3	174.3	39.9	344.8	348.1	239.2	360.3	123.9	7.8	36.5	1837.3
2005	39.7	11.0	68.3	151.1	97.1	238.4	353.7	411.0	252.2	86.3	25.4	0.0	1734.2
2006	2.4	3.6	225.9	148.5	141.3	307.2	363.8	458.8	237.2	73.5	10.7	6.8	1979.7
2007	58.6	30.7	49.4	109.5	160.3	299.2	338.8	336.1	379.1	23.5	0.0	0.0	1785.2
2008	1.5	1.7	2.3	38.5	257.1	285.0	392.2	393.8	311.1	127.7	89.8	1.0	1901.7
2009	46.9	29.9	15.8	85.4	0.0	238.1	412.4	348.1	248.7	87.5	2.7	70.2	1585.7
2010	80.5	112.3	57.7	83.8	170.1	322.5	389.3	383.5	352.2	2.3	16.8	31.6	2002.6
2011	19.7	0.0	87.9	88.2	128.1	327.9	419.4	448.5	176.8	0.7	133.2	0.0	1830.4
2012	29.1	7.4	113.1	75.9	16.9	74.2	377.6	416.6	401.3	3.8	44.3	28.1	1588.3
2013	56.7	62.3	34.0	41.2	374.5	279.3	421.8	338.9	330.8	126.6	47.9	0.0	2114.0
2014	21.6	22.2	89.4	103.0	341.4	284.2	365.4	292.1	380.1	95.2	49.5	0.0	2044.1
2015	19.1	23.0	85.7	6.1	293.1	357.6	278.7	378.8	295.4	58.3	14.4	27.6	1837.8
2016	41.8	36.8	19.6	56.2	230.2	177.3	361.5	303.5	486.6	86.1	2.4	0.0	1802.0
2017	0.0	14.4	52.4	110.1	180.8	332.2	454.4	298.4	303.8	131.5	20.5	6.0	1904.5
2018	26.8	48.1	106.1	142.3	187.1	351.3	559.3	331.0	282.2	36.0	2.1	0.0	2072.3
Mean	33.0	26.0	71.3	104.7	166.8	281.7	384.2	348.1	310.2	74.5	25.6	15.6	
Dep.Rf	6.1	4.4	17.84	146.1	44.2	96.08	340.66	299.42	239.5	7.74	0.36	0	

Appendix C: Climatic data and Estimated ETo Tables

Appendix Table 7. Summary of other climatic data for meteorological stations

No.	Station & Recording	Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Ambo													
	1999-2018	Sunshine(hrs)	9.3	9.3	8.1	7.5	7.5	6.1	3.8	3.5	6.0	8.7	9.0	8.9
	1999-2018	Tmax(°C)	27.5	28.9	28.9	28.1	27.3	24.8	22.8	22.3	23.9	26.0	26.3	26.5
	1999-2018	Tmin(°C)	11.7	13.0	13.5	13.8	12.7	12.5	12.7	12.8	11.7	11.3	11.0	11.2
	1994-2013	Wind(m/s)	1.9	2.1	1.9	1.7	1.3	1.0	0.9	0.8	0.9	1.4	1.8	1.9
	2001-2017	RH(Average)	51	49	50	54	60	71	78	80	76	59	54	51
3	Gedo													
	1994-2013	Sunshine(hrs)	10.0	10.7	9.1	9.2	9.6	8.3	4.4	4.4	9.1	11.1	10.9	10.5
	1999-2018	Tmax(°C)	24	24	24	24	23	21	20	20	21	22	23	23
	1999-2018	Tmin(°C)	10.2	10.7	10.8	11.1	11.5	10.9	10.2	10.2	10.4	10.6	10.4	10.2
	1994-2013	Wind(m/s)	1.6	1.7	1.7	1.9	1.7	1.3	1.2	1.1	1.1	1.6	1.6	1.6
	1994-2013	RH(Average)	45	36	43	47	57	79	90	92	85	67	55	47
5	Tikur Enchini													
	1994-2013	Sunshine(hrs)	9.7	10.6	8.7	8.5	8.6	6.5	3.0	3.1	7.5	10.1	10.7	10.5
	1999-2018	Tmax(°C)	24.8	25.8	26.0	25.4	24.4	22.0	20.8	20.9	21.8	24.0	24.4	24.6
	1999-2018	Tmin(°C)	5.0	6.2	8.4	9.2	10.2	9.9	10.3	10.2	9.3	7.3	5.7	5.0
	1994-2013	Wind(m/s)	1.8	2.0	1.9	1.9	1.6	1.4	1.4	1.2	1.3	1.8	1.9	1.8
	1994-2013	RH(Average)	44	36	45	51	57	80	92	93	85	65	54	46

Appendix: ETo and climatic data of stations

Appendix Table 8. ETo and Climatic data for Ambo meteorological station

Country:	Ethiopia					Station:	Ambo	
Altitude:	2068 m	Latitude:	8.98N		Longitude:	37.8E		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sunshine	Radiation	Eto	
	°c	°c	%	m/s	hrs	MJ/m2/day	mm/day	
January	11.7	27.5	51	1.9	9.3	21.2	4.6	
February	13.0	28.9	49	2.1	9.3	22.5	5.21	
March	13.5	28.9	50	1.9	8.1	21.8	5.13	
April	13.8	28.1	54	1.7	7.5	21.1	4.85	
May	12.7	27.3	60	1.3	7.5	20.6	4.4	
June	12.5	24.8	71	1.0	6.1	18.1	3.62	
July	12.7	22.8	78	0.9	3.8	14.8	2.95	
August	12.8	22.3	80	0.8	3.5	14.7	2.87	
September	11.7	23.9	76	0.9	6.0	18.5	3.48	
October	11.3	26.0	59	1.4	8.7	21.8	4.33	
November	11.0	26.3	54	1.8	9.0	21	4.4	
December	11.2	26.5	51	1.9	8.9	20.1	4.35	
Average	12.3	26.1	61	1.5	7.3	19.7	4.18	

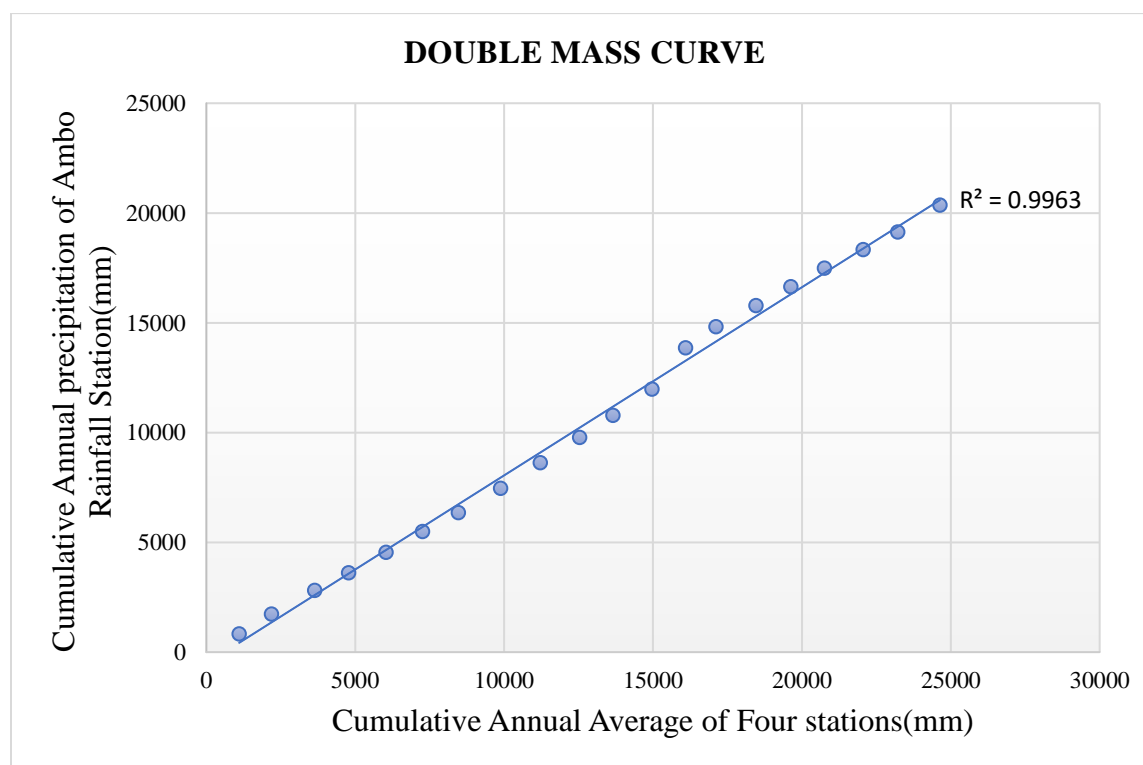
Appendix Table 9. ETo and Climatic data for Gedo meteorological station

Country:	Ethiopia					Station:	Gedo	
Altitude:	2520 m	Latitude:	9.02 N		Longitude:	37.5 E		
month	Min Temp	Max Temp	Humidity	Wind speed	Sunshine	Radiation	Eto	
	°c	°c	%	m/s	hrs	MJ/m2/day	mm/day	
January	10.2	23.7	45	1.6	10.0	22.2	4.32	
February	10.7	23.9	36	1.7	10.7	24.6	4.93	
March	10.8	23.9	43	1.7	9.1	23.3	4.84	
April	11.1	23.5	47	1.9	9.2	23.7	4.93	
May	11.5	23.5	57	1.7	9.6	23.7	4.69	
June	10.9	21.4	79	1.3	8.3	21.3	3.79	
July	10.2	20.1	90	1.2	4.4	15.7	2.8	
August	10.2	20.2	92	1.1	4.4	16	2.81	
September	10.4	21.2	85	1.1	9.1	23.2	3.9	
October	10.6	22.2	67	1.6	11.1	25.4	4.42	
November	10.4	23.0	55	1.6	10.9	23.7	4.32	
December	10.2	23.2	47	1.6	10.5	22.3	4.22	
Average						22.1	4.16	

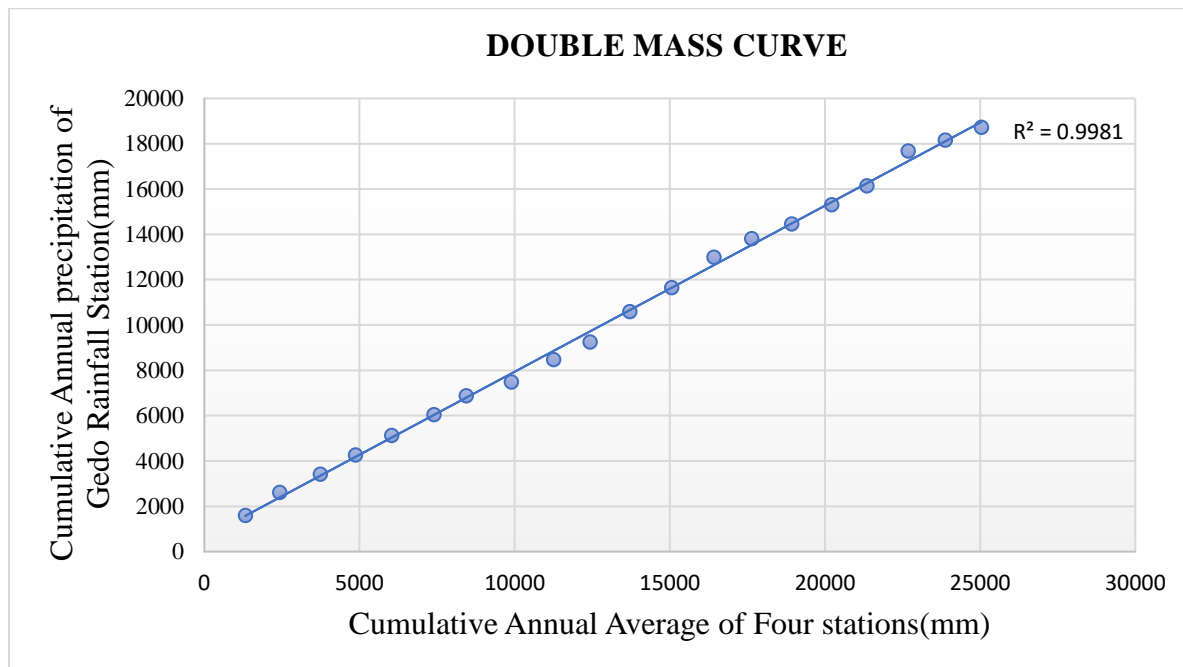
Appendix Table 10. ETo and Climatic data for Tikur Enchini meteorological station

Country:	Ethiopia					Station:	T.Enchini
Altitude:	2467 m	Latitude:	8.84 N	Longitude:	37.7 E		
Month	Min Temp	Max Temp	Humidity	Wind speed	Sunshine	Radiation	Eto
	°c	°c	%	m/s	hrs	MJ/m2/day	mm/day
January	5.0	24.8	44	1.8	9.7	21.8	4.42
February	6.2	25.8	36	2.0	10.6	24.5	5.16
March	8.4	26.0	45	1.9	8.7	22.7	4.97
April	9.2	25.4	51	1.9	8.5	22.6	4.86
May	10.2	24.4	57	1.6	8.6	22.2	4.51
June	9.9	22.0	80	1.4	6.5	18.7	3.45
July	10.3	20.8	92	1.4	3.0	13.6	2.51
August	10.2	20.9	93	1.2	3.1	14	2.57
September	9.3	21.8	85	1.3	7.5	20.8	3.6
October	7.3	24.0	65	1.8	10.1	23.9	4.45
November	5.7	24.4	54	1.9	10.7	23.4	4.5
December	5.0	24.6	46	1.8	10.5	22.4	4.39
Average						20.9	4.12

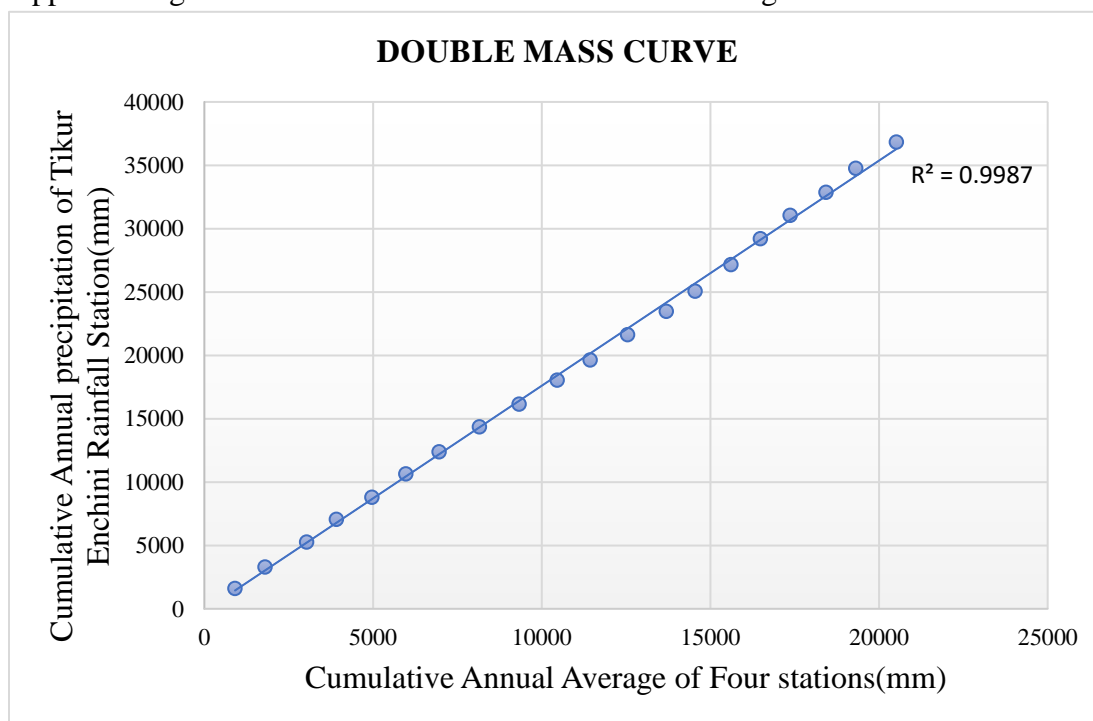
Appendix F: Consistency check and exceedance probability figures



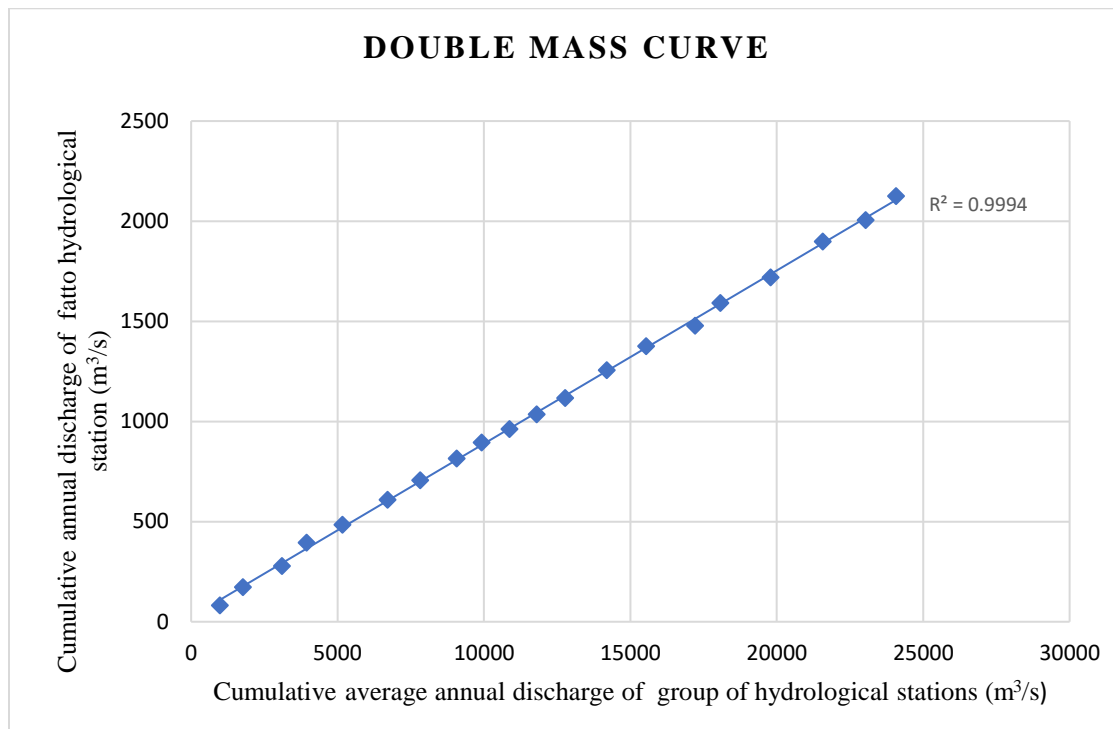
Appendix Figure 1. Double mass curve of Ambo meteorological rainfall station



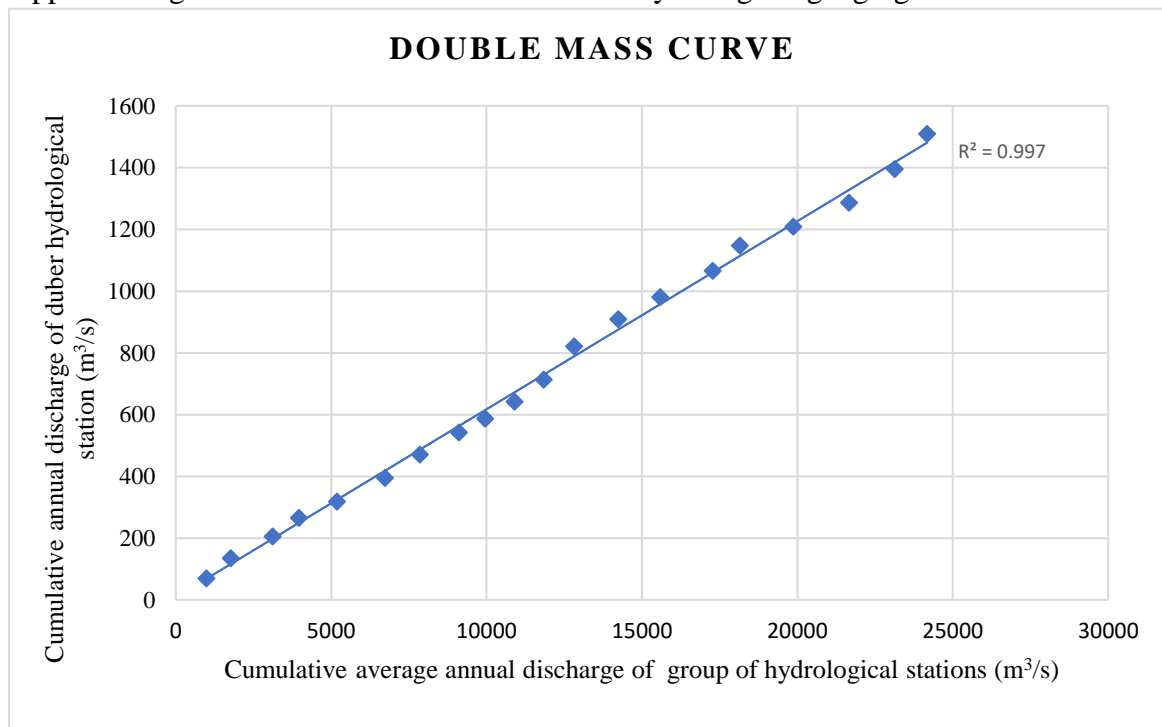
Appendix Figure 2. Double mass curve of Gedo meteorological rainfall station



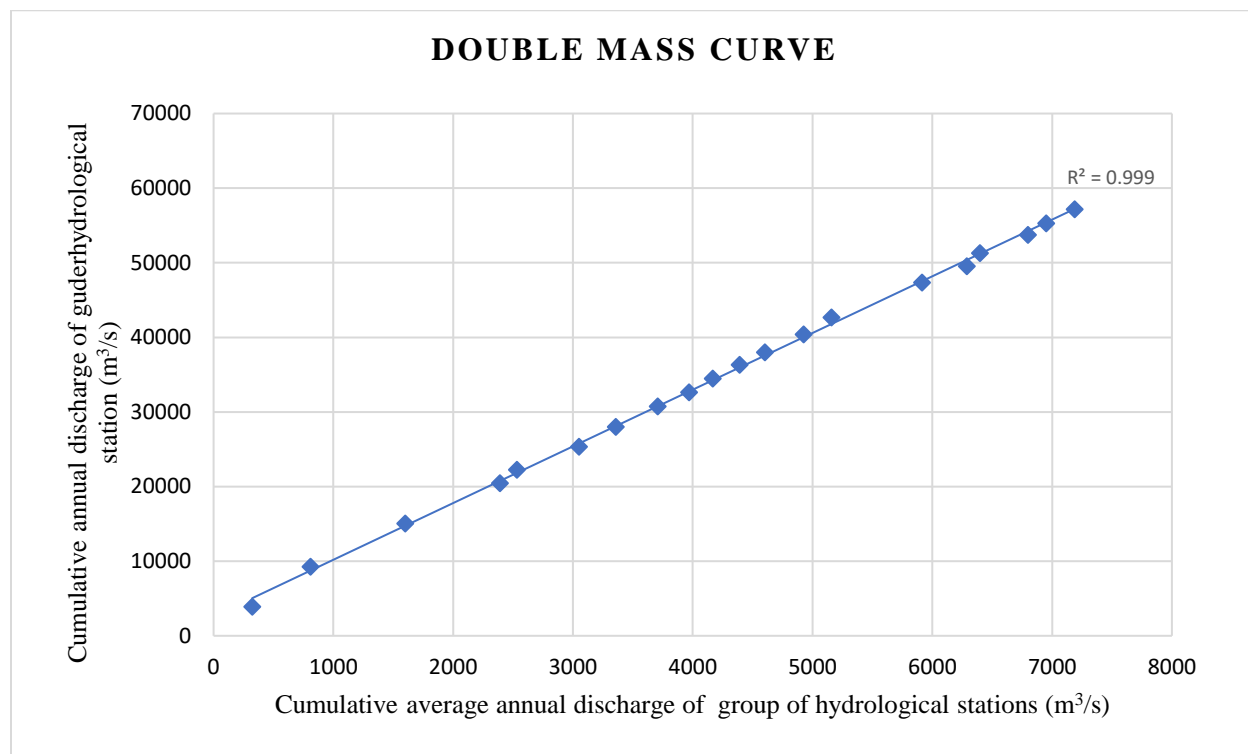
Appendix Figure 3. Double mass curve of Tikur Enchini meteorological rainfall station



Appendix Figure 4. Double mass curve of Indris hydrological gauging station



Appendix Figure 5. Double mass curve of Duber river hydrological gauging station



Appendix Figure 6. Double mass curve of Guder river hydrological gauging station

Appendix G: FAO Crop Data

Appendix Table 11. FAO crop data table for Potato

Crop Name: Potato		Stage of Development				
		Initial	Development	Mid	Late	Total
Crop characteristic						
Length stage	days	30	35	30	40	135
Crop coefficient	coefficient	0.5		1.15	0.75	
Rooting Depth	meters	0.3		0.3	0.3	
Depletion Level	fraction	0.4		0.5	0.5	
Yield response Factor	coefficient	0.4	1.1	0.8	0.4	1.05

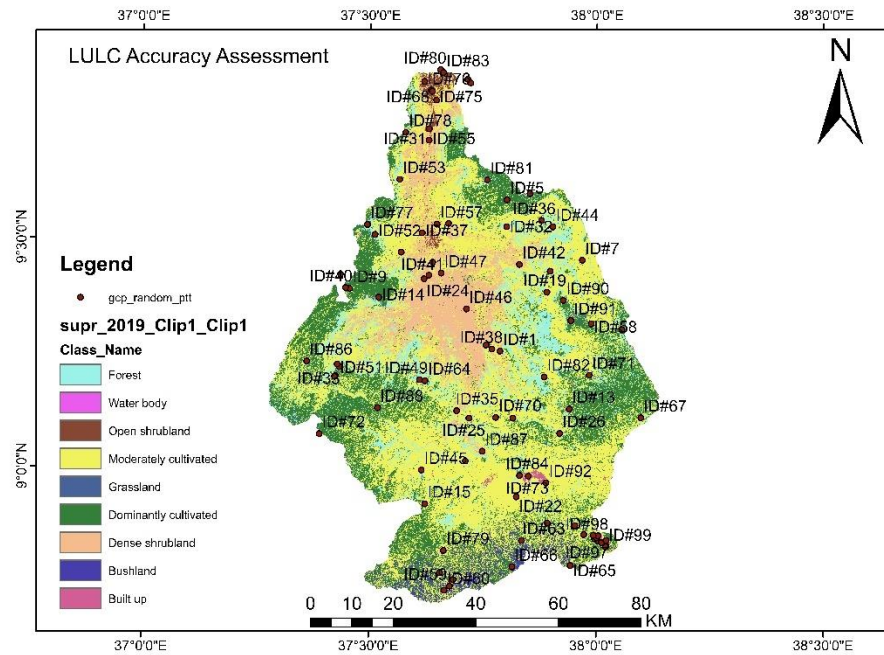
Appendix Table 12. FAO crop data table for Onion

Crop Name: Onion		Stage of Development				
		Initial	Development	Mid	Late	Total
Crop characteristic						
Length stage	days	20	35	45	50	150
Crop coefficient	coefficient	0.7		1.05	0.75	
Rooting Depth	meters	0.2		0.4	0.4	
Depletion Level	fraction	0.4		0.5	0.5	
Yield response Factor	coefficient	0.4	1.1	0.8	0.4	1.05

Appendix Table 13. FAO crop data table for Maize

Crop Name: Maize		Stage of Development				
		Initial	Development	Mid	Late	Total
Crop characteristic						
Length stage	days	25	50	40	35	150
Crop coefficient	coefficient	0.3		1.15	0.35	
Rooting Depth	meters	0.2		0.7	0.7	
Depletion Level	fraction	0.4		0.5	0.5	
Yield response Factor	coefficient	0.4	1.1	0.8	0.4	1.05

Appendix H: Ground Control Points of the study area



Accuracy Assessment (supr_2019.img) - Viewer# 1

File Edit View Report Help

Point #	Name	X	Y	Class	Reference
9	ID#9	330480.000	1038340.000	43	47
10	ID#10	378970.000	1042470.000	23	47
11	ID#11	328270.000	1041800.000	43	43
12	ID#12	326810.000	1017100.000	47	47
13	ID#13	383580.000	1009210.000	43	43
14	ID#14	337520.000	1036230.000	43	43
15	ID#15	348650.000	986330.000	47	47
16	ID#16	349670.000	1041540.000	25	25
17	ID#17	375900.000	966980.000	0	0
18	ID#18	363490.000	1024660.000	25	25
19	ID#19	378190.000	1037400.000	47	47
20	ID#20	335440.000	973930.000	0	0
21	ID#21	358440.000	996650.000	47	47
22	ID#22	370760.000	987980.000	47	47
23	ID#23	333140.000	1081920.000	0	0
24	ID#24	348490.000	1040670.000	25	25
25	ID#25	359330.000	1006990.000	47	47
26	ID#26	381270.000	1003310.000	23	23
27	ID#27	354400.000	1054040.000	47	47
28	ID#28	375950.000	1068930.000	0	0
29	ID#29	314940.000	975480.000	0	0
30	ID#30	350570.000	1044640.000	25	25
31	ID#31	349720.000	1074130.000	47	47
32	ID#32	368460.000	1053240.000	23	23
33	ID#33	328000.000	1019500.000	43	43

Appendix Figure 7. Randomly selected ground control points for LULC accuracy assessment