LAND SUITABILITY ASSESSMENT FOR SURFACE IRRIGATION POTENTIAL ALONG THE GIBE RIVER SUB-BASIN OF JIMMA ZONE, ETHIOPIA

Gadisa Biftu Dabele

A Thesis Submitted to

The Department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies

Adama Science and Technology University

October, 2022

Adama, Ethiopia

Land Suitability Assessment for Surface Irrigation Potential along the Gibe River Sub-basin of Jimma Zone, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled **"Land Suitability Assessment for Surface Irrigation Potential along the Gibe River Sub-basin of Jimma Zone, Ethiopia"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Gadisa Biftu Dabele	_______________________	________________
Name of Student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled ״**Land Suitability Assessment for Surface Irrigation Potential along the Gibe River Sub-basin of Jimma Zone, Ethiopia**״ prepared under my guidance by **Gadisa Biftu** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Water Resource Engineering (Irrigation Engineering).

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Andinet Kebede (PhD)	_______________	________________
Major Advisor	Signature	Date

APPROVAL PAGE OF MSC THESIS’

I, the advisors of the thesis entitled “**Land Suitability Assessment for Surface Irrigation Potential along the Gibe River Sub-basin of Jimma Zone, Ethiopia**” and developed by **Gadisa Biftu**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

<u>Andinet Kebede (PhD)</u>	________________	_______________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis Gadisa Biftu have read and evaluated the thesis entitled “**Land Suitability Assessment for Surface Irrigation Potential along the Gibe River Sub-basin of Jimma Zone, Ethiopia**” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science Water Resources Engineering (Specialization in Irrigation Engineering).

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
CEC	Cation exchange capacity
CI	Consistency Index
Cmol	Centimole
CR	Consistency Rate
CSA	Central Statistics Agency
DEM	Digital Elevation Model
DS	Deci Siemen
EC	Electrical Conductivity
ECe	Electrical conductivity of the saturated extract
ECO	Engineering Corporation of Oromia
ESP	Exchangeable Sodium Percentage
ETM+	Enhanced Thematic Mapper plus
FAO	Food and Agriculture Organization
FC	Field Capacity
GIS	Geographical Information System
I/S	Imperfect/Slow
IWMI	International Water Management Institute
KCL	Potassium chlorides
L	Loam
LUC	Land Use/Cover
LUT	land utilization type
m.a.s.l.	Meter above sea level
M/M	Medium/Medium
M/W	Medium/Well
Meq	Milli equivalent
MCDM	Multi-Criteria Decision Methods
WLC	Weighted Linear Combination
OWA	Overlay Weighting Analysis
RI	Random Index
SiCL	Silt Clay Loam

SiL	Silt Loam
SL	Sandy Loam
SR	Sodium Ratio
SWC	Soil and Water Conservation
USDIBR	United State Department of the Interior Bureau of Reclamation
UTM	Universal Transverse Mercator
WRB	World Reference Base

ABSTRACT

Land suitability mapping methods and GIS have been used to support analysis potential surface irrigation evaluation in the study areas; however, its application and practices are limited in the areas due to some factors such as infiltration rate, availability of water holding capacity and characteristics of rivers data did not gained in the study area. Therefore, the aim of this study was to identify potential sites for surface irrigation by selecting the major limiting factors. To select the potentially suitable sites for surface irrigation, GIS-based Multi-criteria analysis (MCA) was adopted. Eight limiting factors were considered to decide for the weight; namely, topography (slope), land use/cover, river proximity and soil data (texture, depth, drainage, pH and cation exchange capacity) by an analytic hierarchy process (AHP) from multi-criteria analysis. The results show that slope is the most important factor since all its values are less than one, followed by land use/land cover which only has a value lower than one. With respect to slope suitability, 57.4% of the total area was cultivated land and it was highly suitable and 2.8% grazing land was moderately suitable. Marginally suitable classes, which are shrub and bush land in the area, were 9.5 and 30.2% of the study area and they are not suitable for surfaces irrigation. The dominant drainage status was the well-conditioned class of 78% and it was highly suitable. The soil texture results revealed that 90.3% of the study area with soil texture of clay, silt clay loam and silt loam was highly suitable. The soils in the study area that was in pH range of 4.5-5.5, thus moderately suitable class, were more than half (54.8%). 58 .4 % of the command area was close to the water source and thus highly suitable for surface irrigation. Generally, the results showed that 0.8, 9.4, 2.3, and 87.5% of the study area are highly suitable, moderately suitable, marginally suitable and not suitable for surface irrigation, respectively. Thus, the application of GIS-based MCA provided an effective methodology to solve a complex decisional problem in potential surface irrigation site selection in the study area.

***Keywords**: GIS, Multi-criteria analysis, Analytical hierarch process, Surface irrigation, Limiting factors, Jimma.*

1. INTRODUCTION

1.1. Background

Water resources operation through irrigation development in agriculture is a critical contributor to economic and social development. Irrigation development has been honored as a crucial tool to encourage profitable growth and pastoral development, and is considered a root of food security and eradicating poverty in developing countries.

Proper land suitability evaluation of land resources in irrigation command areas is a prerequisite for better application of land resources which helps to optimize and sustain the productivity of these land resources. Irrigation practices lead to land- use change as well as an intensive cropping system. Inappropriate use of irrigation water has redounded in the declination of natural resources leading to declining in the productivity of land resources and deterioration of land quality for its unborn use (Sulieman *et al*., 2015).

Assessing available land resources for irrigation is important for planning their sustainable use. Land evaluation is a process of predicting land performance over time according to the specific types of use. Agriculture land suitability assessment is defined as the process of assessment of land performance when used for indispensable kinds of agriculture.

The top purpose of agriculture land suitability evaluation is to foretell the potential and limitations of the land for crop product. This process generally requires large sets of data as inputs. Information on land resources and possibilities for their sustained use is essential for opting, planning, and enforcing land uses to meet the adding demands for introductory mortal requirements and weal. The affair of suitability analyses handed not only the type of land use for which the land was suitable but also information about the type of limitations facing the application of land. Land suitability classification for surface irrigation is an integral part of multi-objective land-use planning for the development and operation of water sources as land systems for irrigation factors. They will support land use planning and operation by determining suitable lands for surface irrigation (USDIBR, 2005).
Land suitability for potential surface irrigation was done following the standard FAO guidelines (FAO, 1976). Identification of suitable sites for irrigation were carried out by

considering the soil, slope and land cover/use (FAO, 1976) could be weighted and evaluated using ArcGIS according to their suitability for irrigation.

Therefore, before surface irrigation is applied, land suitability analysis is extremely important to work out available suitable lands for surface irrigation. Land suitability analysis of surface irrigation is frequently conducted using the GIS-based analytical hierarchy process (AHP) system considering a group of criteria or parameters; particular attention is given to the physical and chemical properties of the soil, distance from available water sources, and terrain conditions in relation to styles of irrigation considered. In addition, land cover/land use types are considered limiting factors in assessing the suitability of land for irrigation (Abdel *et al*., 2016).

Geographic Information System (GIS) tools can be applied to develop a frame to support the targeting of applicable areas for colorful interventions (Venkatesan *et al*., 2010; Worqlul *et al*., 2015; Akyol *et al*., 2016; Worqlul *et al*., 2017; Schmitter *et al*., 2018). The Multi-Criteria Decision Methods (MCDM) system enables us to structure decision problems and design, estimate and prioritize indispensable scripts or opinions (Malczewski, 2006; Worqlul *et al*., 2015; Worqlul *et al.*, 2017; Schmitter *et al*., 2018). MCDM also enables us to combine geographical data and value judgments (the preferences of the decision-maker) to gain information for decision timber (Malczewski, 2006).

There have been numerous MCDM styles used to assess land suitability, such as ordered weighted normal, simple cumulative scoring, outranking styles, sense scoring of preference, and the logical hierarchical processes (AHP). The ultimate has been highly used to break complex decision- making processes which include multiple criteria, sub-criteria, and alternatives (Aldababseh *et al*., 2018).

AHP involves ranking relative criteria into a hierarchical structure, assessing the significance of these criteria per each position, comparing all alternatives for each criterion, and determining an overall ranking of the alternatives. Also, the determination of land suitability requires the integration of geospatial information from multiple sources among others on land cover, land- use practices, soil type, soil nutrient content, pollution, rainfall condition, water resources, and the technology used in agriculture. Such integration should be done in a geographic information system (GIS) frame where different layers of information could be added up and reused to identify the most suitable position for agriculture for specific crops, coupling thus AHP- GIS.

The AHP- GIS integrated system has been progressively used in recent times as an important spatial decision support system in the areas of water resources management, specifically for land suitability assessment for irrigated agriculture and other purposes. In this system, assessing pretensions, criteria and alternatives need to be linked in relation to the purpose of the study. In opting assessment criteria, attention should be paid to considering only those applicable to the decision- making process and contributing to the final target. A spatial layer that includes all suitability classes with respect to the specific criterion in a specific position presents one evaluation criterion. The suitability classes also need to be rated and added up according to their relative significance based on the donation of each criterion, to achieve the intended idea.

1.2. Statement of the Problem

The land is gradually becoming a scarce resource and population growth may exert pressure on the available limited natural resources. In addition to population growth, climate change, erratic rainfall, poor water management, overexploitation of groundwater and other reasons have emerged as the greatest risk to food security.

Even though the issue of agricultural productivity and food security is widely studied in different parts of the world, the impact of unwise use of land resources and the absence of utilization of the land according to its potential suitability is still a serious problem, particularly in developing countries (Pirbalouti *et al.,* 2011).

According to Girma *et al*. (2020), Ethiopia in general and southwestern Ethiopia in particular, is currently facing various problems resulting from the unwise use of land resources while the level of the problem has not been clearly identified and studied well as expected. In order to increase food production and provide food security, irrigation activities need to be grown in areas where they are best suited.

There is a huge gap between the potential and the level of irrigation applied in the country due to technical, physical and economic challenges (Gebregziabher et al.,2016), but the determinants of participation in irrigation are not fully identified in specific areas of the country. That means, there is no consistent and reliable inventory and well-studied document in water and irrigation related potentials in the Ethiopian context (Haile and Kasa, 2015).

It is advisable and recommendable to carry out a research study of physical surface irrigation potential land suitability analysis in Jimma Zone due to a number of reasons; such as, the agricultural system in the area is commonly rain-fed practice and most of the communities' livelihood is highly dependent on agriculture.

In the zone, there are many perennial rivers such as Gibe, Gilgal Gibe, Bulibul, Beyam, Agilo and etc. Despite this, there is no exploitation of water resources of these rivers for irrigated agriculture in the zone as much as their numbers. Firstly, stream flows from many of the rivers are not known. Secondly, potentially irrigable areas in the Zone have not been identified and matched with the water requirements. Therefore, to overcome these uncertainties, this study was carried out to assess the irrigation potential in Jimma Zone by using GIS as a tool and based on suitability parameters of soil, slope, and land use land cover.

1.3. Objects of the Study

1.3.1. General Objective

The general objective of the study was to carry out land suitability assessment for surface irrigation in Jimma Zone, along the Gibe sub-basin for surface irrigation use with respect to identifying the limitation restrict the suitability classes.

1.3.2. Specific Objects

The specific objects used were

- To characterize the physical and chemical parameters affecting land suitability of the study area for surface irrigation.
- To determine surface irrigation land under suitability classes.
- To develop identified land suitability map of surface irrigation for the study area.

1.4. Research Questions

Based on the specific objectives, the study tried to get answers to the following research questions

- How are the spatial properties characterized?
- How much land is suitable for surface irrigation in the area?
- What's the extent of delineated suitable surface irrigation land in the area?

1.5. Significance of the Study

The function of land suitability analysis is to guide opinions on land use planning in such a way that the land resource of the area is put to the most valuable use for mortal livelihood, while at the same time conserving those resources for the unborn generation (FAO, 1976). Thus, in addressing the problem of land resource application and minimizing the risk of dependence on rain-fed agriculture, this study may help to identify surface irrigation potential land and effective planning of land resources for the growers. Thus, the results of this study may come helpful for land policymakers for land use planning and operation in the zone for better land resources application for sustainable agriculture and biodiversity sustentations.

1.6. Limitations of the Study

With the objective in mind, certain limitations are defined to set the compass of this thesis. The basic soil surveys information needed to make decisions about land management and soil performance for implementing an irrigation system indicates shortage of data on some properties of soils such as infiltration rate, availability of water holding capacity and characteristics of rivers in the study area. These properties of soil were not evaluated for land suitability and analysis. Only the chemical characteristics of the land under the study area were evaluated. As there was no adequate time and budget to collect and analyze the soil physical and chemical characteristics of the study area, ECO soil map in 1:50,000 scale obtained was used in this study.

1.7. Organization of the Thesis

The whole thesis is divided into five chapters. The first chapter provides general introduction about the research work including introduction of the research, research statement, research objectives and significance of the research. The second chapter deals with literature review in which the related works with respect to the research work are presented. In the third chapter information about the chosen study area is given, and description about the methodology and the materials/data used. Fourth chapter presents the findings of this research work and discussion on the results obtained. And also, the fifth chapter were including the conclusion were drawn based on the results obtained along with some recommendations.

2. LITERATURE REVIEW

2.1. Irrigation

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climate volatility in any country. Although Ethiopia has abundant rainfall and water resources, its agricultural system doesn’t yet fully profit from the technologies of water management and irrigation. The majority of rural dwellers in Ethiopia are among the poorest within the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production given underdeveloped rural infrastructure, and little to no access to agricultural markets and to technological innovations. These issues, combined with increasing degradation of the natural resource base, especially in the highlands, aggravate the incidence of poverty and food insecurity in rural areas. Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity (Seleshi, 2010).

Irrigation can be applied in supplemental or full depending on the acceptability of downfall. Also, the need to sustain a double cropping system in the dry season and assuring of growing high- value crops are among the factors those necessitate irrigation (FAO, 1992).

Irrigation eventuality is the accretive suitability of the soil, slope, irrigable land, and suitability or capacity of water available for irrigation on the given milepost without affecting the crop growth (FAO, 1997). Hence environmental and social factors are also taken into consideration in the assessment of irrigation eventuality in order to guarantee sustainable use of the available physical resource, land, and water plays a great part in the assessment of planning of sustainable food product in the country.

Fasina et al. (2008) conducted an irrigation suitability evaluation and crop yield with an illustration of Amaranthus Cruentus in Southwestern Nigeria. The researchers stated that the applicable use of land depends on the fittings or capability of land for specific purposes. That irrigation potential implies a series of hypotheticals about irrigation ways, investment capacity, public and indigenous development, social, health, and environmental aspects, and transnational connections, especially regarding waters, and then the result of the suitability of this all parameter develops or indicates the eventuality of land for irrigation. They conducted the research in both social and environmental points of view.

In the highlands of Ethiopia, irrigation practices have long been in use since ancient times for producing subsistence food crops (Awulachew et al., 2007).

Spate irrigation has also been used traditionally in Ethiopia (Mehari et al., 2011) particularly in Southern Tigray and in some semi-arid areas in Oromia region (MoA, 2011). This irrigation system has been used for water harvesting from flush floods flooded from larger catchments at upper streams.

2.2. Irrigation Development in Ethiopia

In Ethiopia, traditional irrigation was practiced before centuries. Moreover, in the highlands of Ethiopia, irrigation practices have long been in use since ancient times for producing subsistence food Crops (Awulachew et al., 2007). Different authors stressed that supplementary irrigation has been practiced by smallholder farmers of Ethiopia for centuries to solve their livelihood challenges. The traditional irrigation systems were developed and managed through forming a water user’s association for functions of construction, water allocation, operation and maintenance and were headed by individuals. This association comprises up to 200 users grouped into 20 to 30 groups of farmers who share a common main canal or its branches (MoA, 2011)

Most of the traditional irrigated lands in Ethiopia are dominantly supplied by surface water sources, while ground water uses has just been started on a pilot basis in the East Amhara region (MoA, 2011). Modern agriculture irrigation was started in Ethiopia in the upper Awash Valley with the objective of producing industrial Crops as sugarcane, cotton and horticultural Crops on a large-scale basis, explained in a remarkable emergence of irrigation development and establishment of agro-industrial centers.

Ethiopia has an irrigation eventuality of 5.3 million ha of which 3.7 Mha can be developed using surface water sources, and 1.6 million ha using groundwater and rainwater operation. Irrigation contributes to the rapid-fire metamorphosis of agriculture as present- day agriculture is dominated by rain-fed single crops.

Ethiopia has an important occasion in water- led development, but it needs to address critical challenges in the planning, design, delivery, and conservation of its irrigation systems if it's to capture its full eventuality. Irrigation schemes cover about 640,000ha across the country. These irrigation schemes vary extensively in size and structure, from micro-irrigation to river diversion, pumping, small or large dams, etc. (IWMI, 2007)

2.3. Irrigation Development in Oromia Region

Oromia has 63 river systems and 688 tributary streams which annually generate 58 billion cubic meters of surface water, the equivalent of half the nation's surface water resources. The rainfall in the region is bimodal and the annual rainfall ranges from 400 mm in the lowlands to 2,400 mm in the highlands.

The area developed by irrigation in the region is only 5.5% of the potential (OIDA, 2011). In Oromia Region, it is said that out of the estimated 1.7 million ha of potential irrigable land, only 85,400 ha has been developed so far, which about 5 % of the potential is. The modern irrigation practice in many places has been introduced as late as mid 1980's when there was a country-wide drought affecting huge number of populations.

In 2006, about 92,617 ha of land were under traditional and modern irrigation, while 2,426 ha were under construction. Feasibility studies on about 53,762 ha have been carried out, while about 299,820 ha have been identified for possible development. Traditional irrigation schemes which are estimated to cover 48,816 ha constitute the major portion, followed by large-scale state farms consisting of 26,506 ha. All in all, the total developed and planned area, for the development of irrigated agriculture is estimated at 583,998 ha.

2.4. Gibe Sub-basin Irrigation Potential Assessments

According to Megersa (2019) the input data used to process the model and to achieve the objective of the study were soil, digital elevation model (DEM), streamflow, land use land cover. To identify potential irrigation land, irrigation suitability factors such as soil (type, texture, depth, and drainage), slope, land cover land use and distance from water supply were taken into account. Irrigation suitability of each physical land parameters was classified based on the FAO guideline for land evaluation into S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable) suitability classes. The final potentially irrigable land was identified by weighting all the factors of suitability. Result of suitability of land evaluation ratings based on the qualitative land suitability for irrigation indicated that, 26.80% (110578.05ha) are highly suitable (S1), 24.83% (102423.81ha) are moderately suitable (S2), 15.53% (64051.44ha) marginally suitable (S3) and 32.84% (135509.58ha) are not suitable (N) for surface irrigation systems.

The main limitation for this assessment was, the assessment study carried out only around the Gilgel Gibe I watershed.
A study conducted on the Gibe Sub-basin in Oromia regional state by ECO (2018) was used the information obtained as a basis for assessments of irrigation potential. This study includes some parts of the South West Shewa, West Shewa, Jimma, Horo Guduru Wollega and East Wollega Zones.
According to this study a total of 418 augers, and 92 profile pits with 248 soil samples were taken to evaluate suitability of the land units. There are ten major soil types were identified in this study which are only included in potential land suitable areas, Vertisols, Luvisols, Nitosols, Leptosols, Cambisols, Alisols, Acrisols, Ferralsols and Fluvisols. Vertisols is the common soil type and covers large areas of the basin areas.
The study was identified land suitability for surface, sprinkler and drip irrigation methods.
It was found out that 943514Ha or 47.8 % of the basin's land coverage was suitable, 1026417Ha or 52% was not assessed, 7896Ha or 0.4% was previously irrigated areas.
However, according to the study finding out 329638Ha or 16.7% and 613876Ha or 31.1% of the study areas are highly and moderately suitable for surface irrigation respectively. As irrigation methods become improved the suitability areas increased. Therefore, for sprinkler irrigation method 621772Ha or 31.5% and 321742Ha or 16.3% of the potential areas are highly and moderately suitable respectively. But, for drip irrigation 943514Ha or 47.8% of the areas which area relevant to this study, 100%, area highly suitable. From 48% of suitable areas 0.4% is areas previously irrigated.

2.5. Surface Irrigation

FAO (1997) conducted on physical irrigation eventuality with a combination of water resource Availability matched with gross water demand, area of soils suitable for irrigation, and available water resources by basin. However, is potentially irrigable for surface irrigation, if all parameters are fulfilled in the milepost.
Surface Irrigation is an unchanged process and it's aged than its recognition. For thousands of times, people are rehearsing this irrigation process. There's a misconception that the Surface Irrigation process is occasionally considered Flood Irrigation because of unbridled water distribution. But if applied correctly, Surface irrigation can be the stylish irrigation process for water shops.
Surface irrigation is mainly divided in basin, border, and furrow systems. It is widely utilized and therefore a well-known system, which can be operated without any high-tech ap-

plications. In general, it is more labor intensive than other irrigation methods. Proper design of surface irrigation systems takes into account the soil type (texture and intake rate), slope, levelness of the field, stream size, and length of run. It is generally more difficult to obtain high uniformity of water distribution in long fields on coarse textured soils (gravel and sands) than on fine textured soils (loams to clay) (Hill et al. 2008).

2.6. Land Suitability Evaluation for Surface Irrigation

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

Land evaluation for irrigation suitability was concerned with overall land performances, including landforms, climate, vegetation, and soils, for assessing land productivity when the land is used for specified purposes under a specified management system (FAO 2007).

The suitability of the land is characterized depending on the land slope, water Availability, drainage condition, rockiness, land use/ land cover, soil type, and others these each- land evaluation criteria in terms of realistic alternatives for perfecting the use of that land.

FAO (2007) gives focuses on irrigation, and land suitability analysis, and particular attention is given to the physical properties of the soil, the distance from available water sources, and the terrain conditions in relation to styles of irrigation considered.

Land suitability evaluation of a given watershed is vital to predict potential and limitation of the land for irrigation. Land evaluation on its soil properties and slop suitability are necessary and important steps in surface irrigation planning.

Accordingly, Sys, et al. (1991), suggested a parametric evaluation approach for surface irrigation suitability evaluation which is concern on soil physical properties (soil texture, soil depth and drainage), soil chemical properties (salinity/alkalinity status such as calcium carbonate content and gypsum content of the soil), and slop. Any land can be classified as suitable (S), or not suitable (N) orders for surface irrigation. Where, suitable order type of land quality is suitable for use with good benefits and not suitable denote land quality which is not enough for suitable outcomes.

The land suitability evaluation is critical in developing a land-use map based on irrigation potential on a spatial basis (Diallo et al. 2016). The irrigation potential can be assessed by incorporating Multi-Criteria Decision Analysis in the Arc-GIS environment and employing the weight overlay rule (Hussein et al. 2019).

Multiple-criteria decision-making (MCDA) methods include the analytic hierarchy process (AHP) (Saaty 1980). AHP is an MCDA method used for assessing and analyzing land-use suitability. AHP entails multiple selections within a hierarchical system based on the significance and weight of the parameters in comparison with one another (Saaty 1980). It is critical to use a hierarchical approach to develop a specific relationship between a large number of criteria. The system uses scoring and a pair-wise comparison matrix to determine the relative significance of factors on a level. For assessing land suitability, an integrated approach of remote sensing (RS), Geographical Information System (GIS), and MCDA techniques was used (Negash and Seleshi 2004).

Haile Gabriel & Ayne (2007) reported that soil types, with their corresponding physical and chemical characteristics and slope layer, is being the most limiting factor for the consummation of, especially for surface irrigation styles.

Sultan (2013) conducted the study on the assessment of irrigation land suitability and the development of a map for the Fogera catchment using GIS, South Gondar. The author added that EC, ESP, soil depth, texture, pH, top and subsoil stoniness, water table depth, flood tide hazard, groundwater quality (SAR and EC), and slope have a great donation to the evaluation of irrigable land.

2.6.1. Slope

The slope is the inclination or grade of a surface and is generally expressed as a percent. The slope is important for soil conformation and operation because of its influence on run-off, drainage, corrosion, and choice of irrigation types. The slope grade of the land has a great influence on the selection of irrigation styles.

According to FAO (1999) standard guidelines for the evaluation of slope grade, slope which are lower than 2, are very suitable for surface irrigation. But slope, which are lesser than 8, aren't generally recommended. Economically slope plays a great part in the conservation, construction, and lading of surface irrigation water force channels.

2.6.2. Soils

Soil is the unconsolidated material on the surface of the earth, consisting primarily of mineral and organic matter and containing pore space occupied by air and water that has been subjected to and influenced by genetic and environmental factors of parent material, climate, living organisms, and topography. These factors interact over time to develop soil that differs from the material from which it was derived in many physical, chemical, biological, and morphological properties and characteristics.

The soil is a major factor in the suitability of land for sustained irrigation. Its primary influence is on the productive capacity, but it may also influence production and development costs (USDIBR, 2005)

The evaluation of soils for irrigation involves using properties that are endless in nature that cannot be changed or modified. FAO (1997) identifies that all soil properties aren't suitable for surface irrigation due to different factors indeed the soil saltness and alkalinity are conceivably bettered.

Fasina et al. (2008) stated that soil properties including drainage, texture, depth, saltness, and alkalinity are the most determinant factors for the selection of irrigation styles. There may be physical property factors like infiltration and poor internal drainage which beget swab buildup. The evaluation of physical and chemical soil properties to prognosticate its performance for specific use is an essential part of land evaluation.

2.6.3. Surface Water Resource Availability

Until recently, the water potential of the country wasn't accurately notable, associated even nowadays this is often still an eristic issue. water system (water amount and seasonality) is a crucial issue to gauge the land’s quality for irrigation consistent with the amount of water throughout the amount of the year during which it's accessible (FAO, 1985). If water is in brief offer throughout some a part of the irrigation season, crop production can suffer, returns can decline and a part of the scheme's investment can lay idle or valuable (FAO, 2001). wherever potential, the supply of water is preferred to be settled higher than the commented space to irrigate the command space through the free surface flow while not the necessity of power generation.

Ganole (2010) conducted a study of stream construction surface irrigation potential assessment in Dale Woreda. It absolutely was GIS-based and concerns had taken the potential of irrigable land, irrigation demand, and water availably. He identifies that distance from water sources to the command space is a crucial issue that is that the shorter the irrigation canal length the gap is additional economical associated helpful to develop an irrigation project effectively. Knowing the amount of the water system is equally as necessary as land associated alternative factors to the success and development of an irrigation project.

2.7. Limiting Values for Land-use Requirements

A Land Use Requirement (LUR) is a condition of the land necessary for successful and sustained implementation of a specific Land Utilization Type. Each LUT is defined by a *set* of LURs. They are the ‘demand’ side of the land -land use equation (FAO, 1976).

Limiting values are the values of a land quality or land characteristic that verify the category limits of land quality for a particular use. The first and most significant call is to separate land that's appropriate from that isn't. The necessary criteria for electing the quality of land for specific use are property and also the quantitative relation of advantages to prices.

Table 1. Structure of the FAO land quality classification

S	**Suitable**	**The land can support the land use indefinitely and benefits justify inputs**
S1	Highly suitable	Land without significant limitations. Include the best 20-30% of suitable land as S1. This land is not perfect but is the best that can be hoped for
S2	Moderately suitable	Land that is clearly suitable but which has limitations that either reduce productivity or increase the inputs needed to sustain productivity compared with those needed on S1 land
S3	Marginally suitable	Land with limitations so severe that benefits are reduced and/or the inputs needed to sustain production is increased so that this cost is only marginally justified
N	Not suita-ble	Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs

2.8. GIS in Multi-Criteria Decision Analysis

MCDM approaches were developed within the Sixties so as to help decision-makers in incorporating varied choices, reflective the opinions of involved parties, into a possible or retrospective framework. This framework is ‘‘primarily involved with the way to mix the data from many criteria to make one index of evaluation’’ (Yu *et al*., 2011). They were designed to outline the connection between knowledge input and knowledge output. MCDM strategies are often broadly speaking divided into either multi-objective or multi-attribute strategies (Malczewski, 2004), and are primarily involved with ways that of mixing many criteria to make one analysis index. In MCDM, each criterion is given a weight to represent its real importance within the development (Chow and Sadler, 2010).

GIS is best fitted to handling a large vary of criteria knowledge at multi-spatial, multi-temporal and multi-scale from completely different sources for a time-efficient and efficient analysis. Therefore, there's growing interest in incorporating GIS capability with MCDM processes. Because of the massive range of things concerned in higher cognitive process, land quality analysis is often known as a multi-criteria analysis approach (Reshmidevi *et al*., 2009; Yu *et al*., 2011).

The GIS-based approaches for land use suitability analysis originate from manual map overlay techniques which were already being developed in the USA in the early twentieth century (Malczewski, 2004). The ability to integrate data within a GIS is one of the most important features, bringing together data from different sources, formats, and scales and making them compatible with each other (Flowerdew, Green, 1991). GIS-based spatial assessment depends on the weighting of relevant factors (or maps in a GIS database) such as soil, climate, erosion, and slope.

The overlay procedure and principles of multi-criteria analysis that had emerged remain the basis of land suitability analysis. The purpose of the weightings is to convert or normalize all ratings to the same interval scale.

The AHP could be a technique wide employed in MCDM to get the desired weightings for various criteria (Saaty, 1977, 1980; Saaty et al., 1991; Wu, 1998, Ohta et al. 2007). It has been with success utilized in GIS-based MCDM since the first Nineteen Nineties (Carver, 1991; Malczewski, 1999; Makropoulos *et al*., 2003; Marinoni, 2004; Marinoni *et al*., 2009). The AHP technique calculates the desired weights related to the several criterion maps layers with the assistance of a preference matrix, during which all relevant criteria known are compared against one another on the premise of preference factors. The weights will then be mass.

GIS-based AHP has gained quality due to its capability to integrate an outsized amount of heterogeneous knowledge, and since getting the desired weights are often comparatively easy, even for an outsized range of criteria. it's been applied to a range of decision-making issues (Tiwari *et al*., 1999; Nekhay *et al*., 2008; Hossain and Das, 2010; Chen *et al*., 2010).

2.9. Weighted Overlay Analysis

The GIS- based multicriteria analysis is a set of procedures for combining criterion maps and preferences with respect to the relative significance of criteria (Carver, 1991; Malczewski, 1999, 2006; Chakhar and Mousseau, 2008; Greene et al., 2011). The Ordered Weighted Averaging (OWA) is a class of multicriteria combination procedures (Yager 1988). It includes the most frequently used GIS-based map combination models: the Weighted Linear Combination (WLC) and Boolean overlay drivers such as crossroad and union (Jiang and Eastman, 2000). There are three main input factors of GIS-OWA

- Criterion or attribute maps (and associated value functions or standardization procedures),
- Criterion weights (and associated procedures for defining preferences with respect to the relative significance of criteria), and
- Order weights (and associated degree of Orness of the OWA driver).

GIS-OWA styles use the range-sensitive principle (Malczewski, 2011) as a central conception for developing the original form of OWA. The principle suggests that the criterion weights depend on the range of criterion values a criterion that has a large range of values should be given fairly lesser weight than a criterion characterized by a small range of values (Keeney and Raiffa, 1976).

2.10. Selection of Evaluation Criteria

Sys et al. (1991) recommended a parametric evaluation system for irrigation methods which was primarily based upon physical and chemical soil properties. In their proposed system, the factors affecting soil suitability for irrigation purposes can be subdivided into four groups:

a) Physical properties determining the soil-water relation-ship in the soil such as permeability and available water content.
b) Chemical properties interfering with the salinity/alkalinity status such as soluble salts and exchangeable Na.
c) Drainage properties.
d) Environmental factors such as slope

Site selection is a complex process that requires taking many contradictory criteria into account at the same time. Factors that determine the location of the surface irrigation were identified based on literature, slope, soil depth, soil texture, soil drainage, land use/land cover and distance from water supply were used to identify the best possible location and each factor was classified as highly suitable, moderately suitable, marginally suitable and not suitable (FAO, 1997; Worqlul et al., 2017; Girma et al., 2019; Nasir et al., 2019).
Evaluation criteria objects and attributes need to be linked with respect to the particular situation under consideration. The set of criteria named should adequately represent the decision- making terrain and contribute toward the final thing (Prakash, 2003). The attributes of land suitability criteria are to be deduced from spatial and non-spatial, qualitative and quantitative information under different conditions'' (Chen *et al*., 2010). Inland suita-

bility analysis, each evaluation criterion is represented by a separate map in which a 'degree of suitability with respect to that particular criterion is credited to each unit of area. These 'degrees of suitability' also need to be rated according to the relative significance of the donation made by that particular criterion based on original expert knowledge (Sehgal 1996; Prakash, 2003).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The research was carried out in the Jimma Zone Gibe sub basin Oromia Region, covering a total area of 1,230,606 Ha. It is one of the executive Zones in Oromia National Regional State positioned in southwestern Ethiopia. Jimma city is the capital and executive center of the zone, which is located at 350 km from Addis Ababa- the capital city of Ethiopia.

Gibe sub basin is situated in the southwest of Ethiopia between the latitudes of 8° 54′ 56″ and 7° 09′ 59″ North and 36° 46′ 08″ and 37° 52′ 33″ East (Figure 1).

The Gibe rises west of the Chomen swamp (specifically, from Gudeya Bila district, which is located in the East Wellega Zone, Oromia Region), flowing to the southeast towards the Omo River which is an enclosed river basin that flows in to the Lake Turkana in Kenya at southern boundary.

The western watershed is the range of hills and mountains that separate the Gibe sub basin from the Baro-Akobo Basin. To the north and northwest, the basin is bounded by the Abay Basin with small area in the northeast and east bordering the Awash Basin.

The area is home to nearly 2.5 million people (CSA, 2007) and it is bounded by the Kafa zone of South West Ethiopia Regional State in the south, Illu-Babor and Buno-Bedelle zones of Oromia National Regional State in the West and Northwest, respectively and Yemi Special Woreda in the east, and West Shewa in the Northeast.

The topography of the Gibe sub basin as a whole is characterized by its physical variation. Recurrent dissection, highland rolling and Steep slopes are basic physiographic features of Gibe sub basin. The project area has mountainous to hilly terrain cut by deeply incised gorges of the Gilgal-Gibe and main Gibe rivers and their tributaries streams. The study area's altitude ranges from 718 to 3319 m.a.s.l. and the range of slope from flat to very steep. The maximum and minimal temperatures range from 24-30^{o}C and 7-15^{o}C, respectively. It receives mean annual rainfall between 1200-2800 mm.

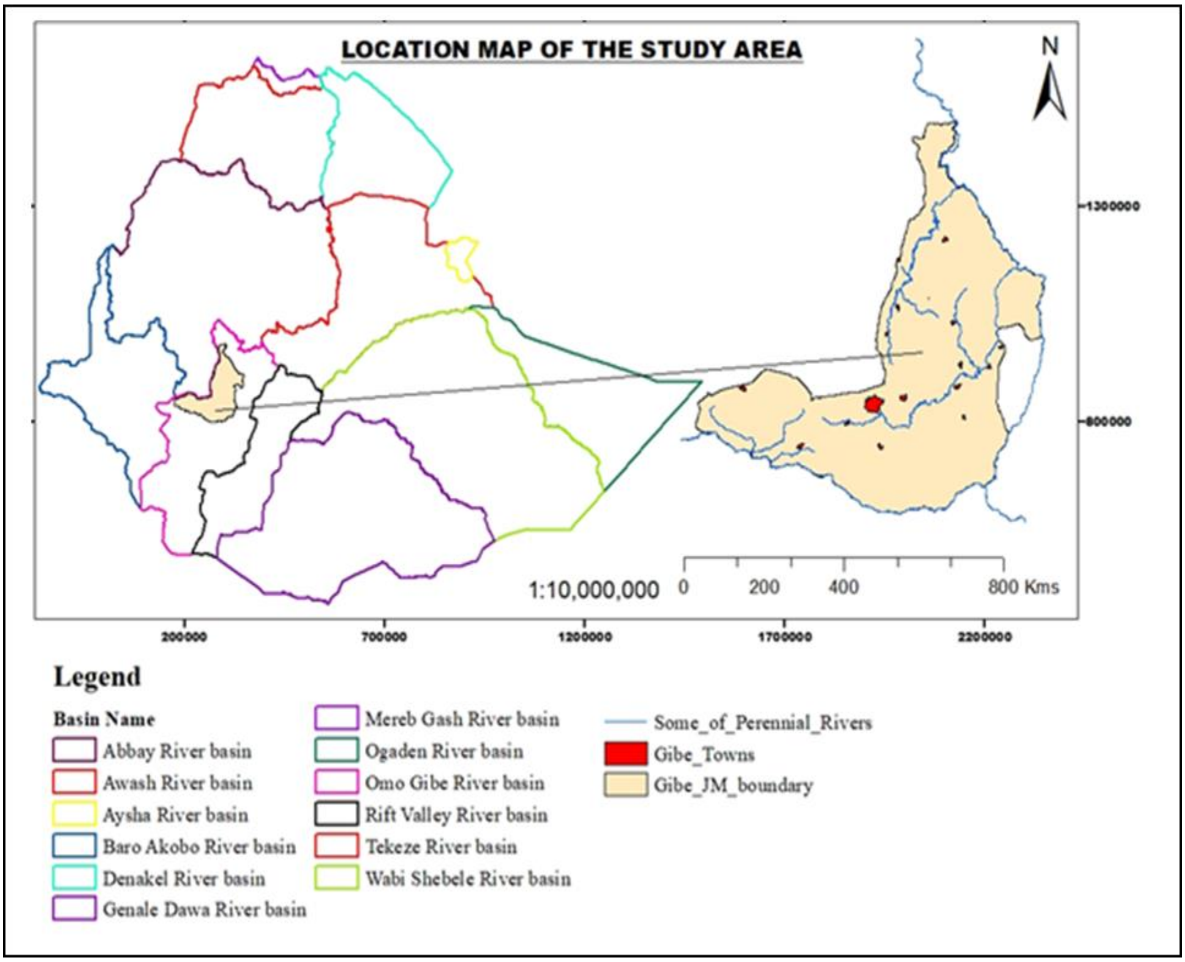

Figure 1. Location map of the study area

3.1.2. Land Use Land Cover of the Study Area

Land use has a major influence on the direction and rate of soil formation; its recording enhances the interpretative value of the soil data considerably.

In a very broad term, most of the catchments of the study area are under extensive cultivation with increased land pressure, meaning the expansion of cultivated areas in to increasingly marginal lands at the expense of wood lands. The main gorges of the basin are relatively unpopulated and support a cover of open wood-land and bush-land with grasses, the northern and eastern part of the basin has some of the most densely populated and intensively farmed areas in the basin (ECO, 2018).

Table 2. Types and area coverage of the land use land cover in the study area

Land Use Land Cover Type	Area	
	Ha	Percent
Bush land	5,111	0.42
Cultivated Land	706,969	57.45
Forest	304,978	24.78
Grazing	35,014	2.85
Settlement	16,354	1.33
Shrub land	111,471	9.06
Water Body	5,424	0.44
Wetland	5,317	0.43
Woody land	39,967	3.25
Grand Total	**1,230,606**	**100**

As show on the figure 2, cultivated land dominantly located in the central, southern, eastern and small areas of the northern parts of the sub basin. The western and north-western parts were more covered by forest. Grass land more located in the northern parts mostly in the Limu Kosa and Lime Seka districts. Bush land distributed in some of the central parts special in the Mena district. More of the Goma, Shebe Sombo and Omo Beyam district were covered by shrubs land.

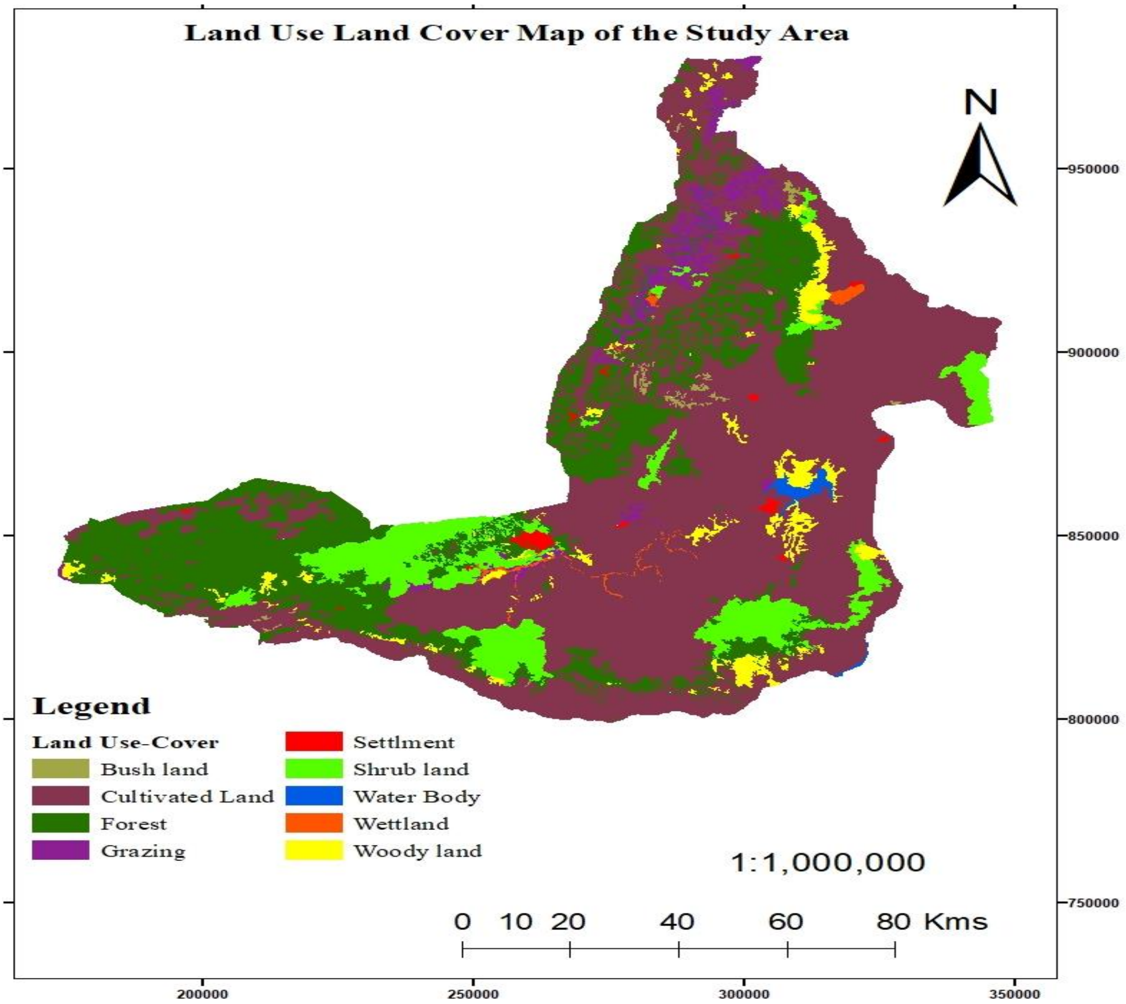

Figure 2. Types of the land use land cover in the study area

3.2. Methods

3.2.1. Multi-Criteria Decision Analysis

Technique for the potential irrigable land assessment was conducted using the Multi-Criteria Evaluation (MCE) method. MCE technique, integrated with geographic information system (GIS), is an arising approach for optimal decision- making and involves multiple spatially variable criteria.

Multi-criteria decision analysis methodologies can overcome problems related to vagueness in description and other uncertainties in suitability analysis. To enrich the interpretations of MCDM, Saaty (1980) introduced the Analytic Hierarchy Process (AHP) as a system to capture aspects of a decision in both a private and objective manner to reduce confounding.

The Analytical Hierarchy Process is a well- known multi-criteria technique that has been incorporated into GIS-based suitability procedures (Jankowski and Richard, 1994; Marinoni 2004). The AHP is a system extensively used in MCDM to gain the needed weightings for different criteria (Saaty 1977, 1980; Saaty and Vargas, 1991; Wu, 1998; Ohta et al., 2007). It has been successfully employed in GIS-based MCDM since the early 1990s (Carver, 1991; Malczewski, 2004; Makropoulos et al., 2003; Marinoni, 2004; Marinoni et al., 2009). The AHP system calculates the needed weights associated with the separate criterion maps layers with the help of a preference matrix, in which all applicable criteria linked are compared against each other on the base of preference factors. The weights can also be added up. The AHP methodology provides compass for combining expert opinions with numerical prognostications from biophysical models to give an intertwined approach to resource operation.

3.2.2. Pairwise Comparison Technique

Weights were assigned to each factor using a pairwise comparison technique based on Saaty (1991), considering the relative significance of each factor for irrigation. The pairwise comparison technique provided an important, simplified, and fairly unprejudiced ranking criterion. A comparison matrix was established comparing each factor one to one based on a pairwise scale. The scale is broken down from 1 to 9 in which the loftiest value (9) indicates absolute significance while the complementary (1/9) indicates absolute negligibility. The weights of each factor assigned by experts were equaled to construct a pairwise matrix.

Table 3. Importance definitions and the corresponding explanations

Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor one over the other
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favoring one over the other is of the highest possibility of validity
2,4,6,8	Intermediate values	When compromise is needed

3.2.3. Data Collection and Preparation Using GIS

The following datasets were prepared:

- Soil maps 1:50000 (from Engineering Corporation of Oromia) are used to decide the soil drainage, soil depth, CEC, pH value, and soil texture.
- Digital topographical maps DEM, and outgrowth subcaste such as slope.
- Land use/ land cover (from Engineering Corporation of Oromia).

Data preparation is the first fundamental step in land suitability analysis. As the methodology is based on GIS analysis, land suitability is estimated by applying different GIS logical ways, including interpolation and overlay based on multi-criteria analysis and AHP. Eight parameters; namely, water resource, land use/land cover, slope, and soil properties, which included drainage, pH of the soil, CEC, soil texture, and soil depth, were considered for analysis. The parameters were selected based on data availability, farming history, literature review, and native condition of the study area.

3.2.4. Standardization of Criteria

The process of setting the relative significance of each criterion is known as the standardization of criteria (Prakash, 2003). A pairwise comparison technique is generally used for standing and homogenizing the ordinal values (Malczewski, 2004). This technique is an extension of the classic double sense, with the possibility of defining sets without sharp boundaries and allowing for the partial engagement of fundamentals to a particular set.

3.2.5. Assessing the Weights

Criterion weights are the weights assigned to the ideal and trait maps (Meng *et al.*, 2011). Inferring weights for the named maps criteria (land characteristics map layers) is an fundamental demand for applying the AHP system (Malczewski, 1999, 2004). The determination of the particular criterion weight is thus a pivotal step in MCDM.

In the operation of the AHP system, it is important that the weights deduced from a pairwise comparison matrix are harmonious. Thus, one of the strengths of AHP is that it allows for inconsistent connections while, at the same time, furnishing a consistency rate (CR) as an index of the degree of consistency or inconsistency (Forman and Selly, 2001; Chen et al., 2010).

The CR is used to indicate the likelihood that the matrix judgments were generated randomly (Saaty, 1977; Park *et al.*, 2011).

$$CR = \frac{CI}{RI} \quad \text{……………………………………Eq-1}$$

Hereby the random index (RI) is the average of the resulting consistency index, depending on the order of the matrix given by Saaty (1977), and the consistency index (CI) can be expressed as:

$$CI = \frac{(\lambda_{\max} - n)}{n - 1} \quad \text{……………………………………Eq-2}$$

in which λmax is the largest or principal Eigenvalue of the matrix, and n is the order of the matrix.

3.2.6. Overlaying Map Layers

The integration of MCDM ways with GIS has allowed considerable advances to be made over conventional maps overlay approaches for land-use suitability analyses (Carver, 1991; Malczewski, 1999). The MCDM procedures (or decision rules) define a relationship between the input maps and the affair maps. The procedures involve the application of geographical data and the manipulation of the data and preferences according to specified decision rules (Malczewski, 1999). The weighted overlay is a technique for applying a common scale of values to different and different input data to produce an intertwined analysis (Kuria *et al*., 2011).

In this study, different maps layers characterizing land suitability have been developed using the weights deduced from the AHP process. The weights were also combined with the trait maps layers in a manner analogous to that used in the direct cumulative combination styles (Malczewski, 2004; Feizizadeh and Blaschke, 2011).

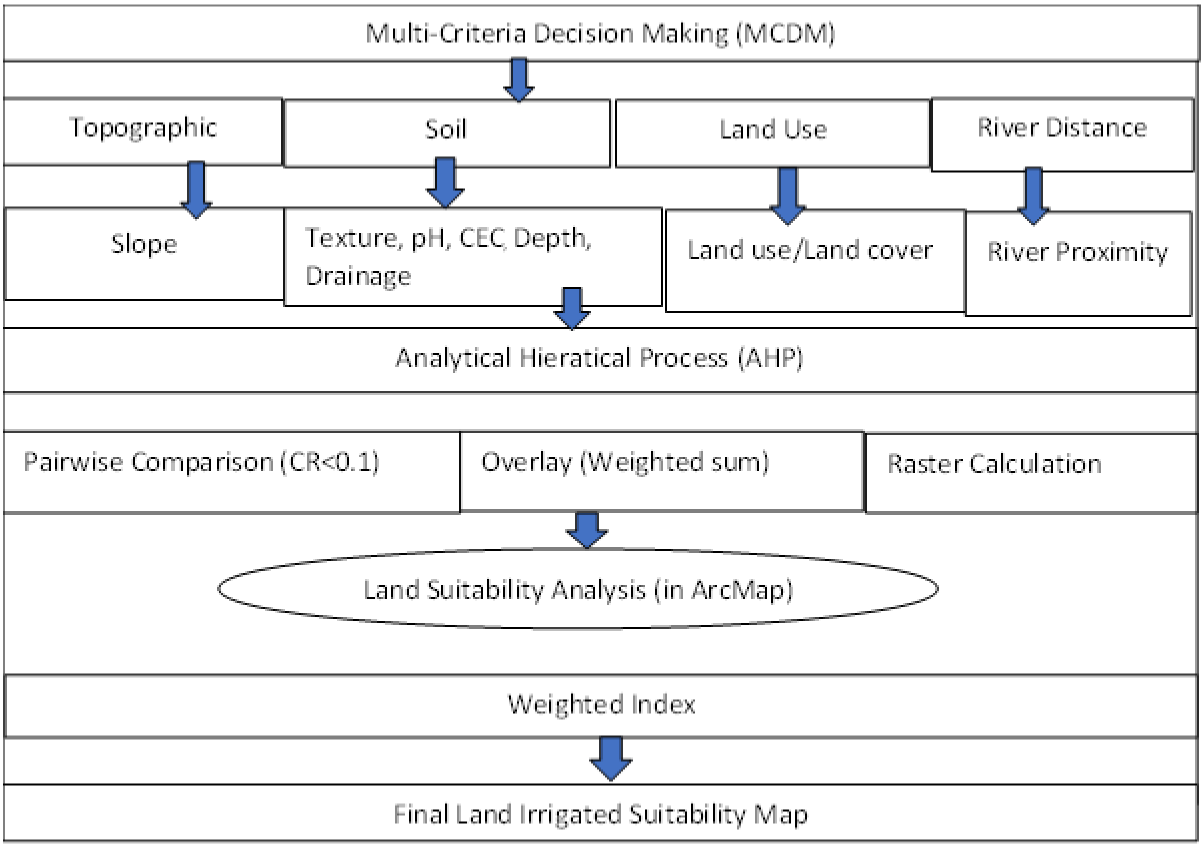

Figure 3. Land suitability evaluation flow chart

3.3. Land Suitability Evaluation

For land suitability analysis of surface irrigation, particular attention is given to the physical properties of the soil, distance from available water sources, and terrain conditions in relation to styles of irrigation considered. In addition, land cover/ land use types are considered limiting factors in assessing the suitability of land for irrigation. Irrigation suitability land classification examinations are an integral part of multi-objective planning for the development and operation of water resource systems with an irrigation element.

3.3.1. Determination of Land Suitable for Surface Irrigation Potential

The land suitability for surface irrigation eventuality was linked by considering physical land factors; such as slope, soil texture, soil depth, drainage classes, land use, and land cover and water resources availability. After the individual suitability of each factor was analyzed, potentially irrigable land was forecasted by weighting overlay analysis of those factors.

3.3.1.1. Slope suitability

A slope is the rise or fall of the land surface. It is important for the farmer or irrigator to identify the slopes on the land. The slope class is derived from the most representative or characteristic slope gradient of the area around the site. Slope is important to soil formation and management because of its influence on runoff, soil drainage, erosion, use of machinery, and choice of crops.

The slope maps were construed from DEM with by operation of spatial analysis tools (surface analysis) in ArcGIS. The slope deduced from the DEM was classified into four suitability classes (S1, S2, S3, and N) depending upon surface irrigation development with the aid of the "Reclassification" tool function in ArcGIS. Consequently, the slope suitability factor conditions linked as 0- 2 is S1, 2- 5 is S2, 5- 8 is S3 and > 8 is classified as N not suitable class (Table 4). After the slope was classified consequently, the area of each slope was calculated in the trait table and the geographical position of each slope suitability maps was linked using ArcGIS tools.

Table 4. FAO slope rating suitability standard for surface irrigation evaluation

Slope (%)	Class Code	Class description
0 – 2	S1	Highly Suitable
2-5	S2	Moderately Suitable
5 – 8	S3	Marginally Suitable
>8	N	Not Suitable

3.3.1.2. Soil suitability

Agricultural land is of worth only because of its capability to produce crops. Maximum evaluations are based on factors that affect this capability to give product. The introductory soil physical properties used in this study for the evaluation of soil suitability for surface irrigation were soil drainage, soil texture, pH of the soil, CEC, and soil depth. The soil properties suitability rating is given in Table 5.

Table 5. FAO soil properties rating suitability standard for surface irrigation evaluation

Soil Factors					Factor rating	Description
Texture Classes	**Soil Depth (cm)**	**Drainage**	**pH**	**CEC meq/100 g soil**		
Loam-Silty Cay, Clay	> 100	Well	5.5-7.0	35-70	S1	Highly Suitable
Silt loam, Sandy Clay	50 – 100	Moderately Well	5.5-4.5, 7.0-8.5	35-16	S2	Moderately Suitable
Fine Sandy, sandy loam	30 – 50	Imperfectly	4 -4.5, 8.5-9.5	16-5	S3	Marginally Suitable
Coarse Sand	< 30	Poor	<4.0, >9.5	<5	N	Not Suitable

3.3.1.3. Land Use Land Cover Suitability

The land use land cover maps of the area were cropped from the Gibe basin land use land cover maps. Consequently, six types of land use land cover classes of the area were linked. These are cultivated land, grassland, bushland, shrubland, forestland, timber land, agreement swamp, and water body. As depicted in Table 6, the rasterized land use land cover maps of these LULC classes were distributed into four suitability classes (S1, S2. S3, and N) and used in the suitability class to probe potentially irrigable spots combined with other factors.

Table 6. FAO land use/cover rating suitability standard for surface irrigation evaluation

LULC	Class Code	Class description
Cultivated land	S1	Highly Suitable
Grassland	S2	Moderately Suitable
Bush and shrub land	S3	Marginally Suitable
Constraints (forest, settlement, water, wetland)	N	Not Suitable

3.3.1.4. Distance from Water Supply

It is important to make sure that there will be no lack of irrigation water. However, crop product will suffer, returns will decline and part of the scheme's investment will lay idle if water is in short force during some part of the irrigation season. The suitability class of a land parcel with respect to river proximity is determined by its distance in relation to the imperishable gutters. Distance to the existing river was calculated in the ArcGIS tool by projecting the locales to a Mercator (UTM) Zone 37N.

To identify irrigable land close to the water force (gutters), distance was generated from the watershed outlets and was reclassified (Mandal *et al*., 2017). The reclassified distance maps were used for weighted overlay analysis along with other factor maps. Table 7 gives the water source proximity rating for its suitability for the surface irrigation system.

Table 7. FAO river proximity rating suitability standard for surface irrigation evaluation

Euclidean Distance (km)	Class Code	Class description
0-5	S1	Highly Suitable
5-10	S2	Moderately Suitable
10-20	S3	Marginally Suitable
> 20	N	Not Suitable

3.4. Evaluation of Irrigable Lands

The investigation of suitable lands for surface irrigation was carried out based on slope, soil types and depth of soil, drainage suitability, and distance from source to the water supply. The suitability of each factor was first analyzed individually, and finally, overall suitability was estimated using the weightage of each factor to obtain potential irrigable sites.

Using an overlay tool in ArcGIS 10.8.1, an overlay (weighted) analysis of the stated factors was performed to determine their surface irrigation suitability based on an overall score value (Ganole, 2010). The suitability of land was broadly classified based on an overall score value from 1 to 9, with the scores representing the following descriptions:

(i) least suitable land factor (score 1);
(ii) marginally suitable (score 3);
(iii) moderately suitable (score 6);
(iv) highly suitable (score 9).

In cases where score values (from 1 to 9) were not assigned for any cell, this indicates that the particular cell (i.e., score) is restricted for surface irrigation, and thus should be eliminated from the evaluation.

The rasterized and reclassified maps of each parameter (slope, soil texture, soil depth, drainage class, land use land cover) were overlaid together to produce one suitability map for surface irrigation. During the weighted overlay, the evaluation scale of 1 to 4 was used, 1 represents highly suitable, 2 moderately suitable, 3 marginally suitable, and 4 represents unsuitable areas.

4. RESULT AND DISCUSSION

4.1. Land Suitability Class

Classification of land suitability for sustainable use requires an understanding of controlling land characteristics and rates in the study area. The main biophysical factors which could impact land suitability evaluation have been defined and analyzed and a thematic maps/ layer has been produced for farther analysis.

Soil physical and chemical properties and topography, a characteristic of the land includes soil depth, texture, drainage, slope, pH, CEC, land use/cover, distance from river and slope were taken to assess the suitability of the land in the study area. The digital soil map was prepared and obtained from Engineering Corporation of Oromia, then analyzed in a GIS environment. Among the different land suitability assessment techniques, this study was interested in parametric evaluation systems prepared by (Sys et al. 1991) based on the soil characteristics.

4.2. Suitability of Individual Factors

4.2.1. Slope Suitability

Slope is closely related to the normal development of soil. The thickness of the soil layer decreases with the increase of the slope angle and increases with the decrease of the slope angle (Geng et al., 2019). At the same time, soil erosion tends to occur in areas with steep slopes, which aggravates the loss of soil nutrients.

On the other hand, slopes also have a direct impact on agricultural production and management, and larger slopes limit mechanized production (Zhang et al., 2015). Therefore, slopes have a direct impact on soil thickness, soil nutrients, and agricultural productivity and further affect land suitability of crop growth.

Slope of an area is also important, which directly controls the balance between runoff response and soil infiltration rates of topography. Higher value of slope causes less infiltration of rainwater and high runoff water through top soil to recharge the groundwater.

The slope map of the study sub basin was grouped in to four classes in percent for surface irrigation; flat or almost flat (0-2%), gentle (2-5%), moderately steep (5-8%), steep to very steep (>8%). Table 8 presents the slope-based suitability analysis of the study area.

Depending on this classification, the slope suitability analysis result indicated that about 1% (9,017 Ha) of the study area was covered with lower than 2% slope class in which it was the least slope class of the study area and highly suitable without any limitations with respect to slope suitability. Areas of flat to gentle slope (0-5%) are easy and does not require modern technology and can largely build on local traditional knowledge for surface irrigation. Such areas also easily adapt well to moderate to low infiltration rates and allows easy leaching of salts. Irrigation allows full utilization of rainwater and can achieve high application efficiencies.

On the other hand, 8% (98,158 Ha) of the topography was 2-5% slope class, which is moderately suitable and 7.3% (89,842 Ha) of the study area topography was set up to be in the range of marginally suitable with 5- 8% slope class.

Most of the study area was of greater than 8% slope class, that set up 84% (1,033,595 Ha), making the study area not suitable for surface irrigation system with respect to slope suitability factor.

Slope >8% (steep slope) is assumed as a trigger of erosion. It increases the number and speed of runoff so that erosion will be accelerated due to more transported and dissolved materials. It also enhances the flow resulting a bigger power and amount of water to transport the soil. Increment of erosion on steep slopes is the result of the increment of surface runoff and also the reason for the decline of infiltration. Generally, slope class of >8% are assumed as a vulnerable area for erosion. Hence, these classes must have special attention and treatment.

Table 8. Slope suitability classes and area coverage

Suitability Class	**Area**		**Slope**	**Suitability code**
	Ha	**%**		
Highly Suitable	9,017	0.7	0-2	S1
Moderately Suitable	98,158	8.0	2-5	S2
Marginally Suitable	89,842	7.3	5-8	S3
Not Suitable	1,033,589	84.0	>8	N
Grand Total	**1,230,606**	**100**		

The slope suitability of the sub basin is depicted in Figure 4. The majority of Gibe sub basin is dominantly steep to very steep sloping surrounded by few hills that divide the water flow. The central (Kersa, Tiro Afeta and Mena), eastern (around some Sokoru) and northern (Limu Kosa, Limu Seka and Nono Benja) districts are the more suitable surface irrigation areas were identified. The most of the southern parts where very steep landscape predominant are not suitable.

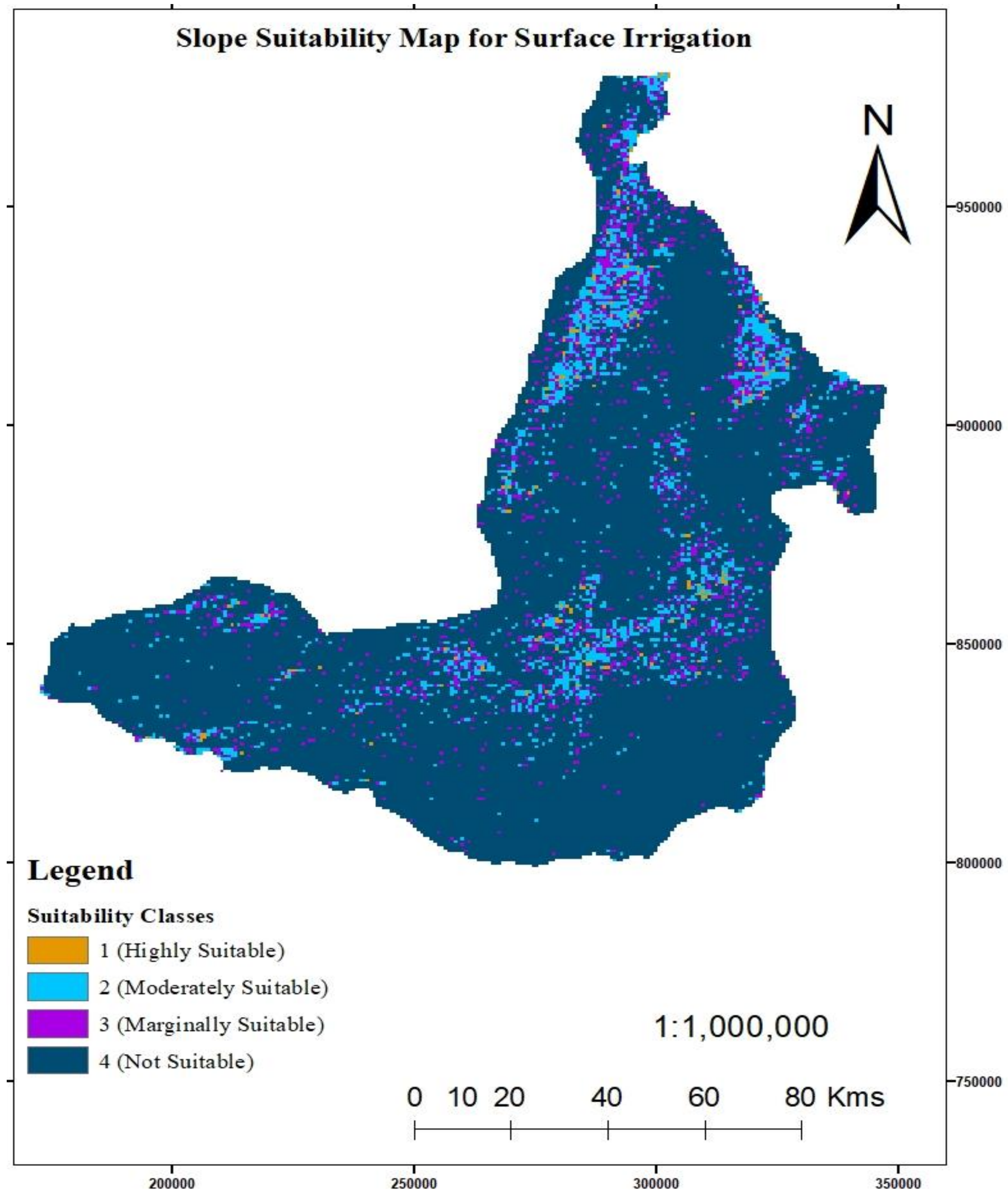

Figure 4. Slope suitability map of the study area

4.2.2. Soil Factors Suitability

Suitable soil for potential surface irrigation was obtained by making weighted overlay analysis that concerned all knowledge sets of soil properties. The ultimate evaluated soil suitability for irrigation indicaing every property when classification of suitability analysis indicate that the study area may be generally classified into four suitability classes; S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable).

Soil properties that can be readily tested or examined are used to describe and separate soil types as physical and chemical properties. From several properties some of these are chosen as the most limiting factors for the study and these include soil texture, drainage and depth from physical properties, whereas pH and CEC from chemical properties. These soil physical characteristics were prepared in the raster format for further weighted overlay analysis.

4.2.2.1. Soil Texture Suitability

Soil is a key factor in determining the suitability of an area for agriculture and sustained irrigation. Its primary influence is on the productive capacity, but it may also influence production and development costs. It decisively influences variety of soil attributes like soil moisture regime, permeability, infiltration rate, run off rate, erodibility, workability, root penetration, and fertility (ILACO, 1989).

The soil texture affects the growth of crops to a great extent and plays an important role in the transport and regulation of water and air in soil, thus fundamentally affecting the suitability of soil for plant root growth (Girvan et al., 2003).

In the present study, the soil textural class of the sub basin was determined based on the particle size distribution. Both the spatial and attribute soil data were obtained from the ECO Database.

Table 9. Soil texture types and area coverage

Soil Texture	Area	
	Ha	%
Silt Loam	411,987	33
Clay	389,519	32
Silt Clay Loam	309,769	25
Sandy Clay Loam	105,669	9
Sandy Loam	13,663	1
Grand Total	1,230,606	100

Silt loam texture is the dominant soil texture, covering 33% (411,987 Ha) of the study area. As shown in table 9 clay and silt clay loam are the next dominant soil texture that were identified in the sub basin respectively. The soil texture results revealed that 90.3% of the study area with soil texture of clay, silt clay loam and silt loam can be irrigated without any limitations, described as highly suitable with respect to the soil texture suitability. About 8.6% (105,669 Ha) of the total study area was set up to be in the class of moderately suitable for surface irrigation and sandy clay loam soil texture also linked to this class. The remaining 1.1% (13,662.8 Ha) of the total study area was categorized to be in the marginally suitable class.

Sandy Loam soils have a low water storage capacity and a high infiltration rate. They therefore need frequent but small irrigation applications, in particular when the sandy Loam soil is also shallow. Under these circumstances, sprinkler or drip irrigation are more suitable than surface irrigation. On loam or clay soils all three irrigation methods can be used, but surface irrigation is more commonly found. Clay soils with low infiltration rates are ideally suited to surface irrigation (FAO, 1985).

Since generally the more loam and clay contained in the soil, the better it will be for irrigation. Coarse soils are easily eroded by running water, which is one of the obstacles to successful surface irrigation.

Table 10. Soil texture suitability classes and area coverage of the study area

Suitability Class	Area		Soil texture	Suitability code
	Ha	%		
Highly Suitable	1,111,275	90.3	C, SICL, SIL	S1
Moderately Suitable	105,669	8.6	SCL	S2
Marginally Suitable	13,662.8	1.1	SL	S3
Grand Total	**1,230,606**	**100**		

As shown on the figure 5, with respect to soil texture almost all parts of the study areas are highly suitable. The eastern (some parts of the Boter and Chora), northern (some parts of Limu Kosa and Limu Seka) and in the central parts of some Kersa districts are identified as moderately suitable. While, near Jimma town and small parts of Omo Beyam areas are found marginally suitable with respect to soil texture suitability analysis for surface irrigation system.

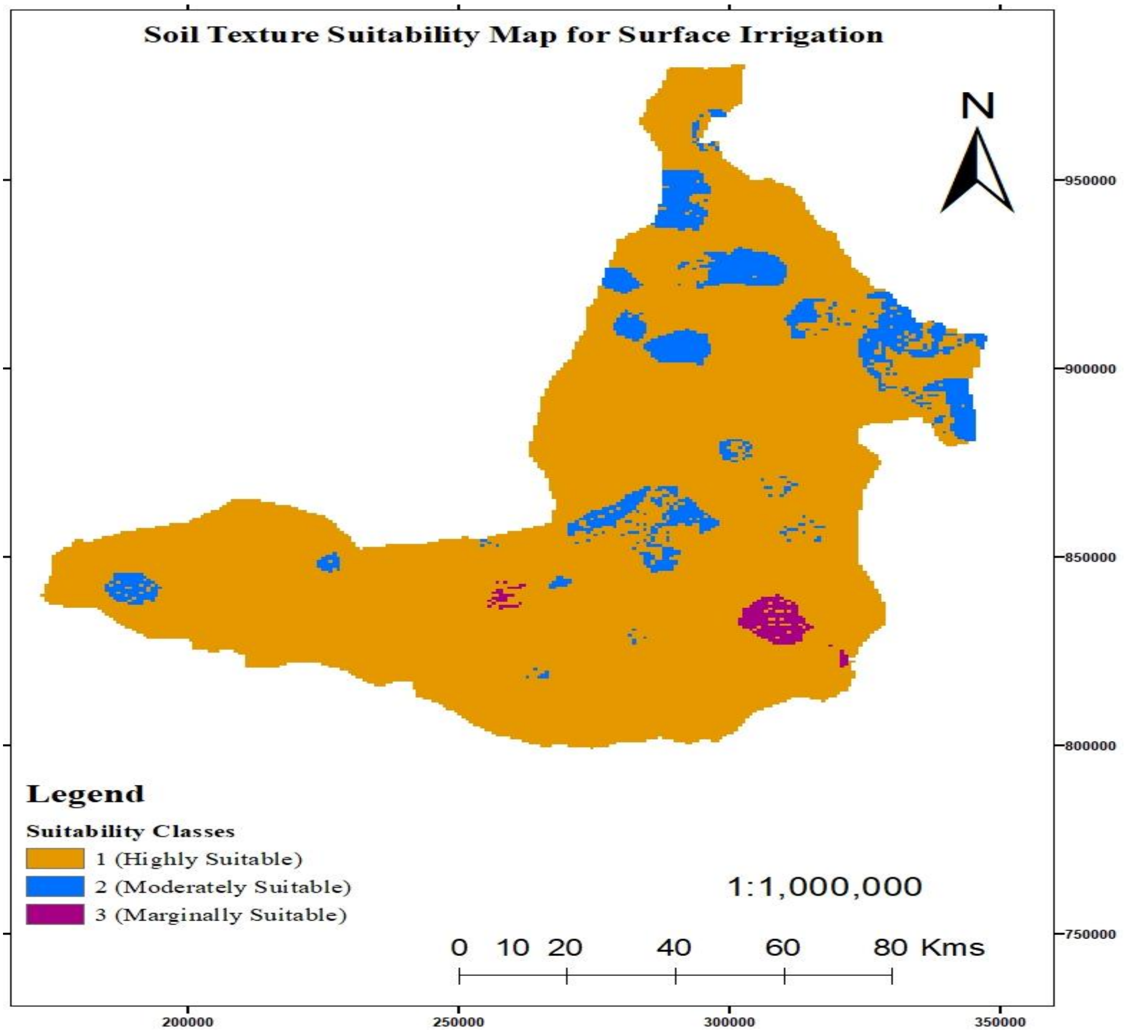

Figure 5. Soil texture suitability map of the study area

4.2.2.2. Soil Depth Suitability

Soil depth refers to the thickness of the soil materials which provide structural support, nutrients and water for plants. The depth of soil that can be effectively exploited by plant roots is an important criterion in the selection of land for irrigation. A soil depth variation from place to place determines the growth of plants and also affects the growth of plant roots. The thickness of the soil materials, that provide structural support, nutrients, and water for crops, is referred to as soil depth.

As it was seen from auger observation and profile description of the soils, soil depths at all sampling points were set up to be very shallow to very deep. Based on the guideline of soil depth suitability evaluation result highly suitable class with >100cm depth is 73.2% (901127 Ha) nearly covered all area, moderately suitable class with 50-100cm depth is 11.9% (146108 Ha), 25-50 cm shallow soil depth classes which are distributed under marginally suitable and 0.9% (10879.7 Ha) of <25cm very shallow soil depth area wasn't suitable with respect to soil depth in the study areas.

Under irrigated conditions soil depth affects drainage, aeration, and water retention properties. Deep soils favor drainage and are therefore optimal for irrigation of dry land crops. Mayaki et al., (1976) found that the root development under irrigation and rainfall conditions varied. The author indicates that in irrigated crops of the root dry matter was in the upper 30 cm with between 0-90 cm. In non- irrigated crops of the total dry matter was in the upper 30 cm within the range of 30-90cm depth

Table 11. Soil depth suitability classes and area coverage of the study area

Suitability Class	Area		Soil depth	Suit code
	Ha	Perc		
Highly Suitable	901127	73.2	>100	S1
Moderately Suitable	146108	11.9	50-100	S2
Marginally Suitable	172491	14	25-50	S3
Not Suitable	10879.7	0.9	<25	N
Grand Total	**1230606**	**100**		

With respect soil depth suitability analysis as illustrated figure 6 highly suitable are predominant in the sub basin. The moderately suitable class was more found around the southern and some easter prats of the sub basin. The marginally suitable predominant in the central to some northern areas of the study areas. Some areas of the eastern and western parts of the study were not suitable class located with respect the soil depth suitability.

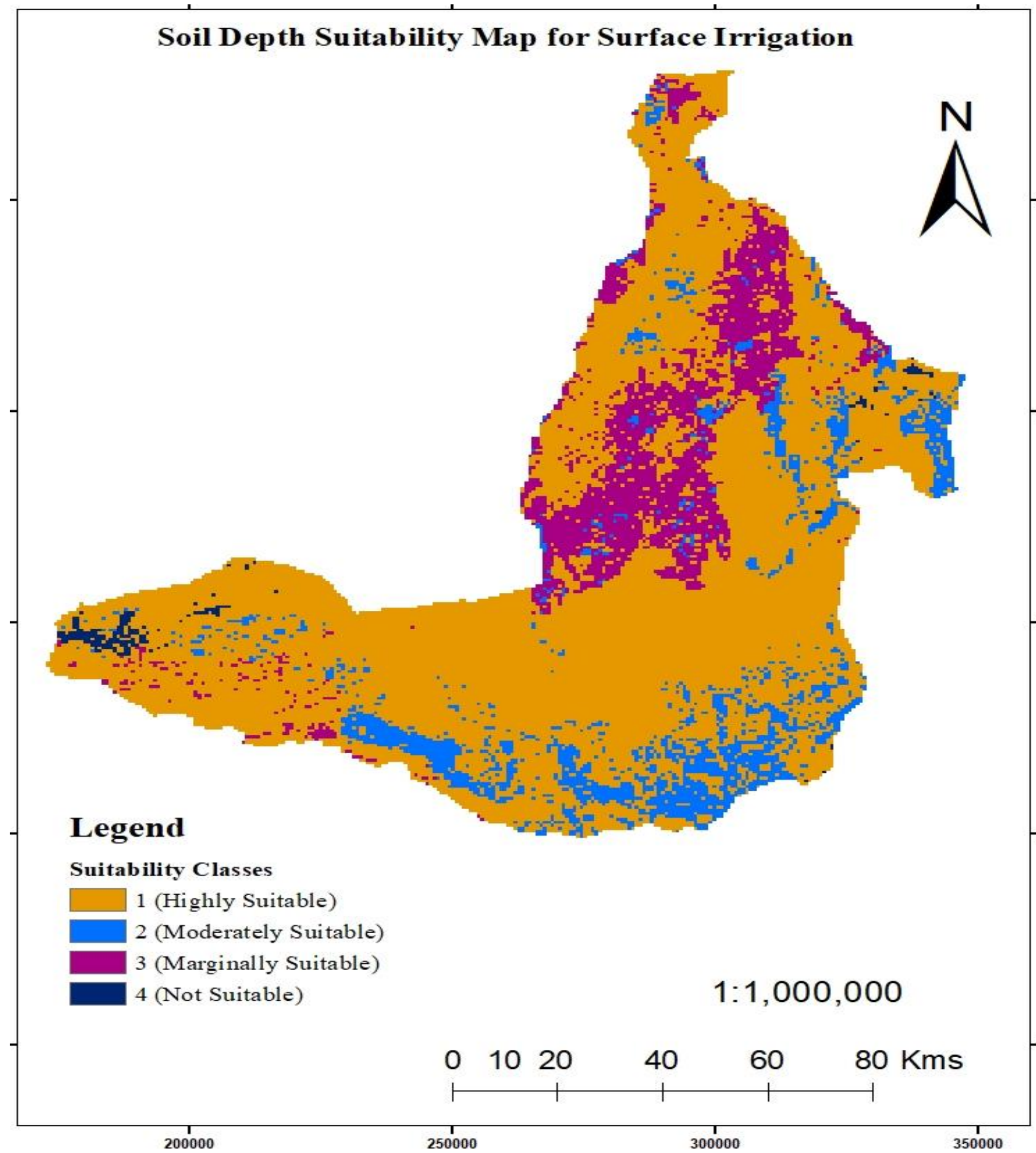

Figure 6. Soil depth suitability map of the study area

4.2.2.3. Drainage Suitability

There is a great relationship between soil drainage capacity and soil texture. The soil with a better drainage capacity will lead to a rapid loss of water and nutrients in the soil, resulting in insufficient water and nutrient supply. The retention of excess water in the soil will block the flow of air, resulting in insufficient oxygen supply in roots and the retention of carbon dioxide, thus affecting the growth of crops (Montgomery, B. et al. 2016).

Soil drainage is also an important factor for land suitability evaluation for surface irrigation as it is treated excess water on surface. Soil drainage in a specific area can be classified into four types. These are well, moderately well, imperfectly well, and poorly drained. Good drainage of the site is essential to allow the continuous movement of water and salt through the profile. Without this continuous leaching, salt may build up to levels that may be harmful to the landscape and crops (Gebre G, et al. 2021).

Soil drainage may determine which types of plants grow best in an area. Many agricultural soils need good drainage to improve or sustain production or to manage water supplies (Haroun, 2004).

The drainage of the soil can be accelerated by the use of surface and subsurface drainage practices. Surface drainage diverts excess water from the soil surface directly to streams, thereby reducing the amount of water that will move into and possibly through the soil. Subsurface drainage, provided by ditches and drainpipes, collects and diverts water from within the soil directly to streams.

Subsurface drainage systems have a positive impact because they generally decrease the amount of surface runoff, reducing the loss of substances generally transported by overland flow.

Drainage in the studied area ranged from well to poor, and the dominant drainage status was the well-conditioned class 78% (963,671 Ha) was distributed under highly suitable. A soil drainage class with moderate drainage class with 6.4% (78681 Ha) was classified as moderately suitable, whereas amiss drainage was classified as marginally suitable was 14.4% (177,566 ha) and not suitable areas were classified as poor drainage class.

Poor drainage (causing water-logged areas) that often dominated by longer periods of saturation, and thereby reducing conditions, there can be mottles that occupy small areas and that differ in color from the soil matrix and it has social and economic impacts.

If the soil doesn’t drain well, the root zone becomes saturated with water, leaving no room for air and causing plants to suffocate. Fortunately, the most common drainage problems are fairly easy to identify and correct.

Table 12. Soil drainage suitability class and area coverage

Suitability Class	Area		Drainage	Suit code
	Ha	%		
Highly Suitable	963,671	78.3	Well	S1
Moderately Suitable	78,681	6.4	Moderate	S2
Marginally Suitable	177,566	14.4	Imperfect	S3
Not Suitable	10,687	0.9	Poor	N
Grand Total	**1,230,606**	**100**		

As shown on the figure 7, highly suitable class areas which have well drainage status were identified almost in all sub basin but in the western and some eastern north western parts of the study area it is not dominant. In these areas marginally suitable class is more predominant. Moderately suitable class of the moderate drainage is found in the central areas around Kersa and Jimma special districts. In some northern parts of the study around Limu Kosa, Limu Seka and Nono Benja districts it was identified. Areas around Gilgal Gibe 1 dam, and eastern parts of the sub basin and few areas wetlands near to Jimma town and Limu Genet town are found as not suitable with respect to soil drainage factor for surface irrigation.

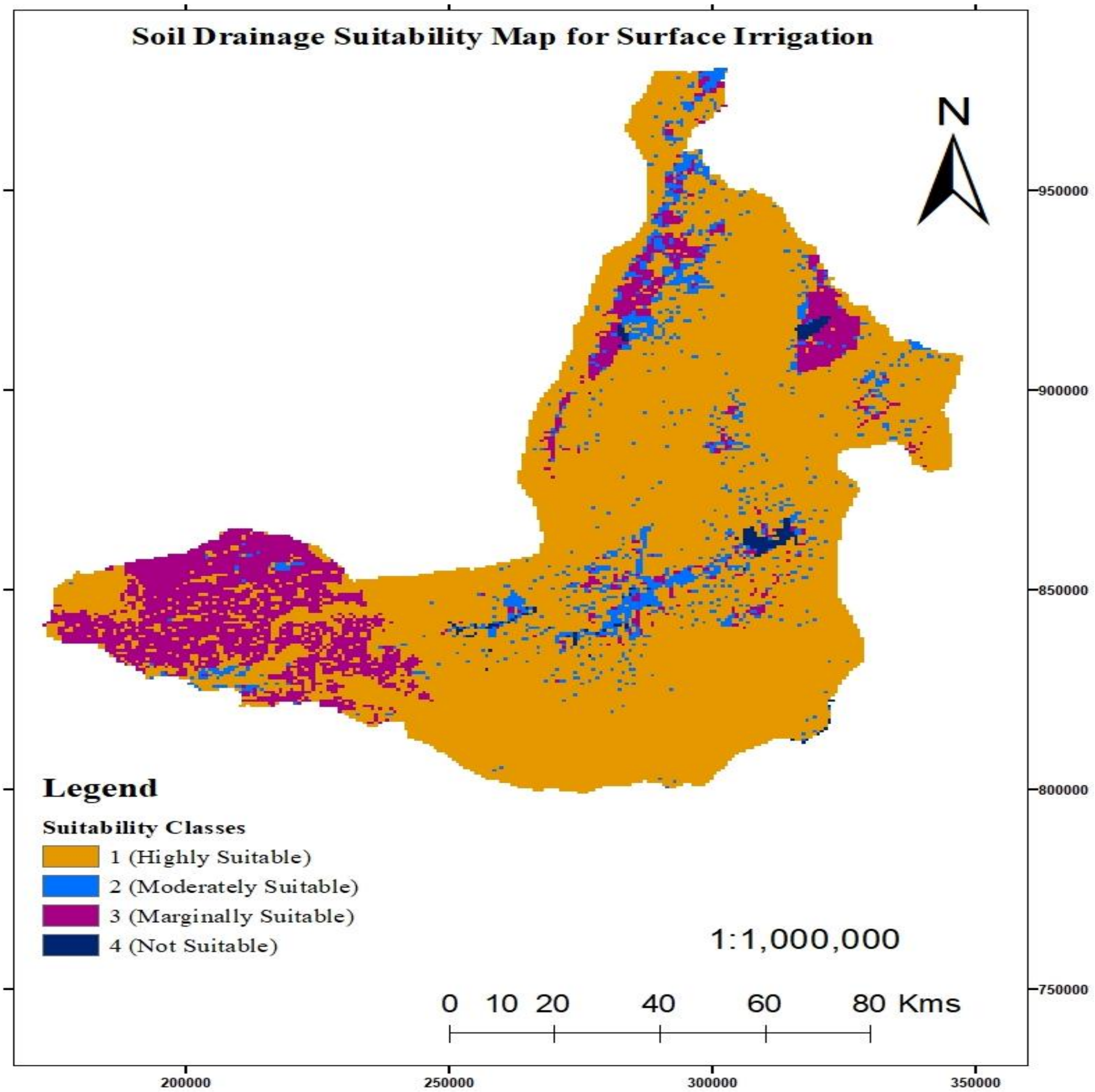

Figure 7. Soil drainage suitability map of the study area

4.2.2.4. Soil pH Suitability

Soil pH is the most important soil criterion in land suitability analysis for irrigation and it controls numerous chemical soil characteristics and some physical soil properties. Soil response controls the solubility of utmost soil minerals; for illustration, high soil pH leads to low micronutrient availability and decreases the availability of macronutrients such as calcium, magnesium and phosphorus.

pH plays a major role in soil nutrient availability, crop growth, and productivity. Besides this, pH affects many physical, chemical, and biological reactions, either directly or indirectly, in the soil, and the optimal pH ranges for different crops have significant differences (Zolekar et al., 2015).

The pH value of the study area varied from 4-6.5. this indicates that the soil considers as very strong acidic to slightly acidic properties. The soils linked in the study area that were set up as 5.5-6.5 pH is 22.7% (279,648 Ha) to be highly suitable. 4.5-5.5 pH range of moderately suitable class is 54.8% (674,801 Ha) and 4-4.5 range classes which are distributed under marginally suitable) in the study area with respect to pH.

Brady and Weil (1999) state that soil pH is the master variable of soil, since it influences many physical, chemical, and biological properties and processes. If the soil pH declines below a critical level, the solubility of aluminium and manganese ions increases, resulting in toxicity and lower yields. Berglund (1996) states that a soil pH below 5 adversely affects roots and a pH below 4 severely restricts root growth. If the pH is higher than 8.5 the soils are considered to be alkaline soils. This causes some essential nutrients such as magnesium (Mg) and calcium (Ca) to be unavailable.

Table 13. Soil reaction pH suitability classes and area coverage of the study area

Suitability Class	**Area**		**pH**	**Suit code**
	Ha	**%**		
Highly Suitable	279,648	22.7	5.5-6.5	S1
Moderately Suitable	674,801	54.8	4.5-5.5	S2
Marginally Suitable	276,158	22.4	4-4.5	S3
Grand Total	**1230606**	**100**		

In general, the study is predominantly moderately suitable with respect to pH suitability analysis as shown on the figure 8. The western, eastern and central parts of the study areas are more highly suitable. Marginally suitable class more dominant in the southern and also located in some areas of eastern and north-western of the study.

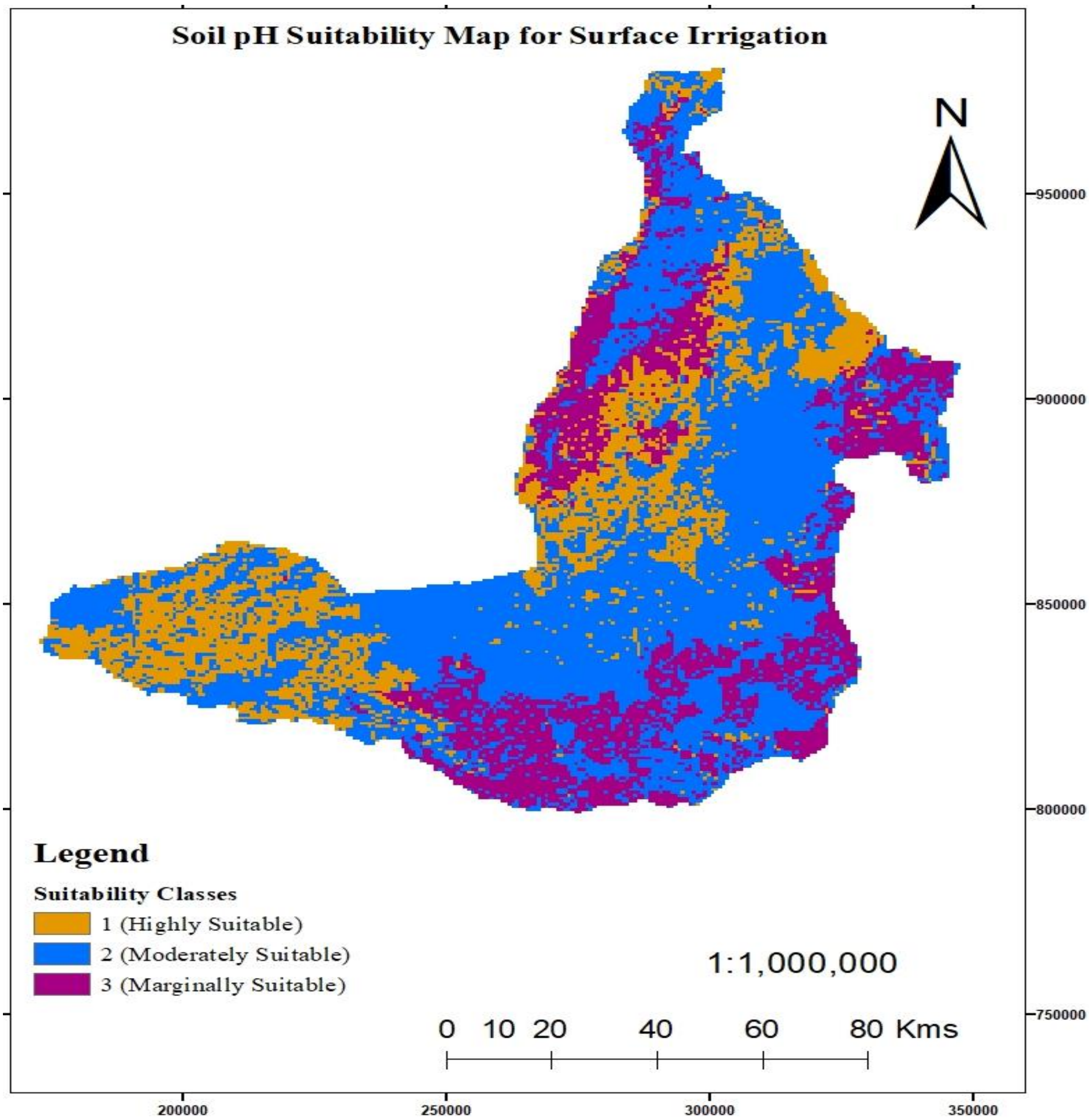

Figure 8. Soil pH suitability map of the study area

4.2.2.5. Soil CEC Suitability

Cation exchange capacity is a measure of the total negative charges within the soil that adsorb plant nutrient cations such as calcium ($Ca2+$), magnesium ($Mg2+$) and potassium ($K+$). As such, the CEC is a property of a soil that describes its capacity to supply nutrient cations to the soil solution for plant uptake.

CEC measurements are commonly made as part of the overall assessment of the potential fertility of a soil, and possible response to fertilizer application. Soils with a high value of CEC are considered fertile, and soils with a low value of CEC are considered infertile (Landon,1984).

Based on the guideline classification result of CEC for irrigation suitability, about 25.9% (319,185 Ha) of land was set up to be distributed under highly suitable with >40% of the CEC, utmost areas of the study with 25-40 CEC were set up 58% (714,125 Ha) is moderately suitable and an area of 16% (197,296 Ha) with CEC 15-25% is set up to be marginally suitable.

Brady and Weil (1999) state that without cation exchange, the soil is not able to retain sufficient cation nutrients to support natural or introduced vegetation, especially following such events as cultivation or fire and also fundamental life-supporting processes. Generally, the CEC is lowest at soil pH of 3.5 to 4.0 and increases as the pH is increased by liming an acid soil. While there is no 'perfect' CEC value that fits every variety, climate, and soil type, soil CEC values typically greater than 15% well-performing for agriculture. Soils with CEC values below 15 are generally considered to be poor at holding cation nutrients.

Table 14. Soil CEC suitability class and area coverage

Suitability Class	**Area**		**CEC**	**Suit code**
	Ha	**%**		
Highly Suitable	319185	25.9	>40	S1
Moderately Suitable	714125	58.0	25-40	S2
Marginally Suitable	197296	16.0	15-25	S3
Grand Total	**1230606**	**100**		

The suitability map illustrated on the figure 9 shows that most of the western (Gera and Goma districts), some of the southern and south western (Shebe-Sombo, Omo Beyam and Omo Nada districts), eastern areas (Sokoru and Botor) and norther areas (around Nono Benja) areas are highly suitable. Very large areas of the central parts, some northern and few other parts the predominant moderately suitable class identified in the study area. Marginally suitable class more found in the northern and north-western of the study areas.

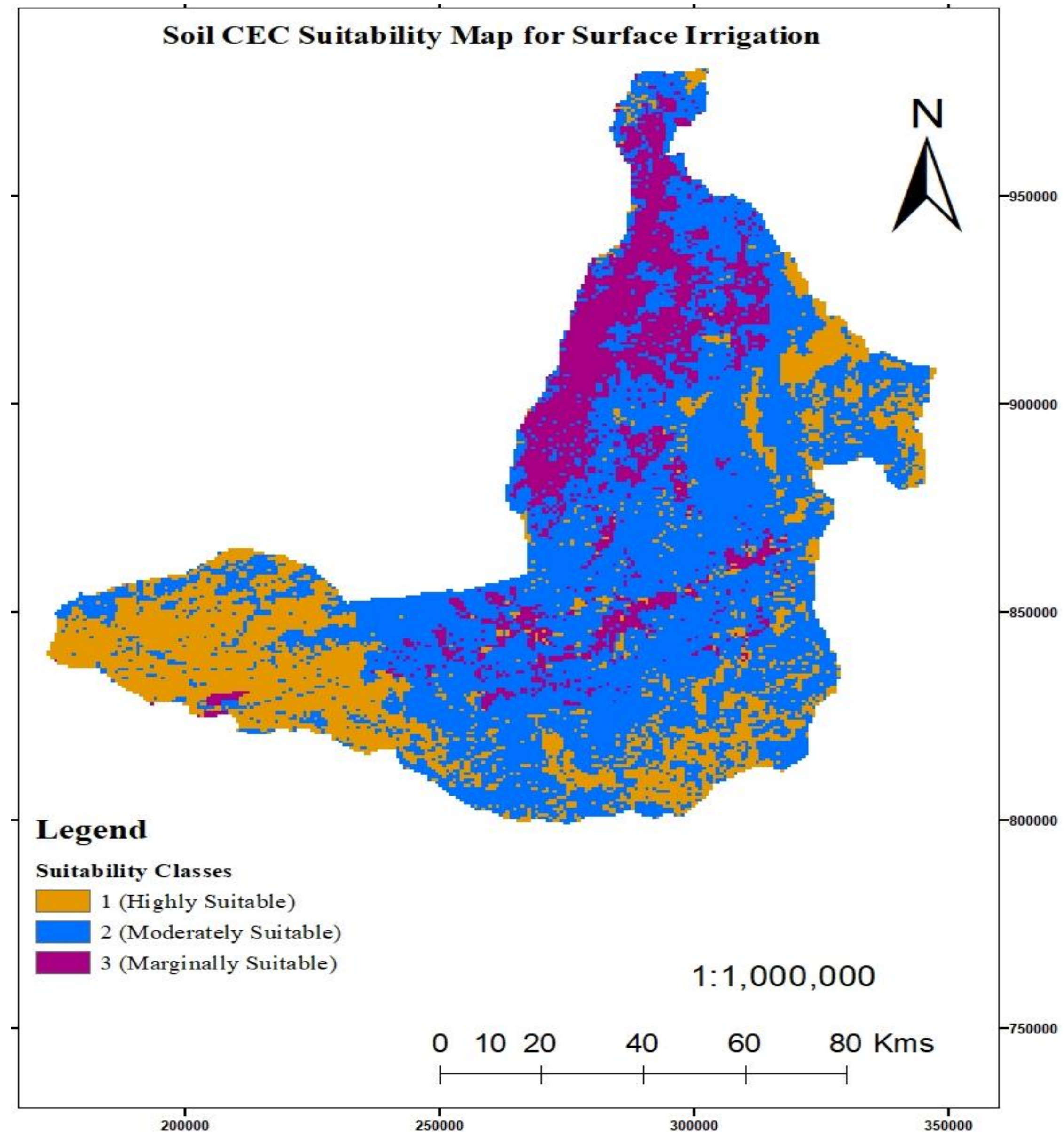

Figure 9. Soil CEC suitability map of the study area

4.2.3. Land Use Land Cover Suitability

Land cover is that which overlays or currently covers the ground, e.g., vegetation (trees, bushes, fields and lawns), bare soil (even if this is a lack of cover), hard surfaces (rocks and buildings), wet areas and bodies of water (wetlands, and sheets of water and water courses) (European communities, 2001). But land use is in terms of functional dimension corresponds to the description of areas in terms of their socio-economic purposes like residential, industrial, commercial, farming, forestry, recreation, conservation and so on (Mucher etal.,1993 in European communities, 2001).

The reclassified suitability classes of land use land cover of the study area for the surface irrigation system are shown in Figure 2.

57.4% (706,969 Ha) of the total area was set up cultivated land and it was in the range of highly suitable for surface irrigation system with respect to land use land cover. 2.8% (35,014 Ha) grazing land of the total area was set up to be in the range of moderately suitable. Marginally suitable classes such as shrub and backcountry land in the area, were covered 9.5% (116,583 Ha) of the total areas of the study area. This result also revealed that 30.2% (372,040 Ha) of the study area was set up as timber, agreement, waterbody and swamp distributed under not suitable for surface irrigation due to the impact of surface irrigation on the terrain and costs to remove or change the land for civilization.

From this land cover or use classes of the study area the cultivated land and grassland were classified as highly and moderately suitable for surface irrigation respectively. This is because of the assumption that the cultivated land will be used to irrigation without limitation and shrub grassland will be used with less limitation. This is because of the forested area may be a choice when the cultivated and shrub grass land no more avail in the study area. The bush and shrub land were classified as marginally. And forested area and water body not suitable for surface irrigation.

Land use practices affect the distribution and supply of soil nutrients by directly altering soil properties and by influencing biological transformations in the rooting zone. For instance, cultivation of forests diminishes the soil carbon (C) within a few years of initial conversion and substantially lowers mineralizable of nitrogen (N) (Majaliwa *et al*., 2010).

Table 15. Land use/cover suitability class and area coverage

Suitability Class	**Area**		**LULC**	**Suit code**
	Ha	**%**		
Highly Suitable	706,969	57.4	Cultivated Land	S1
Moderately Suitable	35,014	2.8	Grazing	S2
Marginally Suitable	116,583	9.5	Bush, shrub land	S3
Not Suitable	372,040	30.2	Forest, settlement, water body, wetland	N
Grand Total	**1,230,606**	**100**		

The Land Use Land Cover (LULC) information is essential to assess the irrigation potential of a sub basin. The LULC cover map and statics of the sub basin are displayed in figure 10. According to the result, the largest portion of the central, southern and eastern of the sub basin are analyzed as highly suitable class. Some areas of the northern areas are moderately suitable. Most of the Goma district of the sub basin portion, Shebe-Sombo, Omo Beyam and Sokoru district areas are marginally suitable. Large portion of the western (Gera district), some areas of the north-western and few areas of the sub basin are not suitable with respect to land use land cover suitability evaluation for surface irrigation.

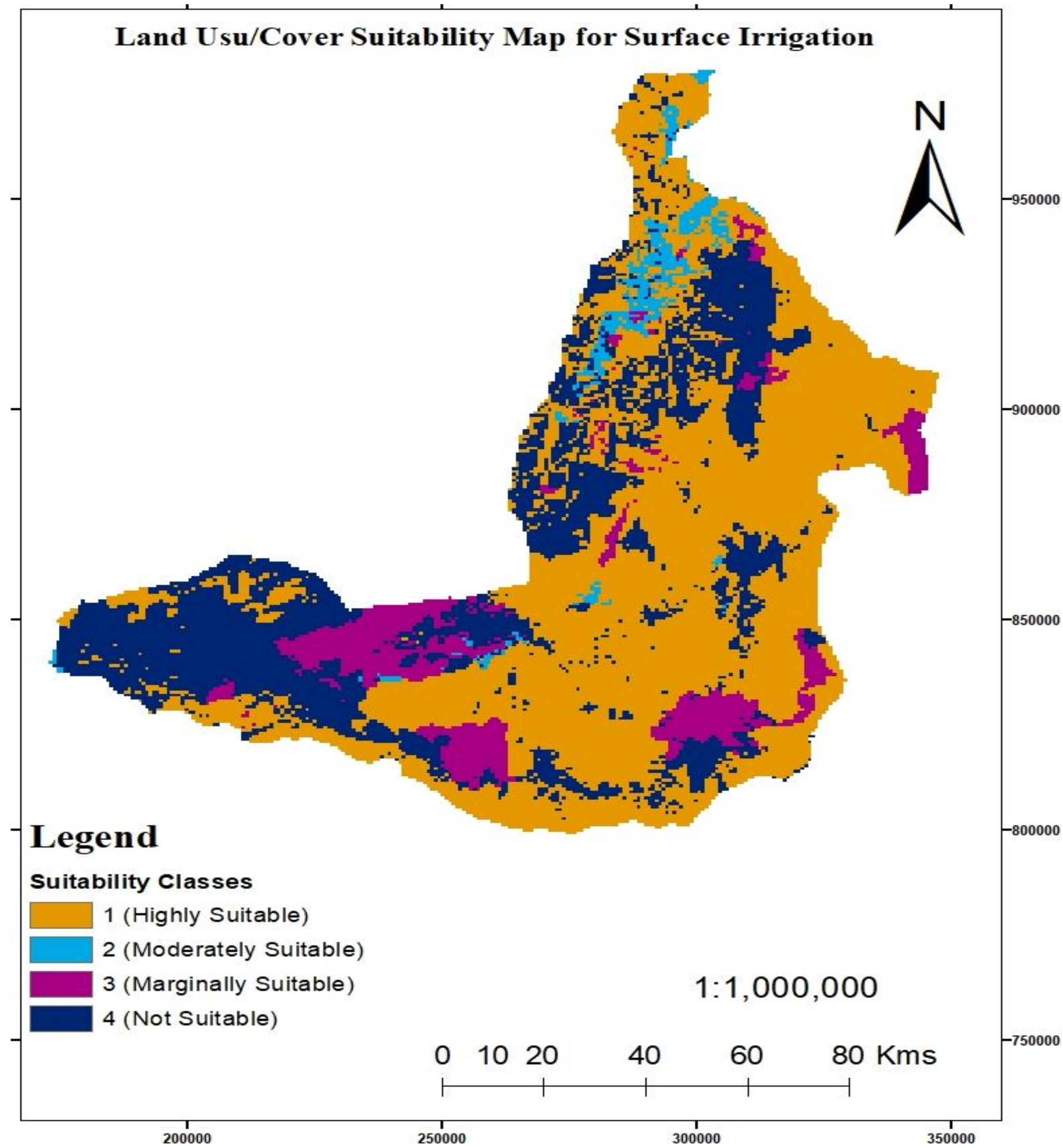

Figure 10. Land use/land cover suitability map of the study area

4.2.4. River proximity/ Distance to the Water

Rivers are used as a sources of irrigation water. River is not a reservoir which contains a fixed amount of water. At each moment a new amount of water is passing any given location along the river. The flow of river fluctuates over time. The flows of some rivers fluctuate greatly over relatively short periods of time; these are mainly small local rivers which respond quickly to rainfall in their catchment area (FAO, 2001).

Distance to water sources to be the variable most likely to impact the point position of surface irrigation (Westcott and Brandon, 2000). The suitability class of river proximity/ distance from the river was distributed in distance of 0- 5 km, 5- 10 km, 10- 20 km and >20 km with suitability range of highly suitable, moderately suitable, marginally suitable and not suitable respectively.

From the delineated sub basin of Gibe River, command area which are closest to the water source were classified as highly suitable for surface irrigation was covered 58.4% (718,266 Ha). Also, moderately suitable areas were set up to be covered 32.9% (405,177 Ha) the total areas of the study. The remaining 8.7% (107,163 Ha) of the total area was set up to be in the range of marginally suitable.

It is important that there is no lack of irrigation water in the study areas for surface irrigation suitability with respect to river proximity.

Table 16. River proximity suitability class and area coverage with respect to command

Suitability Class	Area		River approximate (km)	Suit code
	Ha	%		
Highly Suitable	718,266	58.4	0-5	S1
Moderately Suitable	405,177	32.9	5-10	S2
Marginally Suitable	107,163	8.7	10-20	S3
Grand Total	**1,230,606**	**100**		

The sub basin area is the area which a particular many streams surface flow found. Drainage water mainly originating from precipitation. As shown on the figure 11 irrigable land that is close to the water supply (rivers) based on calculating the straight-line (Euclidean) distance from the streams highly suitable class was more dominant in the study area. Areas where topography is flat to gently as shown in the figure under this suitability class. Moderately suitable areas general found at the gently to moderate steep landscape of the study areas. Marginally suitable was more found at the very steep areas that means the distance irrigable land from the river in the areas is greater than ten kilometers.

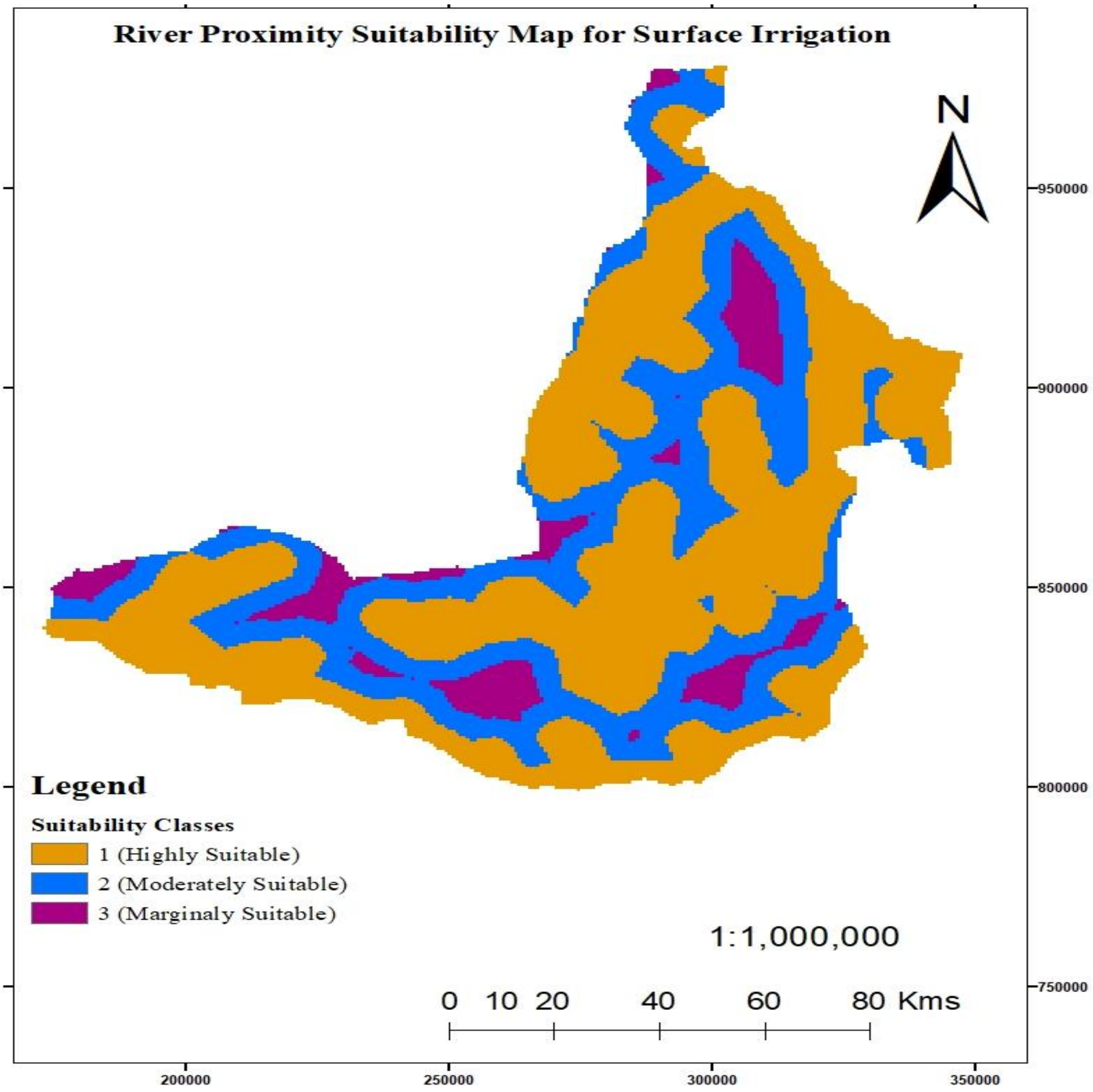

Figure 11. River proximity suitability map of the study area

4.3. Weight Assignment to Parameters

The logic developed by a previous study (Saaty, 1977) was used to produce weights under the Analytical Hierarchy Process (AHP) with a weighted linear combination. AHP was carried out by applying a weight to each parameter, which was followed by a summation of the results to yield a suitability map (Eastman, 2001).

Use of AHP provides scope for combining expert opinion with measurements in making pairwise comparisons between criteria at each level of the hierarchy to come up with relative weights. Malczewski (2004) noted that the relationship between the objectives and attributes has a hierarchical structure.

To reduce the risk associated with over-fitting or noise modelling, eight thematic input layers were used by employing matrix pairwise comparison. The matrix pairwise comparison was obtained from different expects, and factor weights were calculated using a pair-wise comparison matrix.

In pair-wise comparison, each factor was matched head-to-head (one-to-one) with each other, and a pairwise or comparison matrix was prepared to express the relative importance. A scale of importance was divided from a value of 1 to 9 (Table 7). The highest value 9 corresponds to absolute importance and the reciprocal of all scaled ratios was entered in the transpose position (1/9) and shows an absolute triviality.

The results show that the factor slope is the most important factor since all its values are lesser than 1 in its row followed by "land use/ cover" which only has one value lower than 1. The least important factor in considering surface water irrigation suitability is "CEC" with all its row values lower than 1. The judgment is private, the weighting of decision factors is determined based on the significance of each factor and involves knowledge of those familiar with irrigation in the area. The factors slope, land use/ cover, and soil were judged as very important because slope and land use/ cover are associated with a large original investment and the remaining were considered as important to least important.

The accuracy of weights used is subjective as it depends on opinion; however, the results of the relative weights were used in land suitability evaluation because the Consistency Ratios were within the established acceptable limits (0.1).

Table 17. The pairwise comparison for irrigation suitability factors.

Factors	Slope	LUC	Depth	Drainage	Soil text	River Distance	pH	CEC
Slope	Equal importance	Somewhat important	Somewhat important	Somewhat important	Somewhat important	Much more important	Very much more important	Absolutely more important
LUC	Reciprocal	Equal importance	Intermediate values	Intermediate values	Intermediate values	Intermediate values	Somewhat important	Very much more important
Depth	Reciprocal	Reciprocal	Equal importance	Intermediate values	Intermediate values	Intermediate values	Somewhat important	Very much more important
Drain-age	Reciprocal	Reciprocal	Reciprocal	Equal importance	Intermediate values	Intermediate values	Somewhat important	Very much more important
Soil text	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Equal importance	Intermediate values	Somewhat important	Very much more important
River distance	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Equal importance	Much more important	Much more important
pH	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Equal importance	Somewhat important
CEC	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Reciprocal	Equal importance

4.4. Suitability Analysis Using Analytic Hierarchy Process Operation

After the database was built, an evaluation of the connection between land suitability and factors also because the significance of every parameter and sub-criteria was performed using the principle of the analytical hierarchy process. Therefore, eight land suitability factors were reclassified and rescaled. Then, the load of every criterion was calculated employing a pairwise comparison matrix.

In this study, an analytical hierarchy processing method with GIS was used to evaluate the connection between soil parameters, topography (slope), and land-use factors on the suitability of lands for surface irrigation. For this study, eight governing factors like physical factors (soil texture, soil drainage, depth, pH and CEC), land use, topographic factors (slope), and distance to water source were considered as input parameters. The pair-wise comparison matrix was performed for eight major factors compared one to at least one and scored.

For all the eight parameters the relative significance is deduced. Therefore, a common scale (0 to 100%) is attained from the AHP procedure.

After the pairwise comparison matrices were filled, the weight value was used to identify the consistency rate and develop the best-fit weights. The consistency rate (CR) was 0.046, which was respectable for weighting the factors to estimate the land capability of the irrigation suitability maps.

The weighted parameters (criteria) were sum up using weighted overlay methods in ArcGIS to get a land suitability index. After all, the land suitability index map was reclassified into four suitability classes using the natural break method within the ArcGIS tool. These are highly suitable (S1), suitable (S2), marginally suitable (S3), and unsuitable class (N).

Table 18. Pairwise comparison matrix of criteria for land suitability.

Factors	Slope	LU-LC	depth	Drain-age	soil text	River distance	pH	CEC	Weight value
Slope	1	3	3	3	3	5	7	9	33
LULC	0.333	1	2	2	2	2	3	7	17
Depth	0.333	0.5	1	2	2	2	3	7	14
Drainage	0.333	0.5	0.5	1	2	2	3	7	12
Soil text	0.333	0.5	0.5	0.5	1	2	3	7	10
River distance	0.2	0.5	0.5	0.5	0.5	1	5	5	8
pH	0.143	0.333	0.333	0.333	0.333	0.2	1	3	4
CEC	0.111	0.143	0.143	0.143	0.143	0.2	0.333	1	2
Sum	2.79	6.48	7.98	9.48	10.98	14.40	25.33	46	100

The set value between 1 and 9 (equal (1) to strong (9) preference). Compared is raw against column. The transpose values are set automatically.

The slope parameter emerges as the most important (relative weight 33%) followed by the land use/ cover (17%), depth (14%), drainage (12%), soil texture (10%), river proximity (8%), pH (4%) and CEC (2%). This judgment is checked for its consistency.

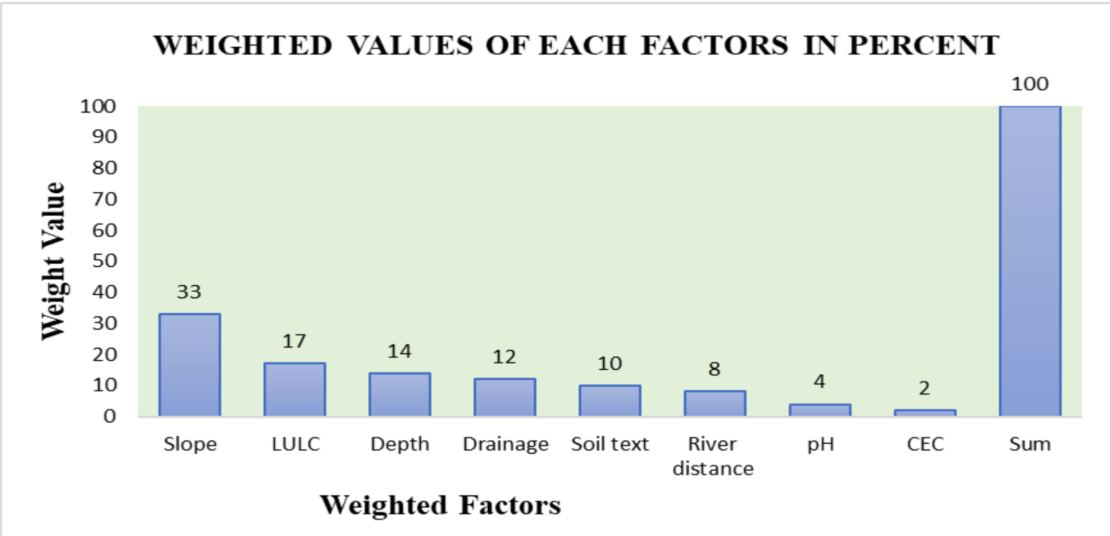

Figure 12. The weighted value of parameters after comparing factors to each other's using AHP

4.5. Overall Suitability Class

Potential irrigable land was attained 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 source. The weighting process of the factors was performed by using Arc GIS 10.8.1, weighted overlay tool of spatial critic tool. While performing the weighted overlay analysis, the weight of each factor (percent weight values) was handed to each of the separate factors. Also, a primary suitable surface of land for irrigation was reckoned.

Eventually, the confined areas which are defined as permanently not suitable for irrigation as FAO guideline, (Verheye, 1976) frame, were derived from the maps using abolish tool of analysis toolbox.

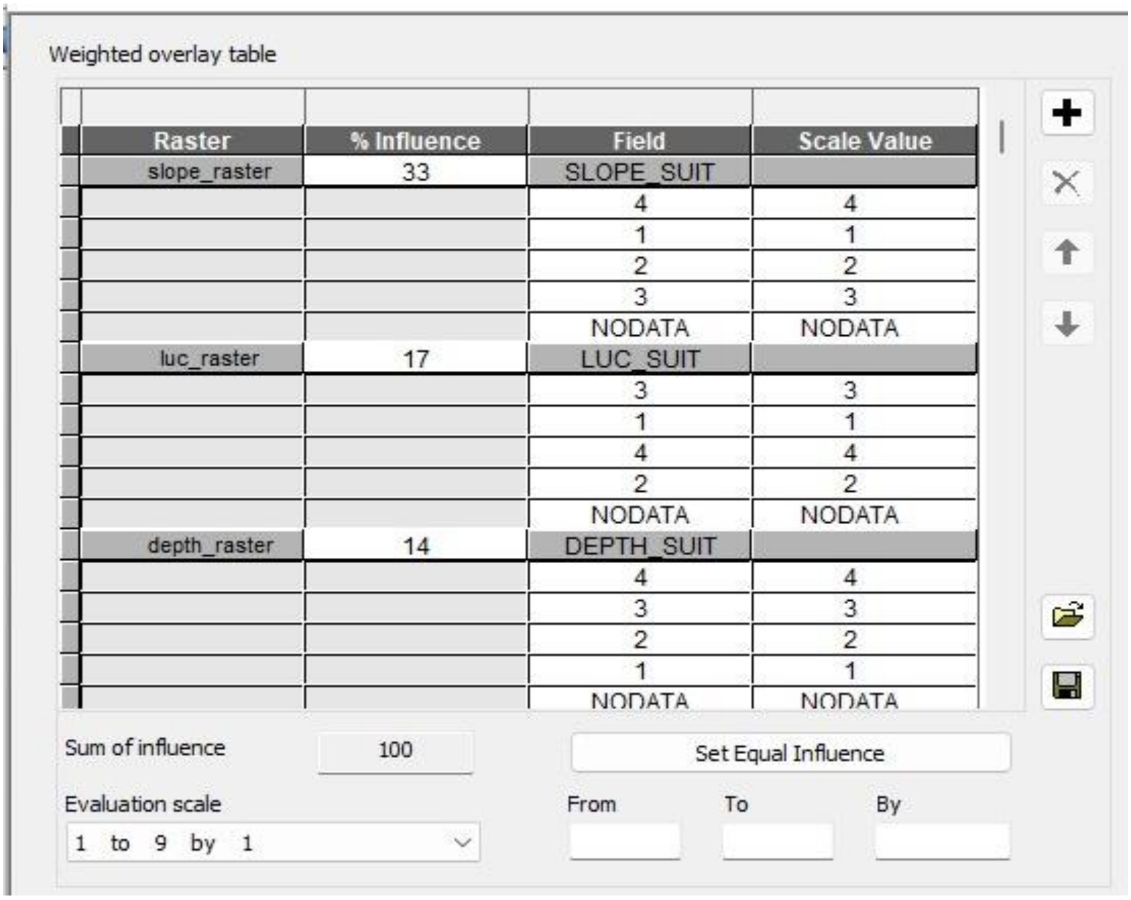

Figure 13. Weighting overlay analysis process for selected factors using ArcGIS

The overall spatial suitability assessment for irrigation based on the overlaid individual layers indicated that about 12.5% of the study area was potentially suitable for irrigation. Of the potentially suitable land, 0.8% was highly suitable that land having no significant limitations to surface irrigation, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level, 9.4% of land that having limitations which in aggregate are moderately suitable. There limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained and 2.3% was marginally suitable land having limitations which in aggregate are severe and will so reduce productivity or benefits, or increase required inputs. Whereas, land having limitations which appear not suitable so as to preclude any possibilities of successful sustained use of the land was cover 87.5% of the study area.

Table 19. Overall final surface irrigation land suitability class and area coverage

Suitability Class	Area	
	Ha	%
Highly Suitable	10,049	0.8
Moderately Suitable	115,370	9.4
Marginally Suitable	28,474	2.3
Not Suitable	1,076,713	87.5
Grand Total	**1,230,606**	**100**

Figure 14 presents the identified potential irrigable lands and Table 19 presents the identified irrigable land areas in hectors along rivers in different sites. The highly suitable areas are found along the streams and flat areas of central, northern and eastern areas of the sub basin. Most of the areas are classified as moderately suitable also found in the northern areas special in Limu Kosa, Limu Seka and Nono Benja districts. The Botor districts around Tolay areas also moderately suitable. Marginally suitable scarcely found throughout the sub basin. In general, the areas are almost not suitable for surface irrigation as this study final result.

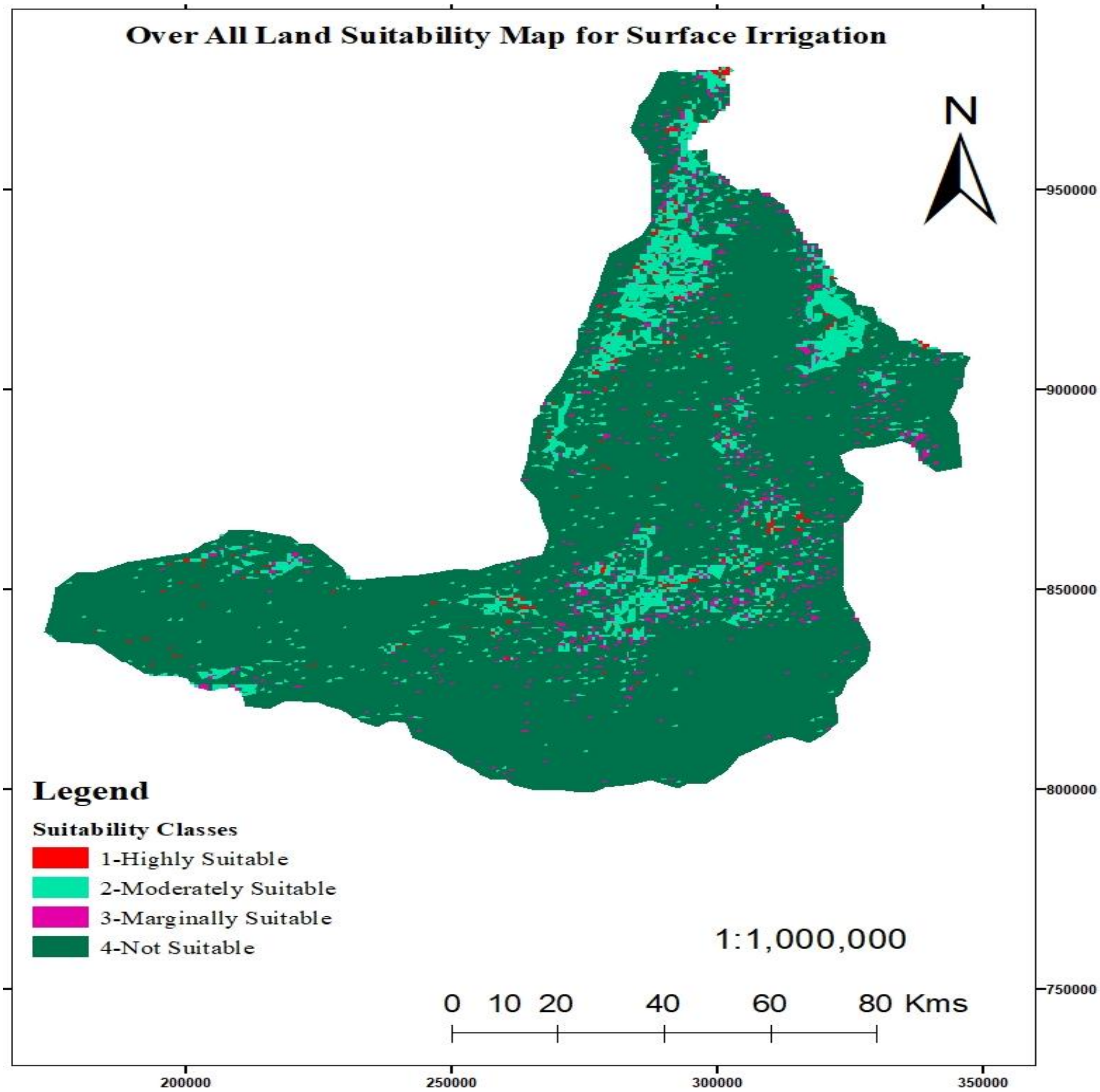

Figure 14. Map of overall final surface irrigation land suitability

As presented in the table 20 below, the highly suitable class is located substantially in north (Nono Benja, 1,549 Ha or 0.13%) and north- east (Chora, 1,179 Ha or 0.1%) parts of the study area. The moderately suitable class of land suitability located substantially in north- east (Chora 18,379 Ha or 1.49% and Boter, 14,474 Ha or 1.18%) and in north (Nono Benja, 13,516 Ha or 1.1%) parts of the study area.

The marginally suitable classes are in the south (Omo Nada 4,098 Ha or 0.33%) and central (Kersa 3,410 Ha or 0.28%) parts of the study area. The results of land suitability analysis showed that the large parts of the studied area were classified as not-suitable 87.5% (1,076,587 Ha). In general, after geomorphology factors land use/Land cover are the most important limiting factors in the studied area.

Table 20. Land suitability distribution of the study areas in terms of district

Highly Suitable			Moderately Suitable		
District Name	**Area**		**District Name**	**Area**	
	Ha	**%**		**Ha**	**%**
Boter	497	0.04	Boter	14474	1.18
Chora	1179	0.1	Chora	18375	1.49
Dedo	188	0.02	Dedo	2004	0.16
Gera	859	0.07	Gera	4030	0.33
Jimma Town	669	0.05	Gomma	695	0.06
Kersa	712	0.06	Jimma Town	2405	0.2
Limu Kosa	705	0.06	Kersa	11442	0.93
Limu Seka	984	0.08	Limu Kosa	7426	0.6
Mancho	184	0.01	Limu Seka	9442	0.77
Nono Benja	1549	0.13	Mancho	2343	0.19
Omo Nada	737	0.06	Manna	762	0.06
Seka Chekorsa	215	0.02	Nono Benja	13516	1.1
Shebe Sambo	117	0.01	Omo Beyam	281	0.02
Sokoru	370	0.03	Omo Nada	12401	1.01
Tiro Afeta	1104	0.09	Seka Chekorsa	1738	0.14
			Shebe Sambo	4002	0.33
			Sokoru	4617	0.38
			Tiro Afeta	5593	0.45
Total Area	**10069**	**0.82**	**Total Area**	**115543**	**9.39**

Marginally Suitable			Not Suitable		
District Name	**Area**		**District Name**	**Area**	
	Ha	**%**		**Ha**	**%**
Boter	2170	0.18	Boter	78657	6.39
Chora	2253	0.18	Chora	61890	5.03
Dedo	1336	0.11	Dedo	85777	6.97
Gera	544	0.04	Gera	94115	7.65
Gomma	271	0.02	Gomma	9187	0.75
Kersa	3410	0.28	Jimma Town	6198	0.5
Limu Kosa	1381	0.11	Kersa	81064	6.59
Limu Seka	684	0.06	Limu Kosa	86176	7
Mancho	1485	0.12	Limu Seka	21051	1.71
Manna	93	0.01	Mancho	69644	5.66
Nono Benja	3230	0.26	Manna	11184	0.91
Omo Beyam	265	0.02	Nono Benja	34588	2.81
Omo Nada	4098	0.33	Omo Beyam	82737	6.72
Seka Chekorsa	439	0.04	Omo Nada	60245	4.9
Shebe Sambo	778	0.06	Seka Chekorsa	75541	6.14
Sokoru	3491	0.28	Shebe Sambo	71082	5.78
Tiro Afeta	2479	0.2	Sokoru	80960	6.58
			Tiro Afeta	66491	5.4
Total Area	**28407**	**2.31**	**Total Area**	**1076587**	**87.5**

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

- The main objective of this study was to estimate a suitability map for surface irrigation based on ArcGIS in Jimma zone along Gibe basin. The study applied weighted sum overlay of the spatial analysis ways to adequately detect the suitable position of surface irrigation in the study area. Therefore, in this research land suitability analysis for surface irrigation was made in using the available data taking soil, slope, land use land cover and river proximity as suitability
- The study was carried out based on geomorphology, soil (physical and chemical properties), land use/ cover and river proximity of the study area. Consideration of these crucial factors was believed to give information that based on the methodology presumed that the integration of GIS with MCDM using AHP. The result of pair-wise comparison matrix showed that eight of the major factors were compared one-to-one and scored. The most important limiting factors were slope, land use/ cover, depth, drainage, soil texture, river proximity, pH and cation exchange capacity with weight of influence of 33, 17, 14, 12, 10, 8, 4 and 2%, respectively.
- The area with low slope is highly suitable for surface irrigation whereas the area with highest slope which is cliff is not suitable for surface irrigation. The area with slope range 0-2% is classified as (S1) highly suitable 2-5% is moderately suitable (S2), 5-8% is marginally suitable (S3) and >8% is classified as not suitable (N).
- From the land cover/ use classes of the study area agricultural land was classified as highly suitable (S1) open areas and shrub/bush land were moderately suitable (S2), forest land was marginally suitable (S3) and water body was not suitable (N) for surface irrigation.
- Based on the suitability factors such as, slope, land cover land use and river proximity, slope was given more weight for weight overlay analysis than land use and cover and others.
- The weighting values of the eight parameters data sets using weighted overlay in ArcGIS10.8.1, the irrigation suitability maps were developed and 0.8 % (10,049 Ha) of the total area of the study was set up to be in the range of highly suitable (S1) for surface irrigation system with respect to all parameters. About 9.4 % (115370 Ha) was set

up to be in the range of moderately suitable (S2) for surface irrigation system, 2.3 % (28,474 Ha) was marginally suitable (S3) and the remaining 87.5 % (10,76713 Ha) of the total area of the study was set up to be in the range of not suitable(N) for surface irrigation system.

- The finding of this study indicates irrigation practice is at lowest level in the sub basin. There has not been evaluation of land for its potential for irrigation so that irrigation practice is not in a position to supplement rain fed agriculture. The most limiting factor in the sub basin is slope and land use land cover followed. In the sub basin sprinkler or drip irrigation should more favorable than surface irrigation due to topographic variation and land use land cover.

5.2. Recommendations

- Result of the irrigation suitability analysis indicated that, from the total area of the study, only small is highly suitable for surface irrigation. Thus, in order to increase the suitable irrigable land, leveling the land surface and making decision on some land cover change need consideration as an important investment for surface irrigation.
- Acidic soil environment ($pH < 5.5$) affects plant growth directly or indirectly by influencing the availability of plant nutrients. Lime or dolomite can be incorporated into the soil to neutralize and replace aluminum with calcium and magnesium.
- The results obtained showed that surface irrigation system is not more suitable for most of the study area. The major limiting factor in using surface irrigation methods in this area was slope and land use/cover.
- Slope of less than 8% is considered to be suitable for surface irrigation with minor adjustment to negotiate the natural slope. And slope ranges between 8-15%, with suitable soil type and limited constraints found to be irrigated with pumped-gravity surface method. Irrigable lands with rugged topographic feature and with moderate slope range are considered to be irrigated by sprinkler and micro irrigation.
- Also, the results of this study could be useful for other investigators who could use these results for different studies. Research in the future should further examine the suitability analysis taking further factors such as soil fertility and socio-profitable conditions into consideration. Fresh examinations can also be done to examine the factors that may determine the sustainable use of the land and farther compare the suitability results with the land use land cover conditions of the study area.

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ANNEX

1. Laboratory Result for Profile Pits Point Sampled

Field No.	X	Y	Depth	pH	EC	Texture	Soil type	Na	K	Ca	Mg	CEC	BS	TN	OM	AvP
GP_ 25	320419	931190	<25	6.2	0.030	SICL	Leptosols	0.05	0.83	31.98	17.25	57.9	87	0.22	4.45	14.48
GP_ 28	230819	845529	100-150	5.1	0.090	SICL	Luvisols	0.09	0.91	14.80	4.28	35.5	57	0.36	6.78	2.60
GP_ 29	265151	813511	50-100	5.1	0.114	SIL	Luvisols	0.06	2.05	15.72	8.12	42.7	61	0.36	6.88	8.58
GP_ 30	311764	836156	100-150	4.8	0.127	SIL	Alisols	0.60	0.17	14.78	3.05	41.7	45	0.59	11.04	7.72
GP_ 31	310698	840530	>150	4.7	0.205	SIL	Luvisols	0.06	0.68	14.60	7.80	37.8	61	0.26	4.87	3.28
GP_ 32	264920	819854	50-100	4.9	0.035	C	Luvisols	0.11	0.37	12.88	3.24	33.0	50	0.24	4.49	2.28
GP_ 33	225914	848299	<25	5.5	0.185	C	Leptosols	0.02	1.92	30.00	7.86	51.9	77	0.34	6.21	0.12
GP_ 34	310053	880880	>150	4.6	0.095	SICL	Luvisols	0.02	0.68	9.26	3.35	24.9	54	0.16	3.05	0.08
GP_ 35	265258	831681	>150	5.1	0.151	SICL	Luvisols	0.13	2.11	9.30	5.37	30.8	55	0.29	5.52	0.60
GP_ 36	264982	823198	50-100	5.0	0.065	SIL	Luvisols	0.05	0.39	19.12	4.13	41.5	57	0.36	6.81	8.90
GP_ 37	272870	820998	25-50	5.0	0.077	SIL	Luvisols	0.13	0.17	14.58	5.77	39.6	52	0.39	7.56	3.10
GP_ 38	263084	828586	>150	5.0	0.145	SIL	Luvisols	0.28	1.04	13.28	3.67	41.0	45	0.34	6.25	0.08

Field No.	X	Y	Depth	pH	EC	Texture	Soil type	Na	K	Ca	Mg	CEC	BS	TN	OM	AvP
GP_ 39	224044	828330	100-150	5.2	0.050	SICL	Luvisols	0.08	0.50	17.05	8.75	44.1	60	0.12	2.44	1.40
GP_ 40	221112	824260	<25	5.3	0.148	SIL	Leptosols	0.44	0.33	9.10	3.79	29.5	46	0.34	6.11	2.72
GP_ 41	315689	881039	100-150	5.1	0.088	SIL	Luvisols	0.01	0.49	12.45	8.08	39.1	54	0.28	5.66	0.80
GP_ 42	306760	836274	>150	5.3	0.124	SL	Luvisols	0.05	1.18	20.81	4.95	46.1	58	0.49	9.62	8.80
GP_ 43	270976	836060	>150	5.5	0.115	SIL	Luvisols	0.18	0.32	17.41	5.26	28.1	82	0.39	7.33	5.40
GP_ 44	296999	828816	50-100	5.2	0.113	SIL	Luvisols	0.03	0.50	14.96	6.94	29.7	75	0.22	4.19	0.96
GP_ 45	259446	840806	100-150	5.3	0.081	C	Luvisols	0.04	1.10	13.01	7.54	36.3	60	0.21	3.93	0.22
GP_ 46	296999	828816	50-100	5.0	0.047	SIL	Luvisols	0.08	0.37	22.86	3.66	45.3	60	0.46	8.54	0.16
GP_ 47	259446	840806	>150	5.6	0.039	SL	Luvisols	0.06	0.26	26.63	10.19	38.8	96	0.03	0.41	8.30
GP_ 48	313576	888055	<25	5.9	0.174	SIL	Leptosols	0.08	5.13	26.76	9.98	50.5	83	0.26	4.82	32.40
GP_ 49	295635	857956	<25	5.6	0.034	C	Leptosols	0.04	0.36	15.29	7.09	30.1	76	0.06	1.31	1.60
GP_ 50	204307	831104	100-150	5.4	0.106	SIL	Luvisols	0.06	3.73	23.05	7.31	39.4	87	0.36	6.87	6.62
GP_ 51	211608	838677	100-150	5.3	0.185	SICL	Luvisols	0.06	4.90	16.50	6.49	33.7	83	0.28	5.05	7.04
GP_ 52	209689	829638	>150	4.8	0.059	SIL	Lixisols	0.16	0.28	12.50	4.84	23.9	74	0.24	4.47	2.04
GP_ 53	282023	824232	>150	5.3	0.064	SICL	Luvisols	0.01	0.83	11.48	3.06	27.5	56	0.22	3.97	0.04
GP_ 54	321257	851027	50-100	6.2	0.191	SIL	Luvisols	0.04	3.95	22.46	7.74	37.4	92	0.20	3.59	50.00

Field No.	X	Y	Depth	pH	EC	Texture	Soil type	Na	K	Ca	Mg	CEC	BS	TN	OM	AvP
GP_ 55	322875	849367	<25	6.4	0.419	SIL	Leptosols	0.02	3.71	41.83	13.17	60.4	97	0.49	9.86	52.00
GP_ 56	261446	855710	100-150	5.2	0.034	SICL	Alisols	0.01	0.30	6.44	3.63	25.0	42	0.17	3.26	0.30
GP_ 58	268391	843109	>150	5.2	0.048	C	Lixisols	0.02	0.92	6.86	4.18	23.2	52	0.22	4.03	0.04
GP_ 59	282196	836918	>150	5.2	0.280	SICL	Luvisols	0.02	2.63	8.24	3.17	24.5	57	0.24	4.33	7.60
GP_ 60	290653	835119	>150	5.2	0.115	SIL	Alisols	0.13	1.37	12.22	3.39	35.0	49	0.28	5.26	1.32
GP_ 61	292995	824247	>150	4.8	0.193	SIL	Alisols	0.16	1.04	15.00	3.10	41.2	47	0.64	12.30	3.00
GP_ 62	247817	846701	>150	5.3	0.145	SICL	Luvisols	0.11	2.57	17.23	6.07	28.9	90	0.22	4.07	3.20
GP_ 63	244060	851159	>150	4.6	0.118	SICL	Luvisols	0.05	0.29	10.68	3.76	27.5	54	0.25	4.68	16.40
GP_ 64	222600	835170	100-150	4.9	0.141	SIL	Luvisols	0.11	1.14	22.99	8.86	47.5	70	0.28	5.04	19.20
GP_ 65	224074	840116	<25	5.3	0.218	SIL	Leptosols	0.07	3.23	32.68	8.67	47.1	95	0.32	6.02	9.00
GP_ 66	248678	836175	50-100	5.8	0.124	SIL	Luvisols	0.07	2.20	34.18	10.22	52.4	89	0.28	5.78	65.20
GP_ 67	247717	826614	>150	5.0	0.039	SIL	Luvisols	0.16	0.23	11.01	4.70	28.9	56	0.18	3.85	4.10
GP_ 69	266800	848850	50-100	4.8	0.037	SIL	Lixisols	0.09	0.65	8.53	3.57	21.8	59	0.26	4.81	0.02
GP_ 70	319544	866496	50-100	5.2	0.076	SICL	Luvisols	0.12	2.54	15.43	5.73	29.8	80	0.22	4.15	0.42
GP_ 71	216524	826876	100-150	5.5	0.145	SIL	Luvisols	0.52	0.36	29.13	9.25	47.1	83	0.28	6.05	20.92
GP_ 72	264740	853500	>150	5.1	0.056	SIL	Luvisols	0.09	0.87	15.27	4.12	27.2	75	0.25	4.78	1.00

Field No.	X	Y	Depth	pH	EC	Texture	Soil type	Na	K	Ca	Mg	CEC	BS	TN	OM	AvP
GP_ 73	271286	847562	>150	4.9	0.054	SCL	Alisols	0.09	0.33	8.35	3.16	28.7	42	0.26	4.80	0.08
GP_ 74	323531	872177	>150	6.4	0.078	SICL	Luvisols	0.07	2.54	14.87	6.01	33.5	70	0.18	3.38	4.60
GP_ 75	276419	850029	>150	4.9	0.261	SICL	Lixisols	0.09	1.34	11.44	4.73	20.2	87	0.20	4.45	1.40
GP_ 76	324388	875609	100-150	5.1	0.039	SICL	Luvisols	0.09	0.93	13.59	5.16	30.0	66	0.24	4.52	0.02
GP_ 77	329148	889154	100-150	4.4	0.048	SICL	Alisols	0.17	0.16	6.97	6.61	32.6	43	0.28	5.24	0.36
GP_ 78	332273	899677	>150	4.5	0.094	C	Luvisols	0.21	0.35	23.80	12.62	49.7	74	0.10	1.64	6.02
GP_ 79	342777	904371	<25	4.5	0.067	SICL	Leptosols	0.13	0.75	15.69	7.90	41.1	60	0.36	6.16	0.28
GP_ 80	341380	908395	<25	4.8	0.110	C	Leptosols	0.30	0.46	29.62	14.16	57.4	78	0.28	5.32	2.40
GP_ 81	329674	892477	25-50	4.5	0.071	SICL	Luvisols	0.10	0.45	11.02	8.49	34.0	59	0.24	5.16	6.36
GP_ 82	332945	899844	<25	5.0	0.169	SIL	Leptosols	0.11	1.32	27.74	8.57	48.4	78	0.44	7.91	2.24
GP_ 83	338675	890671	<25	4.4	0.059	C	Leptosols	0.12	0.78	7.54	5.37	27.7	50	0.19	3.15	0.32
GP_ 84	330191	903969	>150	5.5	0.172	C	Luvisols	0.17	1.04	41.21	12.68	65.8	84	0.18	2.78	0.36
GP_ 85	190940	842260	<25	4.4	0.106	C	Leptosols	0.09	0.48	7.91	4.69	25.5	52	0.14	2.03	0.30
GP_ 86	195998	847620	100-150	4.4	0.119	SICL	Alisols	0.10	0.58	9.75	6.12	34.4	48	0.34	5.66	0.14
GP_ 87	221536	857500	100-150	4.5	0.198	SICL	Alisols	0.09	0.58	9.90	5.48	34.6	46	0.38	5.90	3.18
GP_ 88	204338	859518	>150	4.0	0.043	SIL	Alisols	0.13	0.22	19.15	6.31	55.5	47	0.39	7.25	2.52
GP_ 90	222380	855690	<25	4.0	0.044	SIL	Leptosols	0.12	0.10	7.71	3.12	22.0	50	0.33	5.47	0.10

Field No.	X	Y	Depth	pH	EC	Texture	Soil type	Na	K	Ca	Mg	CEC	BS	TN	OM	AvP
GP_ 91	290064	907052	<25	4.5	0.072	C	Leptosols	0.05	0.67	12.97	7.99	26.4	82	0.18	3.28	0.14
GP_ 92	295858	919898	>150	4.0	0.062	SICL	Lixisols	0.05	0.15	8.37	4.41	19.1	68	0.28	5.26	0.64
GP_ 93	303347	917268	<25	4.5	0.115	SIL	Leptosols	0.06	1.10	10.41	9.00	25.1	82	0.34	6.25	0.08
GP_ 94	313327	944075	50-100	4.6	0.101	SICL	Luvisols	0.08	2.30	15.34	10.34	30.3	93	0.26	4.67	9.42
GP_ 95	280452	902101	100-150	4.2	0.041	SCL	Luvisols	0.05	0.41	8.69	6.03	28.3	54	0.34	5.56	0.08
GP_ 96	304743	925054	100-150	4.1	0.032	C	Luvisols	0.04	0.51	7.31	5.69	26.3	52	0.19	3.05	0.04
GP_ 97	271914	903148	100-150	5.0	0.103	SICL	Lixisols	0.03	1.37	10.39	5.66	21.1	83	0.10	2.01	63.78
GP_ 98	282788	929484	<25	4.9	0.074	SICL	Leptosols	0.04	0.79	10.10	4.86	17.4	91	0.28	5.30	0.00
GP_ 99	287592	915158	>150	4.5	0.038	SICL	Lixisols	0.06	0.27	5.17	4.62	17.4	58	0.27	5.28	0.54
GP_ 100	304170	943737	>150	4.6	0.066	SICL	Lixisols	0.04	1.29	7.13	5.93	16.5	87	0.28	4.41	0.26
GP_ 117	295154	963878	>150	4.7	0.095	C	Luvisols	0.39	0.63	18.00	8.53	34.0	81	0.18	2.86	0.06
GP_ 130	289950	964592	<25	5.1	0.119	SIL	Leptosols	0.12	0.96	14.88	6.40	39.3	57	0.42	8.90	0.06
GP_ 157	260026	834493	>150	5.7	0.18	SIL	Alisols	1.31	0.90	3.25	1.80	34.6	21	0.23	4.65	21.16
GP_ 158	262019	838011	>150	4.6	0.06	SIL	Acrisols	0.65	1.02	2.10	0.71	23.0	19	0.25	4.61	0.00
GP_ 159	261421	842575	<25	4.5	0.09	SIL	Leptosols	0.22	0.13	2.32	3.94	26.7	25	0.28	5.50	5.98

Field No.	X	Y	Depth	pH	EC	Texture	Soil type	Na	K	Ca	Mg	CEC	BS	TN	OM	AvP
GP_ 160	251980	847082	>150	4.6	0.08	SIL	Alisols	0.44	0.26	4.62	1.71	29.4	24	0.22	4.43	0.00
GP_ 161	243260	837634	100-150	4.8	0.14	SICL	Alisols	0.65	0.13	1.63	2.86	36.2	15	0.18	3.29	0.00
GP_ 162	210586	823566	>150	5.5	0.16	SICL	Alisols	0.44	0.38	3.48	6.86	56.1	20	0.28	4.74	0.00
GP_ 163	301314	885206	100-150	5.4	0.04	SIL	Luvisols	0.22	0.90	10.30	6.86	34.6	53	0.24	3.94	0.00
GP_ 164	301657	879553	>150	4.5	0.09	C	Alisols	0.44	0.38	2.03	1.44	29.5	15	0.23	3.56	0.00
GP_ 165	295055	854398	>150	5.2	0.21	SIL	Luvisols	0.00	0.26	14.36	3.36	28.8	63	0.24	4.63	6.20
GP_ 166	206087	859758	100-150	5.3	0.07	SIL	Luvisols	0.00	0.40	14.41	2.62	30.8	57	0.30	5.77	0.78
GP_ 167	202766	859394	>150	4.8	0.12	SICL	Luvisols	0.00	2.18	16.01	4.34	35.9	63	0.35	6.11	0.56
GP_ 168	288488	851035	>150	5.6	0.08	C	Luvisols	0.44	0.54	20.40	5.26	38.8	69	0.16	3.14	0.16
GP_ 169	309089	869680	>150	5.6	0.07	C	Luvisols	0.00	0.09	15.41	7.47	40.8	56	0.18	3.42	0.10
GP_ 170	271118	831382	>150	4.7	0.11	SICL	Luvisols	0.22	0.99	9.98	2.12	25.4	52	0.20	3.70	1.14
GP_ 171	283654	828796	>150	5.2	0.15	C	Luvisols	0.00	0.14	17.47	2.86	32.0	64	0.28	4.90	1.10
GP_ 172	255891	854670	>150	4.6	0.10	C	Luvisols	0.00	1.11	16.27	2.65	29.0	69	0.23	4.09	0.24
GP_ 173	304124	851233	>150	5.6	0.122	SICL	Luvisols	0.05	0.77	10.36	2.17	25.1	53	0.27	4.92	1.18
GP_ 174	285860	860436	>150	4.6	0.040	C	Luvisols	0.08	0.77	15.10	2.14	28.6	63	0.23	3.89	3.32

Field No.	X	Y	Depth	pH	EC	Texture	Soil type	Na	K	Ca	Mg	CEC	BS	TN	OM	AvP
GP_ 175	272399	856454	>150	4.7	0.128	C	Alisols	0.03	1.66	11.61	2.73	32.5	49	0.28	4.76	1.64
GP_ 176	341226	907422	<25	6.0	0.253	C	Leptosols	0.06	1.79	31.57	7.15	55.6	73	0.14	2.44	9.72
GP_ 177	303557	841299	>150	4.7	0.063	SICL	Acrisols	0.03	0.26	8.02	1.07	19.3	49	0.18	3.05	3.28
GP_ 178	330242	894217	>150	4.5	0.055	C	Acrisols	0.05	0.26	7.96	1.53	22.0	45	0.26	4.41	1.02
GP_ 179	315966	856790	>150	4.9	0.085	C	Luvisols	0.08	0.51	14.00	3.18	28.0	64	0.09	1.20	0.04
GP_ 180	314242	856649	>150	5.2	0.084	C	Alisols	0.18	0.90	10.96	2.60	34.0	43	0.21	3.43	0.88
GP_ 181	311698	839661	>150	5.7	0.18	SIL	Alisols	1.31	0.90	3.25	1.80	34.6	21	0.23	4.65	21.16
GP_ 182	320926	856942	>150	4.6	0.06	SIL	Acrisols	0.65	1.02	2.10	0.71	23.0	19	0.25	4.61	0.00
GP_ 183	316924	870022	>150	4.5	0.09	SIL	Alisols	0.22	0.13	2.32	3.94	26.7	25	0.28	5.50	5.98
GP_ 184	302554	862812	>150	4.6	0.08	SIL	Alisols	0.44	0.26	4.62	1.71	29.4	24	0.22	4.43	0.00
GP_ 186	317428	905725	100-150	6.1	0.053	SICL	Luvisols	0.15	0.56	31.69	6.68	43.4	90	0.13	2.51	8.20
GP_ 187	315575	911748	100-150	6.0	0.028	C	Luvisols	0.01	0.97	11.58	4.02	26.9	62	0.15	2.89	1.42
GP_ 214	271770	885824	>150	5.7	0.074	SIL	Luvisols	0.05	0.27	9.41	8.84	31.1	60	0.145	3.891	1.12
GP_ 215	274572	887452	>150	5.2	0.031	SIL	Luvisols	0.10	0.49	10.41	4.91	28.9	55	0.150	4.513	5.52
GP_ 216	295167	923891	>150	4.8	0.050	C	Acrisols	0.01	0.14	7.41	3.05	23.3	46	0.207	2.852	1.36

Field No.	X	Y	Depth	pH	EC	Texture	Soil type	Na	K	Ca	Mg	CEC	BS	TN	OM	AvP
GP_ 217	286414	911959	>150	4.8	0.077	SICL	Acrisols	0.03	0.20	6.21	3.03	20.0	47	0.131	2.203	1.10
GP_ 218	270656	895240	>150	4.6	0.183	SIL	Luvisols	0.02	0.16	6.41	5.77	24.1	51	0.378	7.847	7.36
GP_ 219	283155	912215	>150	4.8	0.053	C	Alisols	0.01	0.23	7.41	5.94	29.1	47	0.419	8.665	3.30
GP_ 220	276376	919294	>150	5.4	0.063	SICL	Luvisols	0.01	2.67	7.18	4.60	28.8	50	0.120	2.673	1.92
GP_ 221	278705	923191	>150	4.7	0.061	C	Luvisols	0.02	1.18	6.98	4.10	24.5	50	0.177	3.810	1.80
GP_ 222	289927	945124	>150	5.5	0.084	C	Luvisols	0.03	4.66	8.98	5.65	32.3	60	0.212	4.511	1.40