Land capability, Irrigation Potential and crop suitability analysis using GIS and Remote Sensing in Upper Kesem (Awash Basin)

Dissertation submitted for Partial Fulfillment of the Requirements for the Award of the Degree of

MASTER OF SCIENCE

In
Remote Sensing and Geographical Information Systems (GIS) of Addis Ababa University, Addis Ababa, Ethiopia

By

SLEHAK MELAK

Under the guidance of

Dr. K.V. Suryabhagavan
Lecturer, Department of Earth Sciences.
Addis Ababa University, Addis Ababa

Department of Earth Sciences
Faculty of Science
Addis Ababa University, Addis Ababa – 1176

JULY 2007

Land capability, Irrigation Potential and crop suitability analysis using GIS and Remote Sensing in Upper Kesem (Awash Basin)

Dissertation submitted for Partial Fulfillment of the Requirements for the Award of the Degree of

MASTER OF SCIENCE

In

Remote Sensing and Geographical Information Systems (GIS) of Addis Ababa University, Addis Ababa, Ethiopia

By

SLEHAK MELAK

JULY 2007

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Land capability, Irrigation Potential and crop suitability analysis using GIS and Remote Sensing in Upper Kesem (Awash Basin)

By

SLEHAK MELAK

Faculty of Natural Science
Department of Earth Sciences
Remote Sensing and GIS

Approval By Board of Examiners

Dr. Balemwal Atnafu ______________________________
Chairman, Department
Graduate Committee

Dr. K.V. Suryabhagavan ______________________________
Advisor

Dr. Dagnachew Legesse ______________________________
Examiner

Dr. Mohammed Umer ______________________________
Examiner

Table of content

LIST OF FIGURE

LIST OF TABLE

LIST OF ABBREVIATIONS

AHP: Analytic Hierarchy Process
FAO: Food and Agriculture Organization
GIS: Geographic Information System
GPS: Global Positioning System
LUT: Land Use Types
MCDM: Multi-Criteria Decision Making
MCE: Multi Criteria Evaluation
MOA: Ministry Of Agriculture
PCM: Pairwise Comparison Matrix
PC: Pairwise Comparison

ACKNOWLEDGMENT

First and for most, I greatly thank the Almighty God, master of this world, for giving me the endurance and power for completion of this thesis with foreseen and unforeseen problems which I faced during the thesis period.

I express my deep sense of gratitude and indebtedness to my Project guide Dr. K. V. Suryabhagavan, Lecturer, Department of Earth sciences, Addis Ababa University, Addis Ababa for his guidance and valuable suggestions during the research work.

I am also greatly indebted to Dr.Arraya, Dean, Faculty of Science, and Addis Ababa University for his generosity in extending facilities to me to submit this project. I would like also to thank the staff of Earth Sciences Department of Addis Ababa University who helped me in various ways, especially, the Department head, Dr. Balemual Atnafu, who assisted me when I need and Dr. Dagnachew Legesse, the department advisor, who helped me to use the computer laboratory and materials at any time. My warmest gratitude also goes to Dr. Seid Ali and Dr. K.S.R. Murthy who thought me Remote sensing and GIS subjects.

My heartfelt thanks to **“my dear parents and family members”** for their love, affection, advice, suggestions, consoling talks overseas and so on. Especially my father Melak Semeneh and my mother Almaz Ayele, who give me permission and financial support to continue my post graduate study.

Special thanks go to my lovely girl friend, Simmenesh Reta (Honey), who has been the source of my strength and motivation. She gave her advice, love and care. I would also like to extend this special thanks to my brothers (Mulualem, Belayneh and Abu) who gave me all the encouragement to accomplish my study.

Finally, the completion of this thesis was made possible with direct and indirect contribution of several people, which is not possible to mention every one, but all of them deserve my gratitude.

ABSTRACT

Land Capability, Irrigation potential and Land suitability analysis is a prerequisite for sustainable agricultural production. Land Capability (Classification) evaluates parameters like slope, soil depth, past erosion, waterlogging, infiltration, soil texture and stoniness of the study area. GIS and remote sensing are a tool to evaluate the above parameters and leads to a conclusion that 60 % of the study area well matched to annual crop production. Multicriteria decision-making techniques like ranking, rating etc. are employed for the analysis that includes pairwise combination and weighted linear combination.

The parameters used for suitability analysis for surface irrigation are slope, soil drainage, soil depth, texture, waterlogging, land use and soil type. After evaluating the physical land capability for surface irrigation, irrigation suitability map was developed. This map was classified in to five suitability classes based on FAO guideline. The result shows that 93.87 sq km (18%) very suitable, 85.63 sq km (17 %) suitable, 176.93(34 %) marginally suitable, 126.13sq km (25 %) marginally not suitable and 33.20 sq km (6 %) permanently not suitable.

Land suitability analysis for specific crops especially Teff and Wheat was also done using Temperature and Rain fall amount of the study area in addition to the factors mentioned above that are used for surface irrigation evaluation. Suitability maps for both Teff and Wheat were also developed. The suitability map for each crop was classified in to five suitability classes. Regarding Teff 84.32 sq km (16 %) very suitable, 86.50(17%) suitable, 168.95 sq km (33%) marginally suitable, 107.34 sq km (21 %) marginally not suitable and 68.65 sq km (13 %) permanently not suitable for the study area. Suitability classes for Wheat were 73.50 sq km (14%) very suitable, 96.71 sq km (19 %) suitable, 118.93 sq km (23%) marginally suitable, 106.60 sq km (21%) marginally not suitable and 120.02 (23%) permanently not suitable.

Keywords: Land Capability; MCDM; Land suitability; surface irrigation; annual crop

CHAPTER I

1. INTRODUCTION

1.1. Background and Justification

Agriculture, being the most primitive occupation of the civilized man, draws much on its development starting from shifting cultivation to advanced precision farming. With the advancement in the civilization man came to know about more crops and started to cultivate many crops. Population increase and advancement in the civilization made man to settle at one place and to cultivate the same area year after year. Now agriculture became a profession is given the name commercial agriculture, and precision agriculture and sustainable agriculture as being the part of it.

Nowadays, the population of the planet is growing dramatically. In order to meet the increasing demand for the food the farming community has to produce more and more. Under present situations, where the land is a limiting factor, it is impossible to bring more area under cultivation (extensive farming), so farming community should tackle this challenge of producing more and more food with the available land only (intensive farming). On the contrary, the increasing global concern towards the health of mankind and environment protests the use of higher amount of pesticides and fertilizers, genetically manipulated plants etc. However, latter are the current technologies having the potentiality to increase the food production. To overcome this concern the farming community has to produce more and more, high quality food using eco-friendly practices. This need for eco-friendly practices have paved the way for the concepts like precision farming, sustainable farming, organic farming etc. Higher productivity, profitability and health of mankind as well as environment are the concerns of the present agriculture. Hence much attention is shifted on selection of a crop, which suits an area the best.

This suitability is a function of crop requirements and soil/land characteristics. Matching the land characteristics with the crop requirements gives the suitability.
So, 'Suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use.′ (FAO).

To study irrigation potential for a country, water, soil and plant are most important things to be considered. However, different factors like investment, technology and political choices are also necessary (FAO, 1995). The area that can potentially be irrigated depends on the physical resources, soil and water, combined with the irrigation water requirements as determined by the cropping patterns and climate (FAO, 2003).

Global estimates indicate that irrigated agriculture produces nearly 40 % of food and agriculture commodities on 17% of agricultural land. At present in Africa, about 12.2 million hectares benefit from irrigation, which is equal to only about 8.5% of the cultivated land. FAO also stated that in sub-Saharan Africa, only about 10% of the agricultural production comes from irrigated land. Trends in irrigated land expansion over the last 30 years show that, on average, irrigation in Africa increased at a rate of 1.2% per year. However, this rate began to fall in the mid-1980s and is now below 1% per year, but varies widely from country to country (FAO, 2003).

Physical characteristics of the land of the study area were given more emphasis to evaluate the irrigation potential, Land capability and crop suitability of the Upper Kesem.To enable careful planning of the development of the water resources, especially for agriculture a good knowledge of the irrigation potential for the country is necessary. However, environmental and socioeconomic constraints also have to be taken into consideration in order to guarantee a sustainable use of the available physical resources. There are different types of irrigation (sprinkler, dip, surface etc). But this study may focus on the evaluation of performance of surface (gravity) irrigation, Land capability and crop suitability analysis in the study area.

1.2 Objectives

❖ General objective:

- To evaluate the Land physical characteristics and its quality of the study area for land capability, suitability of surface irrigation potential and crops using multi-criteria decision evolution (MCDE) method.

❖ Specific Objectives:

- To develop Land Capability (Classification) Map.
- To develop physical land suitability map for irrigation of the Upper Kesem.
- To develop Teff suitability map of the study area.
- To develop Wheat suitability map of the study area.

1.3 Significance of the study

Land capability is the most important thing to be done for every place in order to make the area more profitable. About 85 % of the Ethiopian people are highly dependent on rain fed agriculture with small amount of land. As a result production of crops does not much with the growth of population of the country. So capability of the land should be studied in order to make the fragmented land more profitable. Specific crop and irrigation suitability analysis study also important for the country to have sustainable agriculture this is because many people in Ethiopia suffer from drought and famine from year to year due to shortage of rain. Rainfall distribution in Ethiopia is also seasonal and variable and suffers from the most unstable rainfall regime. Irrigation is used on full season agronomic crops to provide a reliable yield every year. It is also used on crops where water stress affects the quality of the yield. Generally this study becomes viable due to the above facts.

2. LITERATURE REVIEW

2.1 Crop-Land suitability and Precision Farming

Precision farming aims to optimise the use of soil resources and external inputs (fertilizers and herbicides) on a site-specific basis. Precision farming involves the use of most advanced technologies like GPS, GIS, Remote Sensing and VRT (Variable Rate Technologies). Such systems are designed to monitor, analyse and control plant production with the aim to optimise expenses and ecological effects and to increase the income. To fulfil such contrasting aims the first prerequisite is to select the best suitable crop for the area. The land suitability analysis will best suffice such a basic need.

2.1.1 Land Suitability and Capability Analysis

Land suitability is the ability of a given type of land to support a defined use while Land capability is the ability of a given natural land to perform as it is. For example the capability of the land may be to be forest area but the land may be suitable for annual crops. The process of land suitability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use. The main objective of the land evaluation is the prediction of the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, in order to minimize the socio-economic and environmental costs.

Land suitability analysis is an interdisciplinary approach by including the information from different domains like soil science, crop science, meteorology, social science, economics and management. Being interdisciplinary, land suitability analysis deals with information, which is measured in different scales like ordinal, nominal, ratio scale etc.

Based on the scope of suitability there are two types of classifications in FAO framework.

- **Current suitability**: refers to the suitability for a defined use of land in its present condition, without any major improvements in it.

- **Potential suitability**: for a defined use, of land units in their condition at some future date, after specified major improvements have been completed where necessary.

2.2 Definition of irrigation potential

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

2.2.1 Irrigation potential in Ethiopia

The Ethiopian plateau is the source of the Abay, Awash, Tekeze, Mereb, Baro, Akobo and Omo rivers that flow to the west and southwest. The Baro/Akobo basin has potentially the largest possible irrigable area (~489,000 ha) although negligible area has been developed in Awash River basin. The Rift valley is the only river basin that is extensively used for commercial plantations with industrial and horticultural crops. From the total irrigated land of about 161,125 hectares, over 43 % is found in the Awash River basin. The remaining potential for irrigated agriculture using Awash River is estimated at 136,220 hectares (World Bank, 1993)

According to recent Minister of Water Resource data (cited in MEDAC 1999: 484-85), some 30 large and medium-scale irrigation projects with a combined command area of over 600,000 hectares have been identified in various parts of the country for development by the state since the 1980s. Of these, about 15 percent have already been completed. The largest water project to be constructed since the 1970s is the Alwero dam in the Gambella region, which has an irrigation potential of over 10,000 hectares, but which remains unutilised two years after completion.

The surface drainage systems need a design that combines erosion control and water conservation functions. In addition, new subsurface drainage systems are needed on irrigated areas where water logging and salinity already occur.

2.3 Role of GIS and Remote Sensing

GIS is the tool for input, storage and retrieval, manipulation and analysis, and out put of spatial data (Marble et al. 1984). GIS functionality can play a major role in spatial decision-making. Considerable effort is involved in information collection for the suitability analysis for crop production. This information should present both opportunities and constraints for the decision maker (Ghafari et al. 2000). GIS have the ability to perform numerous tasks utilizing both spatial and attribute data stored in it. It has the ability to integrate variety of geographic technologies like GPS, Remote Sensing etc. The ultimate aim of GIS is to provide support for spatial decisions making process (Foote and Lynch 1996). In multi-criteria evaluation many data layers are to be handled in order to arrive at the suitability, which can be achieved conveniently using GIS.

Remote sensing provides the information about the various spatial criteria/factors under consideration. Remote sensing can provide us the information like land use/cover, drainage density, topography etc. Many of the non-spatial parameters can also be inferred by looking at the various spatial parameters. Remote sensing in combination with GIS will be a powerful tool to integrate and interpret real word situation in most realistic and transparent way. Research by Leingsakul et al. (1993) shown that integrated GIS and Remote Sensing technology apart from saving time and yielding good data quality have the ability to locate potential new cropland sites.

Based on the scale of measurement of the suitability there are two types of classifications in FAO framework

- **Qualitative*:*** the classes are evaluated based on physical production potential of the land, commonly employed in reconnaissance studies. It is used to evaluate environmental, social and economical criteria.

- **Quantitative:** the classes are defined in common numerical terms; where comparison between the objectives is possible. Here considerable amount of economic criteria are used.

Quantified land evaluation (Beek et al. 1987) made an evolution in land suitability evaluation by introducing quantification of the indicators of land suitability over an entire area. The area is divided into small grid cells and made an initiation of cell based modelling. However, the Indicators must be quantifiable. In such land suitability analysis geographical information systems and geostatistical techniques are widely used.

2.4 Multi-Criteria Decision Making (MCDM)

Agricultural crop suitability involves integration information from various streams of science. There are many criteria upon which land suitability depends. The suitability analysis evaluates many alternative land use types under the light of various criteria from various streams. Alternatives here are competing with one another; criteria are both qualitative and quantitative. Decisions have to be taken at various levels starting from selecting the LUTs till the allocation of the LUTs for area that suit best. So the suitability analysis is a multiple criteria decision-making process.

Earlier, the multi-criteria land suitability was assessed more non-spatially, assuming the spatial homogeneity over the area under consideration. This, however, is unrealistic in cases like land suitability studies, where decisions are made using criteria which vary across in space (Malczewski 1999). Non-spatial conventional MCDM techniques average or total the impacts that are judged appropriate for the whole area under consideration (Tkach and Simonovic 1997). To address the spatial decision making, MCE and GIS can be integrated (Jankowski 1995). MCE seems to be applicable in GIS-based land suitability analysis (Pereira and Duckstein 1993) for different crops.

Widely used MCE methods in the land Capability and suitability analysis are ranking and rating. These methods lack theoretical foundation in deciding the weights.

These methods assign the weights rather arbitrarily. They don't take comparison among the criteria and classes into considerations. Moreover, the outcomes of such analysis are aggregated using simple Boolean overlay or weighted aggregation. Both the methods are supposed to yield similar results, which they never do. The reason is being with the logic of aggregation. The Boolean method of characterising the criteria is too *black and white*. *Boolean intersection* (AND) results in a very strict output, i.e. if it fails to fulfil single criteria a region will be excluded from the results (Black). In contrast, *Boolean union* (OR) will include an area in the result if that area fulfils a single criteria (White). Where as in the weighted linear combination the higher score of the rest can compensate low score on one criterion (Jiang and Eastman 2000). These ranking and rating methods are criticized for not reflect the decision maker's views clearly and also for not having any rationale behind the approach.

Ceballos-Silva and Lopez-Blanco (2003), used matrix pair wise comparison for land suitability. This method overcomes the problem of determining the weights. But they have not taken into consideration the hierarchical organisation of the criteria, which is the basic principle of Analytical Hierarchy Process (AHP). Hence it shows that they have just used the matrix pair wise comparison as a tool to derive weights. AHP is a widely used method in decision-making and is introduced by Saaty (Saaty 1977; Saaty and Vargas 2001). It is developed to select the best from a number of alternatives with respect to several criteria. AHP allows for both the inconsistency in the decision and provide the means to improve the consistency. Here the decision maker or the user will perform simple Pairwise Comparison i.e. he/she will compare two elements at a time. The values of the Pairwise Comparison are determined according to the scale introduced by Saaty. The available values for the comparison are the member of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}, 9 representing absolute importance and 1/9 the absolute triviality (Saaty 1980; Triantaphyllou and Mann 1994). The AHP gained high popularity because of easiness in obtaining the weights and capacity to integrate heterogeneous data, and therefore AHP is applied in a wide variety of decision problems. The AHP is criticised by (Belton and Gear 1983; Dyer 1990; Triantaphyllou 2001) despite of its popularity. They focused mainly on four principal areas of AHP,

the axiomatic foundation, the correct meaning of the priorities, the 1-9 measurement scale and the rank reversal (Mikhailov 2003). Mikhailov (2003) quote from (Lai 1995) that most of the problems are almost resolved at least for three level hierarchic structures.
MCDM methods deal with real world problems that are multi dimensional in nature. When it comes to environmental issue the methods have to deal with heterogeneous criteria that are both qualitative and quantitative in nature. In order to incorporate heterogeneous information with different measurement scales, one has to bring them into a common domain of measurement. This process is called *Standardization*, a basic operation in MCE. Criteria should be standardized keeping in mind the goal and alternatives that are under evaluation. Standardization can change the outputs entirely if proper attention is not paid. For environmental criteria, there is a lack of valid and reliable standardization processes.

Decision-making is a subjective process, as the perception regarding a problem can diverge from person to person. One cannot expect a decision maker or an expert to be highly consistent while dealing with such a subjective process. The real world problems are influenced by many natural factors and processes, which are difficult to measure and model precisely. The decision situations are surrounded by uncertainty. *Sensitivity Analysis* is a way to address this uncertainty in estimating the parameters (Malczewski 1999). After the problem is evaluated for optimum conditions, sensitivity analysis assesses different conditions near the optimum values to check for the sensitivity of the criteria. Many decision-making methods lack a valid approach towards sensitivity analysis. Sensitivity analysis also aids in understanding the interaction between the criteria, dominant criterion and its effect, i.e. the variation in the final results when the weight of that criterion is varied. Triantaphyllou and Sanchez (1997) reviews the research on sensitivity analysis and present a sensitivity analysis procedure in AHP, Weighted Product Model (WPM) and Weighted Sum Model (WSM). They state it as a complementary procedure that can be carried out together with the AHP method proposed by (Masuda 1990). This AHP method considers only the multiple levels of hierarchies, i.e. it considers only the single vector at a time and not the individual judgements.

CHAPTRE - II

2. GENERAL OVERVIEW OF THE STUDY AREA

2.1 Study Area Description

Upper Kesem Watershed lies in the Western Highland portion of the Awash River Basin. The location of the Watershed is shown in FIG (2.1) and it is located between 9^0 03'N- $9^0$17'N latitude and $38^0$59'E- $39^0$19'E longitude. The area of the sub-catchment is 64,606ha and administratively it falls in three woredas namely Aleltu (North Shewa Zone of Oromiya Zone), Gimbichu (East Shewa Zone of Oromiya Zone) and Hagere Mariam Woreda (North Shewa Zone of Amhara Region).

The towns in the sub-catchment are Aleltu, Beke, Koremash and Sendafa, though Chefe Donsa, which is outside the catchment, is the nearest town of any major importance.

TABLE 2.1: WOREDA AREAS WITHIN UPPER KESEM WATERSHED

Woredas	Estimated % of the Watershed in the Woreda	Estimated % of the Watershed from Woreda Area
Aleltu	45.7	26.7
Gimbichu	42.9	25.1
Hagere Mariam	11.4	6.7
Total		58.5

Note: Estimates based on the area of the watershed and the area of the woreda.

2.2 Climate and Watershed Characteristics

The Upper Kesem watershed is characterised by a moist climatic zone, with considerable annual rainfall. The topography is undulating high plateau in the upper part of the watershed and deep dissected gorges in the lower portion. The elevation ranges from 1500m (at the Upper Kesem River) to 2800m (near Fiche Gelila). The watershed lies in the Moist Deg*a* and Woina-Dega agro-climatic zones. The main tributary of the watershed is the Germama, which further downstream becomes the Kesem River .The main tributaries include the Inkoy, Senga Bele, Mikawa, Kumte, Defo Bar and Beke. Four meteorological stations that are found inside and around the study area i.e. Aleltu, Chefedonsa, Sendafa and Upper kesem are used to analyse both temperature and rain fall data. Ten years metrological data (from 1995 up to 2005) was obtained from National Meteorological Service to make spatial distribution of temperature and rainfall.

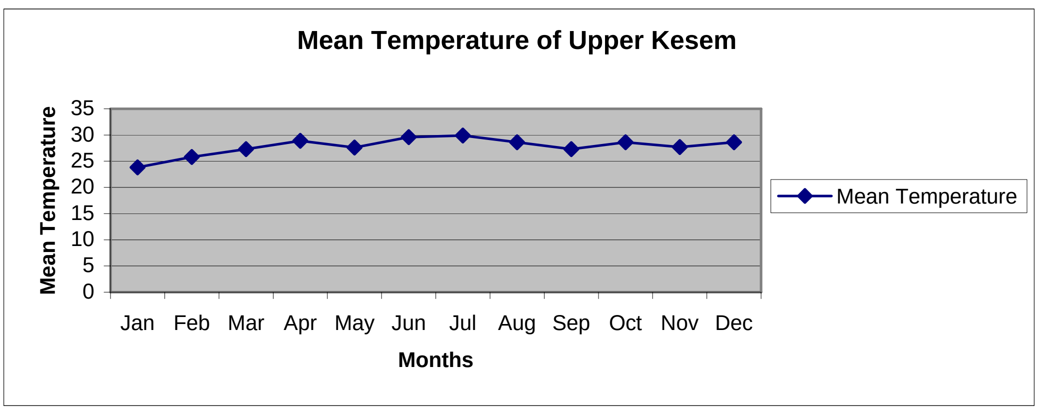


Fig 2.1 MEAN ANNUAL TEMPERATURE OF THE UPPER KESEM

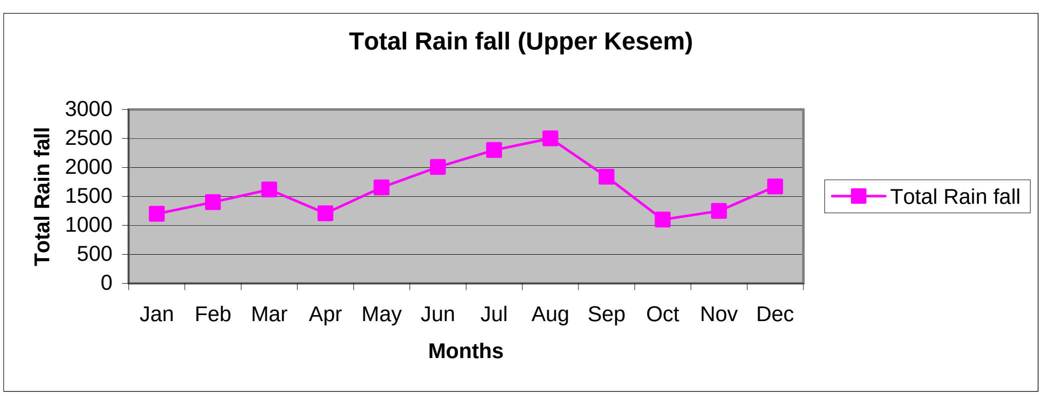


FIG 2.2 TOTAL ANNUAL RAIN FALL OF THE UPPER KESEM

2.3 Woreda Profiles

Aleltu Woreda

Aleltu Woreda is a newly designated woreda, which used to be part of Berehna Aleltu. It is one of 12 woredas of the North Shewa Zone and the capital is Aleltu, which is located at about 55km north of Addis Ababa. The woreda has an area of about 58,800ha and is bounded by Amhara Region to the north and east, Gimbichu Woreda to the south and Bereh Woreda in the west. Administratively the woreda is divided into 19 rural kebeles and 1 urban kebele.

Gimbichu Woreda

Gimbichu woreda is also in East Shewa Zone and the capital, Chefe Donsa, is located at about 32km north of Debre Zeyit. The woreda has an area of 75,071ha and is bordered to the north by North Shewa Zone, to the south by Adaa Liben and Lume Woredas, Amhara Region in the east and North Shewa Zone and Akaki Woreda to the West. The woreda is divided into 33 rural kebeles and 1 urban kebele.

2.4 Land Use

Land use data from the woredas given in Table 2.2 shows the extensive areas of arable land in both Aleltu and Gimbichu and high potential for livestock production in Aleltu. According to FAO the study area has four types of surface form i.e. Deperation, undulating, steep, rolling and also it has four types of landscape i.e. hills, plateaus, valleys and piedmont plain. The study area also dominantly covered by cultivated lands with some bush land, grass land and forest area.

TABLE 2.2: LAND USE IN THE WOREDAS (2005)

Woreda	Cultivated Land %	Grazing Land %	Forest and Bushes%	Unused Land %	Village and Others %	Total Area (ha)
Aleltu	51.3	15.6	5.3	9.2	18.6	58,800
Gimbichu	65.1	5.5	2	24.4	3	75,071

Source: Woreda agriculture and rural development offices

2.5 Population and Ethnic Composition

The total population of Aleltu and Gimbichu woredas is shown in Table 2.3 and is based on data collected from Rural Development and Agricultural Offices. The population density of Aleltu and Gimbichu is 123 and 98 persons per km^2 respectively.

The people of Aleltu and Gimbichu Woredas mainly belong to the Oromo ethnic group (approximately 90%) and in the small part of Hagere Mariam Woreda that lies within the sub-catchment the Amhara ethnic group is estimated to make up 95% of the population.

Woreda	Woreda Population	Woreda Area (km^2)	Population Density (Persons/ km^2)	Proportion of the Watershed (%)	Area in Watershed (km^2)	Estimated Population in the Watershed
Aleltu	72,310	588	123	45.7	267.1	12,207
Gimbichu	73,219	751	98	42.9	250.7	10,757

Table 2.3: Population and Population Density in Upper Kesem watersheds

2.6 CROP PRODUCTION

2.6.1 Crop Type and Production

The major crops produced in the watershed are cereals (teff, wheat, and barley), pulses (lentil, faba bean, chick pea, vetch and pea), oil seeds (linseed) and vegetables (garlic, onion, green pepper, potato). Lentil is produced and semi-processed for market on a reasonably large scale around Beke and provides a valuable cash crop for the study area.

Based on the information collected from Woreda Agriculture and Rural Development offices, wheat, teff and lentil are the most important crops in terms of area coverage, production per hectare and market demand, followed by faba bean; chick pea, vetch and pea (see Table 2.4)

TABLE 2.4: CROP PRODUCTION OF ALELTU WOREDA

Crop Type	Area Coverage (ha)	Annual Production (100kg)	Average Yield (100kg/ha)
Teff	8,608	129,147	15
Wheat	1,286	383,820	30
Barley	3,347	62,600	20
Bean	2,745	41,850	10
Lentil	1,217	14,712	12
Chick Pea	1,115	7,805	7
Vetch	320	3,200	10
Pea	342	2,394	7

Cropping Calendar: the cropping calendar is determined by climatic, soil conditions, the farming system and rotations with other crops. The cropping calendar of major crops grown in the watershed indicated below (Table 2.5).

TABLE 2.5: CROPPING CALENDAR OF THE UPPER KESEM WATERSHED

Crop type	Land preparation	Planting	Weeding	Harvesting
Teff	April-June	July	Aug-Sept	Nov-Dec
Wheat	June	July	Aug.-Sept	Nov-Dec
Barley	June	July	Aug.-Sept	Nov-Dec
Faba bean	April-June	June-July	Aug.-Sept	Nov-Dec
Lentil	Aug.-Sept	Aug.-Sept	-	Dec-Jan
Chick pea	April	June-July	Aug.-Sept	Nov-Dec
Vetch	Aug	Aug.-Sept	-	Dec-Jan
Pea	April	June-July	Aug.-Sept	Nov-Dec

Source: Discussion with farmers and technicians from Woreda Agriculture and Rural Development.

Crop protection: there are different types of insects and pests in the watershed area, which attack crops. Similarly fungus and rust diseases attack cereal and pulse crops. The high prices and timely availability of pesticides and insecticides often inhibits the use of chemicals.

Crop diseases: the yield loss and occurrence of crop diseases is less than compared with insect pests. Some of the common diseases are rust, smut and root rot, which attack wheat, barely and horse bean respectively.

Crop rotation: crop rotation is a biological means of maintaining soil fertility and controlling diseases and pest. The following crop rotation is practiced by the farmers in the watershed area.

Wheat/ Barley →Faba Bean/Chick Pea →Barely/ Wheat

Teff →Lentil/Chick pea/Vetch →potato

In the watershed area there is sever land degradation, especially in Hagere Mariam Woreda. From the PRA discussions with elderly people living in the area, they recounted that 30 years ago the very steep areas now used for cultivation were formerly covered with dense forest, with different indigenous trees like Tid (*Juniperus procera*) and Woira (*Olea africana)* and many kinds of wild animals and birds. Now land even steeper than 60% is under cultivation and as a result there is severe erosion along the gorges.

2.6.2 Cropping Patterns

Various factors affect the preferred cropping pattern, the main ones being rainfall, temperature, soil conditions, food habit and market demand. A list of major crops grown and the cropping pattern in the watersheds is shown in Table 2.6 below.

TABLE 2.6: MAJOR CROPS GROWN AND THE CROPPING PATTERN

Zone	Altitude	Major crops grown	Cropping pattern
Woyna Dega	1,500 – 2,300m	Teff, Wheat, Lentil, Field pea, Potato	Wheat →Teff →Barley
Dega	2,300 – 3,200m	Barley, Faba bean, Wheat, Potato	Barley →Faba bean →Wheat

2.6.3 Cultural Practices

Land preparation

Land preparation is carried out mainly by the combination of family labour and draught animals. Farmers still use old fashioned tillage implements, which are suitable neither for efficient seedbed preparation nor for minimizing the workload in order to increase labour productivity.

Planting/seed rate

In the watershed area broadcasted seed are covered either by another plough or by just brushing the field with branches. Generally, planting takes place from May to August. Farmers plant teff at 25 to 30 kg/ha, barley 125 to 150, wheat the same and faba bean 200-250.

Weeding

Various types of annual and perennial weeds exist in the watershed. The most parasitic weed known locally as 'striga' is widely distributed in the maize fields. Other weed species include *Cynadon, Johnson* and *bermuda* grass, *avena* species, *amaranthus, datura,* etc. The parasitic nature, high seed production potential (20,000 seed/plant), extended period of longevity (20 years in the soil without losing viability) make it difficult to control striga easily.

Peak time of weeding in the watershed is during August to September. Weeding is usually done by hand and Teff is given the highest priority with two or three weedings, for other crops it depends on time and resources available.

Input utilization

Farmers believe the area is not fertile and the benefits of both organic and inorganic fertilizers are widely acknowledged. Where the fields are near the homestead farmers are more likely to use manure as fertilizer.

Generally farmers tend to apply the same quantity and type of fertilizer regardless of the type of crop and soil. For example 100kg DAP/ha is commonly applied, though the MOA recommendation is 100kg DAP + 50kg urea per hectare. From focus group discussions, the reasons for not using the recommended fertilizers rates included unreliability and uneven distribution of rainfall and high cost of fertilizers.

Harvesting and threshing

Generally, the time of harvesting is governed by the sowing date and the varieties used (early verses late maturing). Harvesting is done manually using a sickle for teff, barley, wheat, faba bean, etc, pulses (field pea and lentils) and oil crops (flax) are harvested by manually uprooting the mature plants. Harvested teff is stoked for three or four days to dry. Threshing is done by driving oxen over the produce or for smaller amounts beating with sticks. Grain is then stored in traditional storage structures.

2.6.4 Crop Yields

The focus group discussions, suggest crop production and productivity have been declining and currently yields are very low for most of the crops, with an average not exceeding 15 quintals per hectare. The major reasons quoted for the low productivity is frost, poor yielding traditional varieties, poor soil fertility and lack of fertilizer use, pests and diseases particularly in the Hagere Mariam Woreda. The productivity in Aleltu and Gimbichu Woredas is rather better with an average yield per hectare for wheat, barley and teff of 30, 20 and 15 qts/ha respectively

2.6.5 Agricultural Support Services

Community discussion and secondary data obtained from various sources suggested that currently agricultural extension services are inadequate. Private, community based and governmental institutions such as farmer's co-operatives are the main providers of agricultural services.

Agricultural extension

Currently the number of extension workers in the kebeles varies from one to three. Ideally the kebeles should have three extension agents, one for crop production, one livestock production and the third for natural resources conservation, but there are many instances where one extension work is expected to cover two kebeles.

Farm inputs like fertilizer, improved seeds and pesticides are available through the agriculture and peasant cooperative organisations promotion office in the woreda. The common inputs are fertilizers (DAP, Urea) and improved seeds particularly (wheat, barely and potato), pesticides (2-4-D) and these are supplied through the Woreda Rural Development and Agricultural Office, farmers cooperative from Ambasel trading or Agricultural Input supply Corporation (AISCO).

Crop Marketing and Processing Facilities

There are small market centers in Aleltu, Sendafa, Beke, Wenoda and Chefe Donsa, which serve the watershed community. Farmers take their produce to markets using pack animals (donkey) and sell to consumers and traders. Most families need to sell a portion of what they produced in order to meet small cash needs. Traders purchase the production transport to the big markets in Debre Zeit and Addis Ababa. The market days for the Aleltu markets are given in Table 2.7, together with the importance ranking.

TABLE 2.7: MARKET DAYS IN ALELTU WOREDA

Market centers	Market days	Rank
Beke	Monday and Saturday	1
Aleltu	Tuesday and Saturday	2
Fiche Gelila	Sunday	3 (small)

2.6.6 Constraints to Crop Production

The community representatives identified the problems related to crop production during group discussions. The followings were the major problems identified:

i Low crop production;

ii In adequate supply of improved crop varieties;

iii Problems of disease, insect pests and weeds;

iv Depletion of soil fertility and high fertilizer prices;

v Soil erosion;

vi Shortage of oxen for timely land preparation;

vii Lack of improved farm implements; and

viii Scarcity of cultivable land.

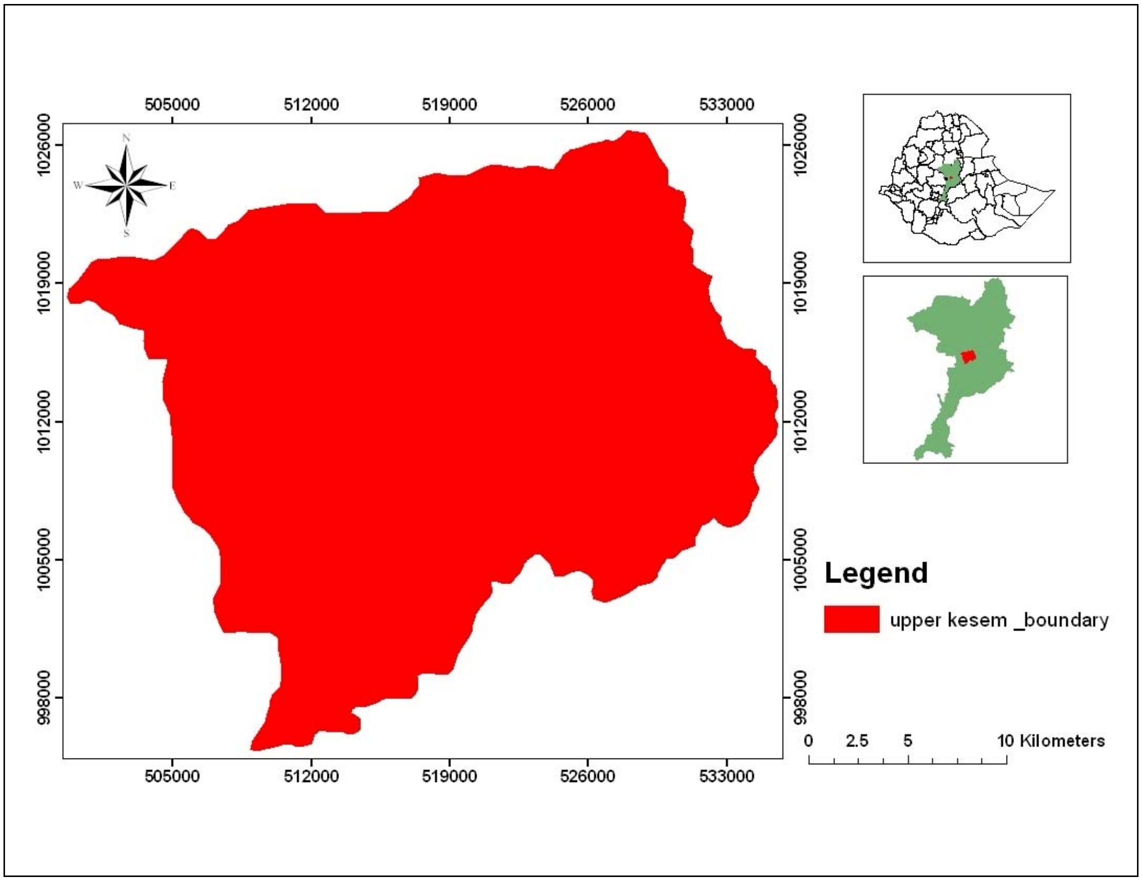


FIG 2.3LOCATIONS MAP OF THE STUDY AREA.

CHAPTRE - III

3. DATA SOURCES, MATERIALS USED AND METHODOLOGY

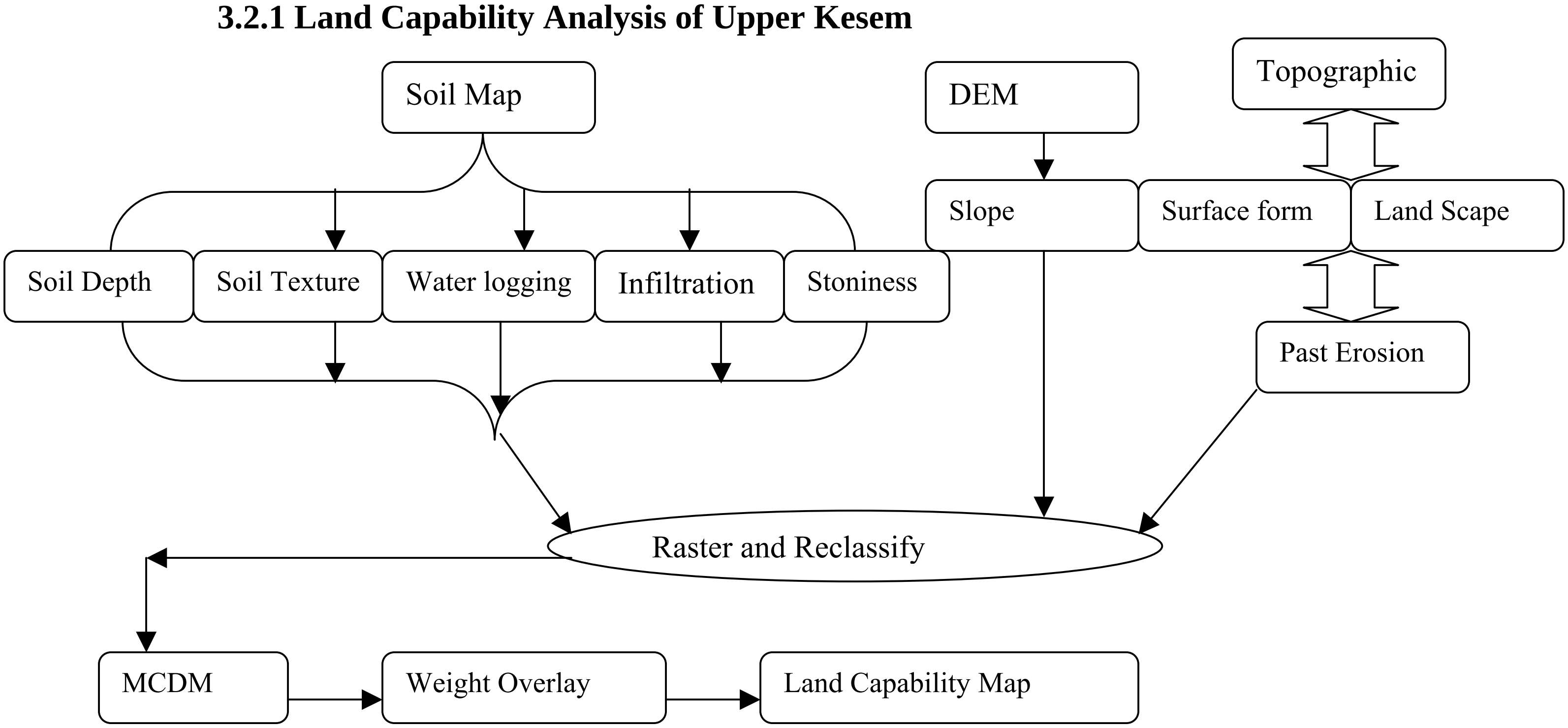
3.1 Data Sources and Materials

The materials used are:

- ✓ Topographic maps for the areas studied on 1:50000 scale, produced by Ethiopian Mapping Authority (EMA)
- ✓ Land satellite images (2000) for the areas studied to develop land use of the area with the help of field data obtained.
- ✓ Government department records on soil, population, crop productivity, rainfall, land use, and drainage systems which are found from Ethiopian Minister of Water Resource, meteorological data from National Meteorological Agency other data, which described the study area from the Region Bureau.
- ✓ FAO soil data and suitability description which is modified for Ethiopian cases.

3. 2 Methodology

3.2.1 Land Capability Analysis of Upper Kesem



3.2.2 Methodology used for Crops (Teff and Wheat) and Irrigation Suitability

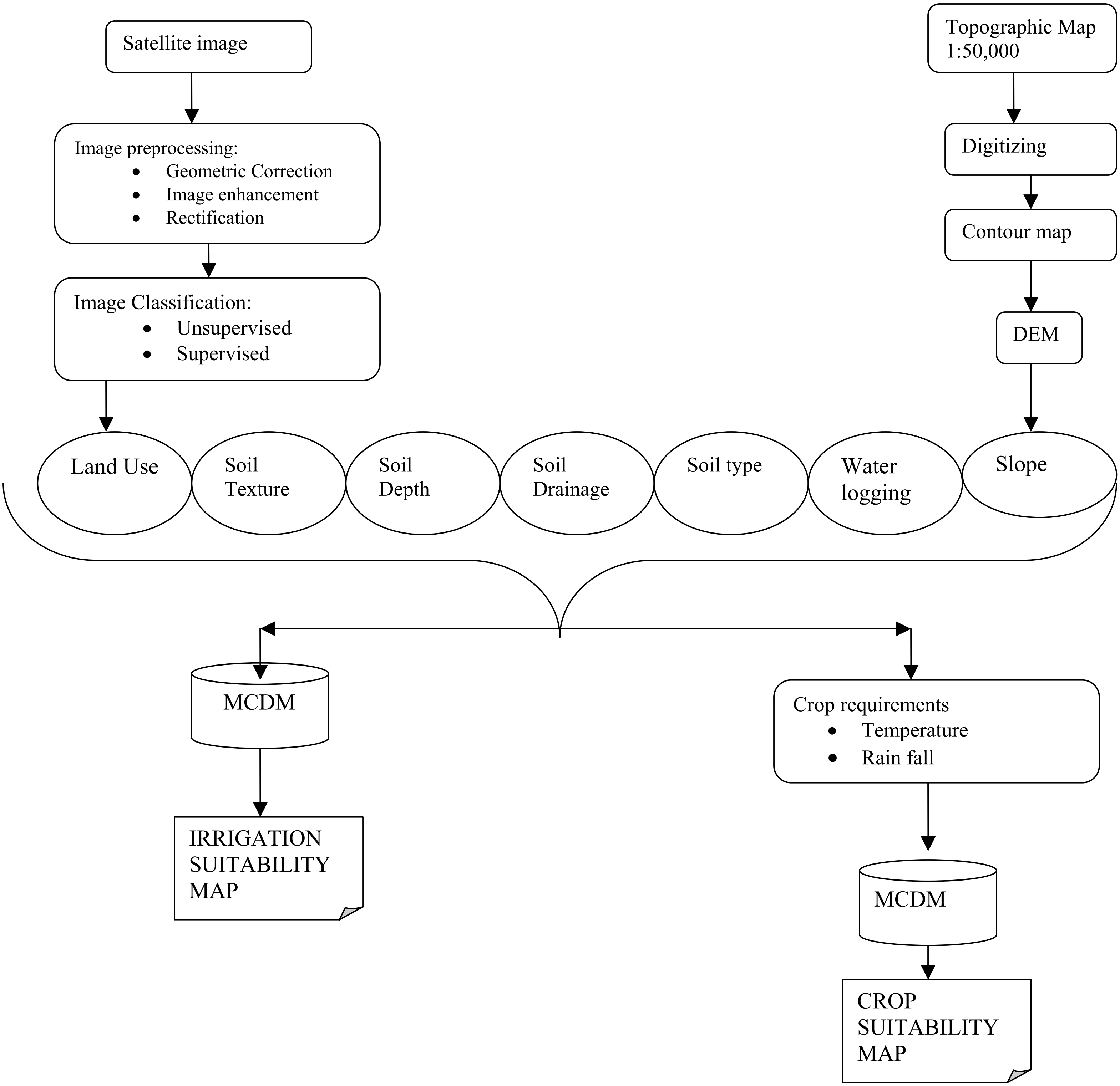


Fig 3.1 Flowchart showing the processes involved and the output produced

3.2.3 Selection of Land Use Types

The aim of this research is to investigate Land Capability of the study area, to arrive at the possible land use type which is suitable for irrigation and crops. The parameters like agro-climatic (or agro-ecological) zone, present Land use and cropping-system, topography, physical property of the soil, past erosion are taken into account. Experts in the fields of agriculture, soil science and local policy-making are consulted to decide upon the potential land use types for the study area.

For this study area, the different land use types (crops) for evaluation that are considered are:

- Teff
- Wheat
- Barley
- Sorghum

3.2.4 Selection of the evaluation criteria

Evaluation criteria, objectives and attributes, should be identified with respect to the problem situation. A set of criteria selected should adequately represent the decision-making environment and must contribute towards the final goal. It is known that set of attributes or criteria depends upon the system that is being analysed. There is no set technique to select the evaluation criteria. The process of selecting the criteria is iterative in nature. Literature survey, analytical study and the opinion survey are tools that aid in the selection of evaluation criteria.

The following evaluation criteria are considered to address the land Capability and suitability decision-making.

1. Soil

    a. Physical

        i. Texture
        ii. Drainage
        iii. Depth
        iv. Soil Type

2. Climate

    a. Temperature
    b. Rainfall

3. Irrigation

    a. Surface irrigation

4. Topographic

    a. Slope
    b. Surface form (Undulating, Steep, Rolling and Depression)
    c. Land scape (Hills, Plateaus, Valleys and piedmont plain)

5. Land use

    a. Vegetations (Bush land, Grass land and Cultivation)
    b. Past erosion
    c. Stoniness/Rockiness

3.2.5 Method of land suitability Evaluation

In this paper the method that was used to evaluate the land suitability for surface irrigation and crops was based on FAO guideline (FAO, 1976). This guideline is standard and is also accepted by many researches. This guideline has procedures to evaluate the suitability of the land for intended land use. Because land cannot be graded from "best" to "worst" irrespective of the kind of use and management practiced, since each kind of use has a special requirement.

Evaluation of land suitability is the most central part of land evaluation. There fore in order to attain the objectives of the study in this paper, procedure was set which is derived from FAO guideline. Generally the procedure answers the following questions:

- For any specified kind of land use, which areas of land are best suited?
- For any given area of land, for which kind of use is it best suited?

In simplified form, the procedures used were as follows:

I. Description of land-use types

A land-use type is a kind of land use described in terms of its products and management practices. Such descriptions serve two purposes. First, they are the basis for determining the requirements of a use. Second, the management specifications can be used as a basis for extension services and for planning necessary inputs. The land-use types for this paper were for the selection of the land for surface irrigation and suitable crops with in the study area.

II. Selection of land qualities and land characteristics

Land-use requirements are described by the land qualities needed for sustained production. A land quality is a complex attribute of land that has a direct effect on land use. For examples, the availability of water (drainage), the soil depth and slope gradient greatly affect surface irrigation. Most land qualities are determined by the interaction of several land characteristics, measurable attributes of the land. For example, the soil texture is determined by the requirement of crops.

In any particular project, only a limited number of land qualities need to be selected for use in evaluation. Criteria for selection should be:

- The quality must have a substantial effect either on performance or on the costs of production.

- Critical values of the quality must occur in the planning area. For example, if the slope gradient of the land is greater than 8% it is not recommended for surface irrigation.

III. Mapping of land units and their characteristics

After land units were identified in the above procedures (Step2) as a basis for the diagnosis of problems. These units have to be mapped in more detail using GIS. Then compare the requirements of the land-use types with the properties of the land units to arrive at a land suitability classification using pairwise comparison rating scale technique in IDRIS software. This technique is used to compare the factors in order to give the weight for the factors that determine the land use types based on their requirements. Accordingly based on their weight given the suitability map of the land can be developed based on the requirements of the specified land use using spatial analyst in ArcGIS 9.1 by the technique called Weighted Linear Combination (WLC).

The suitability map of the land must be classified based on their land use quality priority for specified land use requirements. According to FAO (1976), generally land suitability map is classified in to two classes i.e. Suitable and not suitable. These suitable and not suitable classes are further classified based on their benefits and limitations (Table 3.1).

TABLE 3.1 STRUCTURE OF THE LAND SUITABILITY 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.
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 are increased so that this cost is only marginally justified.
N	Not suitable	Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs.
N1	Permanently not suitable	Land with limitations to sustained use that cannot be overcome.

Source: A framework for land evaluation, 1976

CHAPTRE - IV
ANALYSIS AND RESULTS
4. INTRODUCTION

Land capability of the area is the most important in order to make reliable decisions for suitability analysis of the area. From the four LUTs selected for the study area, Teff and wheat that are the most important crops used to be analysed based on the Land capability of the study area. Evaluation criteria are framed and organised in a hierarchy. Discussions with relevant experts, literature survey and fieldwork are the major tools aided in deciding upon the LUTs, the evaluation criteria and their hierarchical structuring. Irrigation potential of the area also investigated to make the area more profitable in having Sustainable Agriculture Production. Even if there are different types of irrigation practices, more focused given to surface irrigation. Surface irrigation has its own advantage and disadvantage. Surface irrigation offers a number of important advantages at both the farm and project level. Because it is so widely utilized, local irrigators generally have at least minimal understanding of how to operate and maintain the system. In addition, surface systems are often more acceptable to agriculturalists who appreciate the effects of water shortage on crop yields since it appears easier to apply the depths required to refill the root zone.

The second advantage of surface irrigation is that these systems can be developed at the farm level with minimal capital investment. The control and regulation structures are simple, durable and easily constructed with inexpensive and readily available materials like wood, concrete, brick and mortar, etc. Further, the essential structural elements are located at the edges of the fields that facilitate operation and maintenance activities. The major capital expense of the surface system is generally associated with land grading, but if the topography is not too undulating, these costs are not great. Recent developments in surface irrigation technology have largely overcome the irrigation efficiency advantage of sprinkler and trickle systems.

There is one disadvantage of surface irrigation that confronts every designer and irrigator. The soil which must be used to convey the water over the field has properties that are highly varied both spatially and temporally. They become almost undefinable except immediately preceding the watering or during it. This creates an engineering problem in which at least two of the primary design variables, discharge and time of application, must be estimated not only at the field layout stage but also judged by the irrigator prior to the initiation of every surface irrigation event. Surface irrigation systems are typically less efficient in applying water than either sprinkler or trickle systems. Many are situated on lower lands with heavier soils and, therefore, tend to be more affected by waterlogging and soil salinity if adequate drainage is not provided. The need to use the field surface as a conveyance and distribution facility requires that fields be well graded if possible. Land levelling costs can be high so the surface irrigation practice tends to be limited to land already having small, even slopes.

4.1 Reliability of the Data

Most of the data used for the analysis of Land Capability of the study area obtained from FAO (Soil of East Africa). FAO Considerable differences in reliability (RELIAB) of the sources of information occur in the different parts of the area covered. Four classes of data reliability were distinguished as shown in the Table (4.1).

Code	Reliability
H	High (based on recent 1:1 Million scale soil surveys and/or profile description)
M	Medium (based on reconnaissance soil surveys with moderately good unit descriptions)
L	Low (based on remote sensing, soil surveys with poor unit descriptions and geological information)
V	Very Low (based only on remote sensing and geological information)

TABLE 4.1 THAT SHOW THE RELIABILITY OF THE DATA

Based on the above four classes of data reliability the study area (Upper Kesem) has **HIGH reliability**.

4.2 Physical Land Characteristics of the Upper Kesem.

Physical Land Characteristics and quality of the study are should be studied well in order to make decisions on land utilization types. In this paper physical land properties were evaluated based on the crops requirements. The physical land properties of the study area, which were evaluated, include drainage, slope gradient, soil texture, soil depth, soil type, waterlogging, stonnines, infilitration, past erosion and land use. Climate (Temperature and Rain fall) of the area was also used based on the data obtained from Ethiopian Meteorological Agency.

4.2.1 Slope gradient

The topography of the Upper Kesem is undulating high plateau in the upper part of the watershed and deep dissected gorges in the lower portion. The elevation ranges from 1500m (at the Upper Kesem River) to 2800m (near Fiche Gelila). Gentle land is suitable for agriculture than steep land. The supplying of water, flood protection, leaching, and salt accumulation are often problems of land related topography. Some lands occupy a high slope gradient where they are inaccessible for water. Some lands are low-laying and subject to flooding and seepage if lands above them are irrigated. Low-laying lands are also frequently subject to frost damage (Fig 4.1).

TABLE 4.2 SLOPE SUITABILITY OF THE STUDY AREA

Slope class	% Range	Code
Flat or almost flat	0-3	L1
Gently sloping	3-8	L2
Sloping	8-15	L3
Moderately steep	15-30	L4
Steep	30-50	L5
Very steep	>50	L6

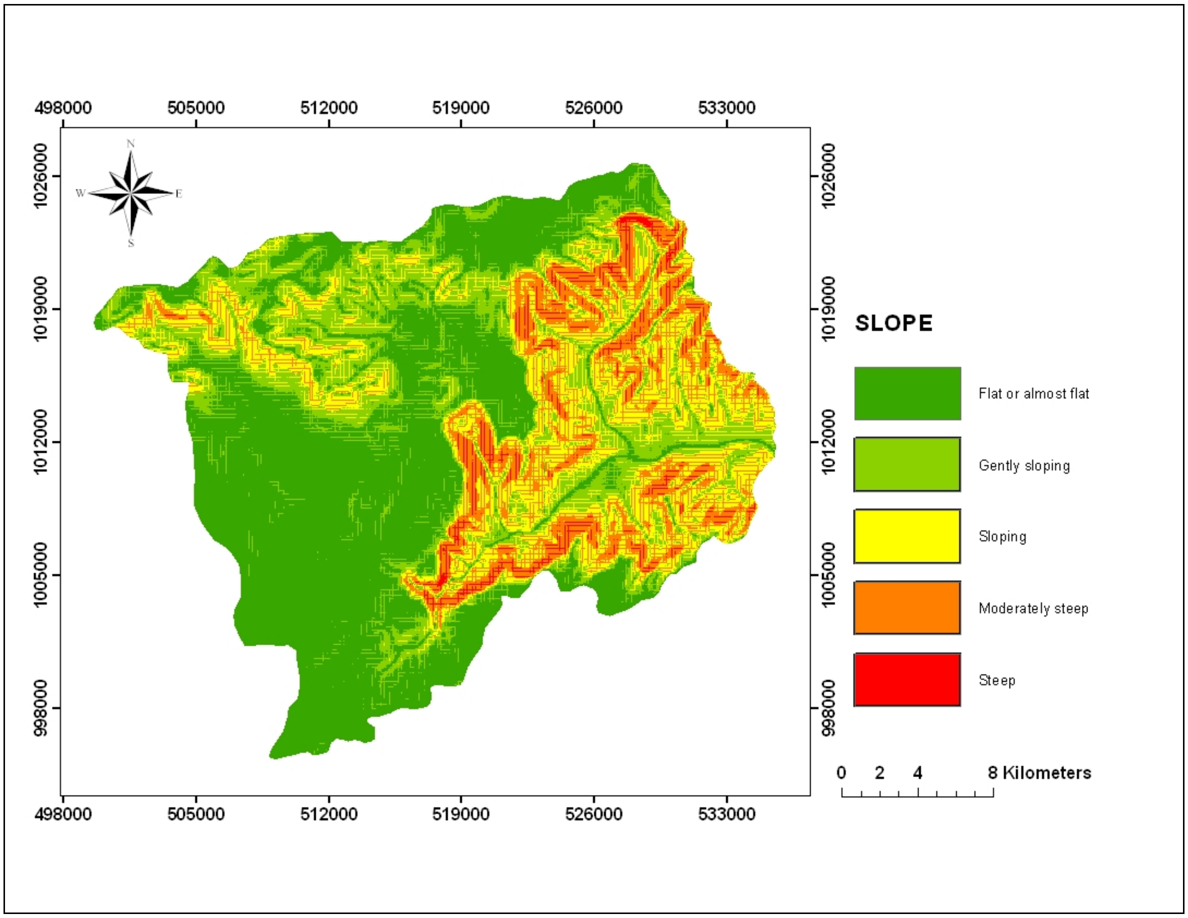


FIG 4.1 SLOPE MAP OF THE STUDY AREA.

4.2.2 Soil Depth

A soil depth variation from place to place determines the growth of plants and also affects the growing of plant roots. The thickness of the soil materials, which give structural support, nutrients and water for crops, is referred as soil depth. The soil depth of Upper Kesem was classified in to four (Fig.4.2). The depth was given in centimeter. Soil series that have bedrock between 25 and 50 centimeters from the surface were described as shallow. Bedrock between 50 and 100 centimeters was described as moderately deep.100-150 was also deep and if it is grater than 150 cm it is very deep.

Soil depth class	Cm	Code
Very deep	>150	D1
Deep	100-150	D2
Moderately deep	50-100	D3
Shallow	25-50	D4
Very Shallow	<25	D5

TABLE 4.3 SOIL DEPTH SUITABILITY OF THE STUDY AREA.

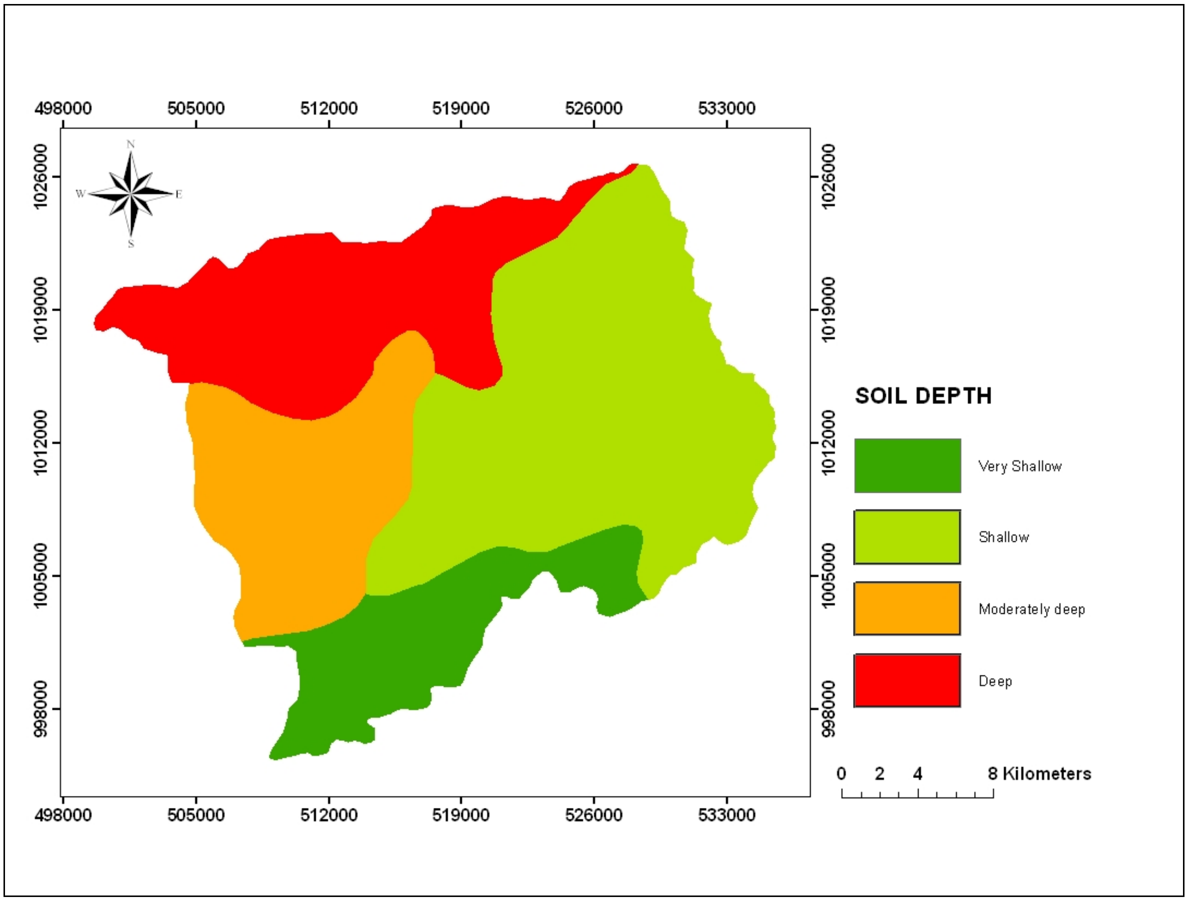


FIG 4.2 SOIL DEPTH MAP OF THE STUDY AREA.

4.2.3 Past erosion

Past erosion of the study area studied based on the topography i.e. Surface form and landscape form of the area using extensive field survey.

Erosion classes	Definition	Code
Nil	No erosion noticeable	E0
Slight	-Some surface wash and small rills. Slight topsoil loss.	E1

	-No sub soil exposed -Micro pedestals observed in upper parts of the field -Trees/plant roots slightly exposed	
Moderate	-Rills cover most of the surface at regular intervals (after rain showers of medium/high intensity) -Bleached spots in several parts of the field surface -Much topsoil removed in upper portions of the field (coarser materials left) -Pedestals 1-5 cm frequent. -Occasionally, small patches of subsoil exposed. -Double slopes observed as the result of continuous ploughing of rills. -Tree/plant roots well exposed.	E2
Severe	-Shallow gullies frequent (occasionally deep ones) -Most or all topsoil removed, the surface layer is almost entirely subsoil. -Small areas of topsoil remaining exposed. -Occasionally large stones on top of 10-50cm pedestals. -Tree roots almost completely exposed.	E3
Very severe	-Most of the land is dissected by gullies. -Only small areas of topsoil and upper subsoil are still present between the gullies. -The land consists of exposed parent material or rock resulting from the complete removal of topsoil and subsoil.	E4

TABLE 4.4 PAST EROSION SUITABILITY OF THE STUDY AREA.

4.2.4 Soil Texture

Generally, the soil texture of the specified land use is divided in to three Textural groups based on the FAO guidelines (FAO, 1986). These are Coarse, medium and fine textured.

According to FAO guidelines for soil evaluation, the soil texture of the study area was evaluated and classified in to clay and clay loam (Fig.4.3). Clay has important effects on the physical properties of soil. It acts as a binding agent, holding sand, silt and clay together in aggregates. Clay loam is medium textured soil which has a high absorption capacity for water. It swells and shrinks with soil moisture changes (Thorne and Peterson, 1949). They also stated that usually soils with intermediate clay contents (5 to 40 percent) are preferred for agricultural purposes. Clay is a fine textured soil which has slow water observation capacity.

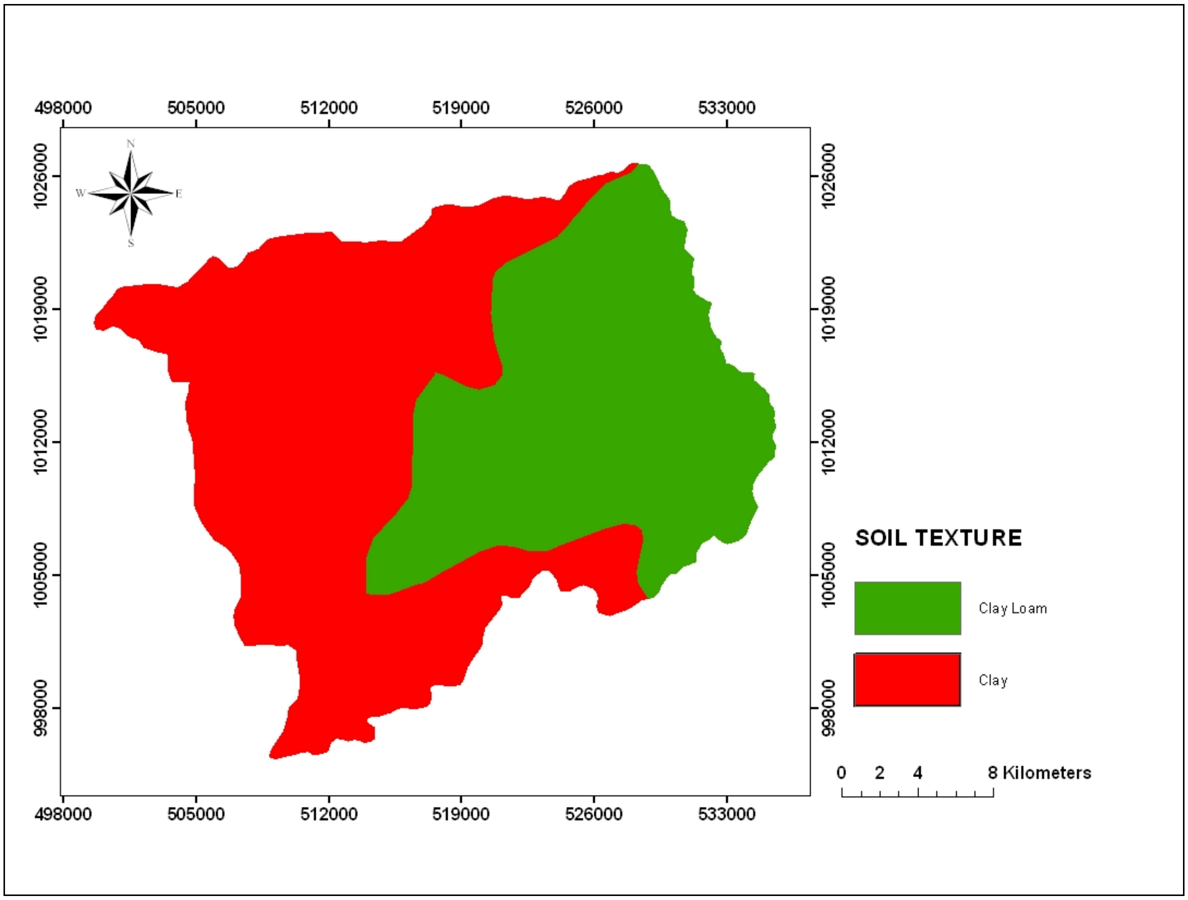


FIG 4.3 SOIL TEXTURE MAP OF THE STUDY AREA.

Textural group	Textural class	Code
Coarse	Sand (S) Sandy Loam (SL) Loam (L)	T1 T2 T3
Medium	Silt Loam (SiL) Clay Loam (CL)	T4 T5
Fine	Clay, Silt Clay(C, SiC) Heavy Clay(C)	T6 T7

TABLE 4.5 SOIL TEXTURE SUITABILITY OF THE STUDY AREA.

4.2.5 Water logging

According to FAO water logging classified in four classes i.e. no waterlogging, intermittently waterlogged, regularly waterlogged and Swampy areas. Upper Kesem is characterized by there of them, no waterlogging, intermittently waterlogged and regularly waterlogged. Water logging occurs (as is common for salinization) in poorly drained soils where water can't penetrate deeply. For example, there may be an impermeable clay layer below the soil. It also occurs on areas that are poorly drained topographically. So water logging highly affects crop production and irrigation practices.

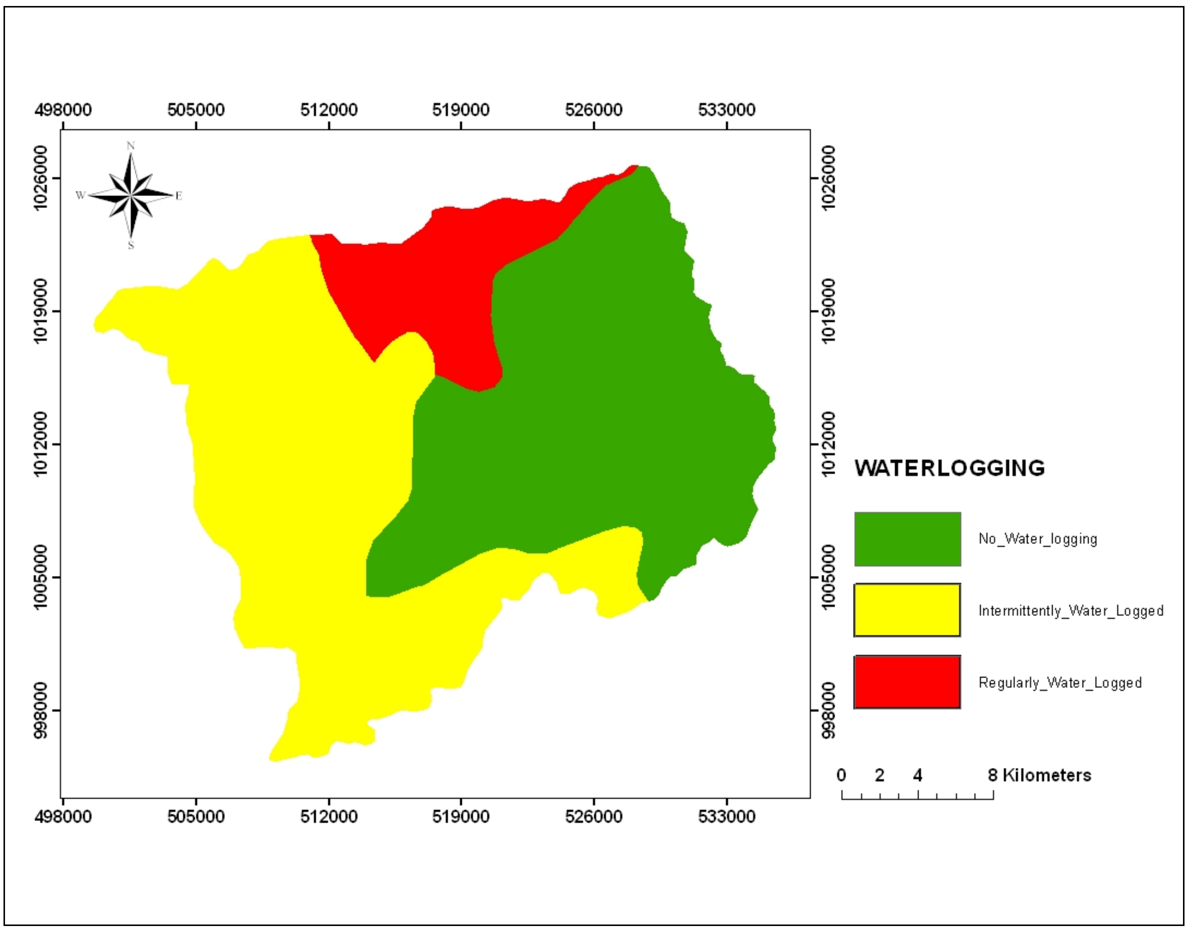


FIG 4.4 Waterlogging map of the study area.

Waterlogging	Definition	Code
No waterlogging	Well drained soil	W0
Intermittently waterlogged	Imperfectly drained areas. Occupy level and sometimes depressed sites. Area is wet and waterlogged during the heavy rains for few days/weeks. Brown of yellow mottles may occur in the profile (common on vertisols)	W1
Regularly waterlogged	Poorly drained areas. Occupy bottomlands, commonly flooded during the wet season and waterlogged for some time during the dry season. Color of the soil is predominantly grey with brown mottling.	W2
Swampy areas	Very poorly drained areas. Water table at or near the surface during the wet season. Soils are generally grey in color	W3

TABLE 4.6 WATER LOGGING SUITABILITY OF THE STUDY AREA.

4.2.6 Infiltration

According to FAO water logging classified in to three classes which are stated below in the table (4.7)

Infiltration classes	Definition	Code
Good	The soil in the surface layer or very permeable or has a good structure to absorb rapidly. When the dry soil is ploughed it breaks in to fine clods and grains. Good plant cover or grasses observed.	I0
Moderate	The soil on the surface layer has a massive structure or has a moderate to slow permeability. The structure has a tendency to compact and seal. Crusts form rapidly after first shower.	I2
Poor	In addition to massive structure the soil has a strong tendency to seal on welting or settling to an almost impermeable crust on drying. When dry, the soil does not show cracks at the surface.	I3

TABLE 4.7 SOIL INFILTRATION SUITABILITY OF THE STUDY AREA.

4.2.7 Stoniness

According to FAO water logging classified in to five classes which are stated below in the table (4.8)

Stoniness class	Rockiness class	Area cover%	Code
No stones or few	No rocks or few	<15	S0
Moderately stony	Moderately rocky	15-30	S1
Stony	Rocky	30-50	S2
Very stony	Very rocky	50-85	S3
Rubble land	Rock outcrops	>85	S4

TABLE 4.8 STONINESS SUITABILITY OF THE STUDY AREA.

4.2.8 Soil drainage

According to FAO standard guidelines, soil drainage of a specified area can be divided in to five classes. These are well drained, moderately drained, imperfectly drained, poor drained and very poorly drained. There fore, based on its soil permeability of water in the study area, the Upper kesem was classified in to well, moderately well and imperfect drained. Most of (70 %) the area is well drained in the study area.

Soil Drainage	Area in Sq km	Area in %
Well	449.10	70
Moderately well	74.23	11
Imperfect	122.79	19

TABLE 4.9 SOIL DRAINAGE PERCENTAGE OF THE STUDY AREA

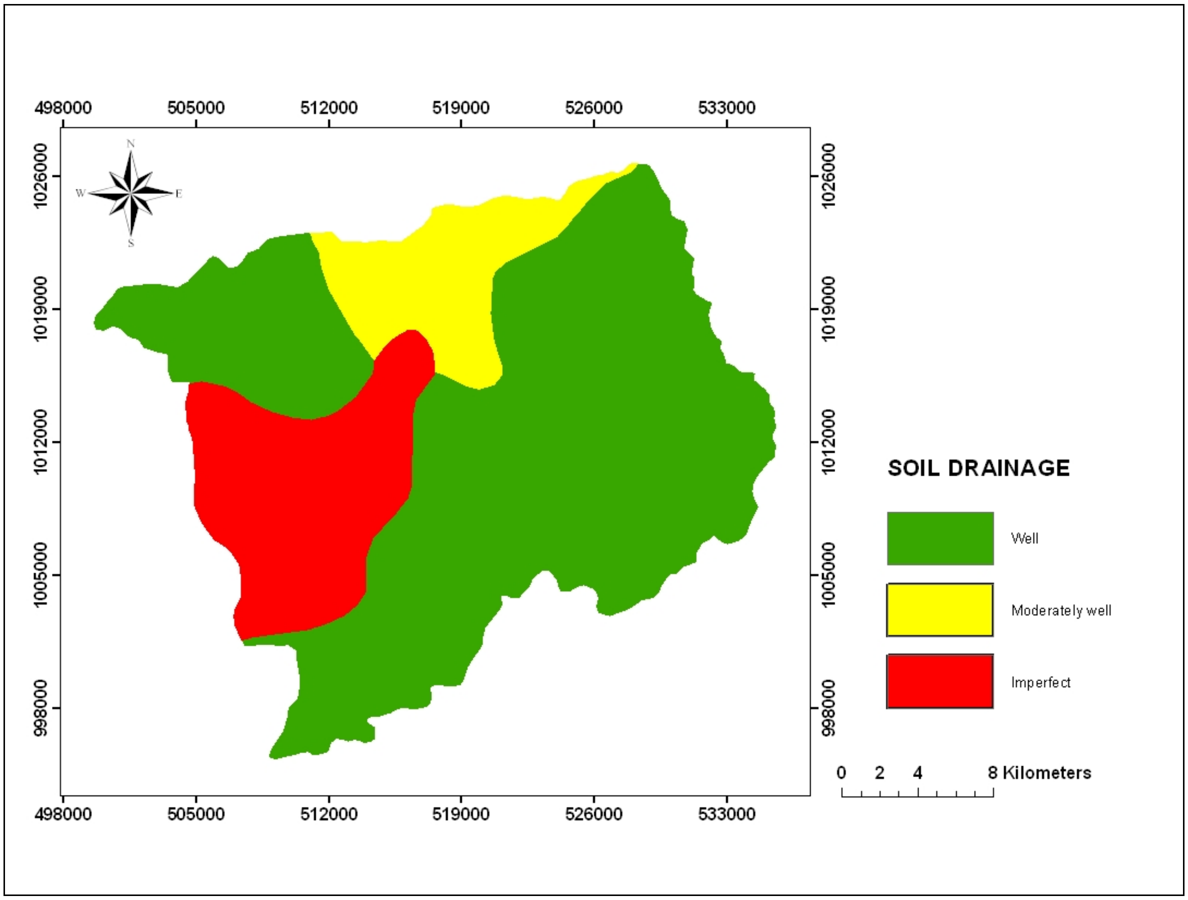


FIG 4.5 SOIL DRAINAGE MAP OF THE STUDY AREA.

4.2.9 Soil Type

The types of soil found in the study area are Eutric Regosols, Leptosols, vertic cambisol, chromic cambisol, orthic solonchakes, calcic xerosols, pellic Vertisols. Soils on the high plateau are principally Pellic vertisols, while those on high relief hills and severely dissected side slope are Eutric cambisols and Nitosoils.According to FAO (1988), Vertisols are characterized by their high clay content.

They are often dark colored, Due to their semitite clay mineralogy, they are very hard and crack when dry, but becomes sticky and plastic (often impassible) when wet. These are chemically rich soils, but they may develop on an undulating micro relief, which hampers mechanization. Vertisols have great agricultural potential, but special management practices are required.

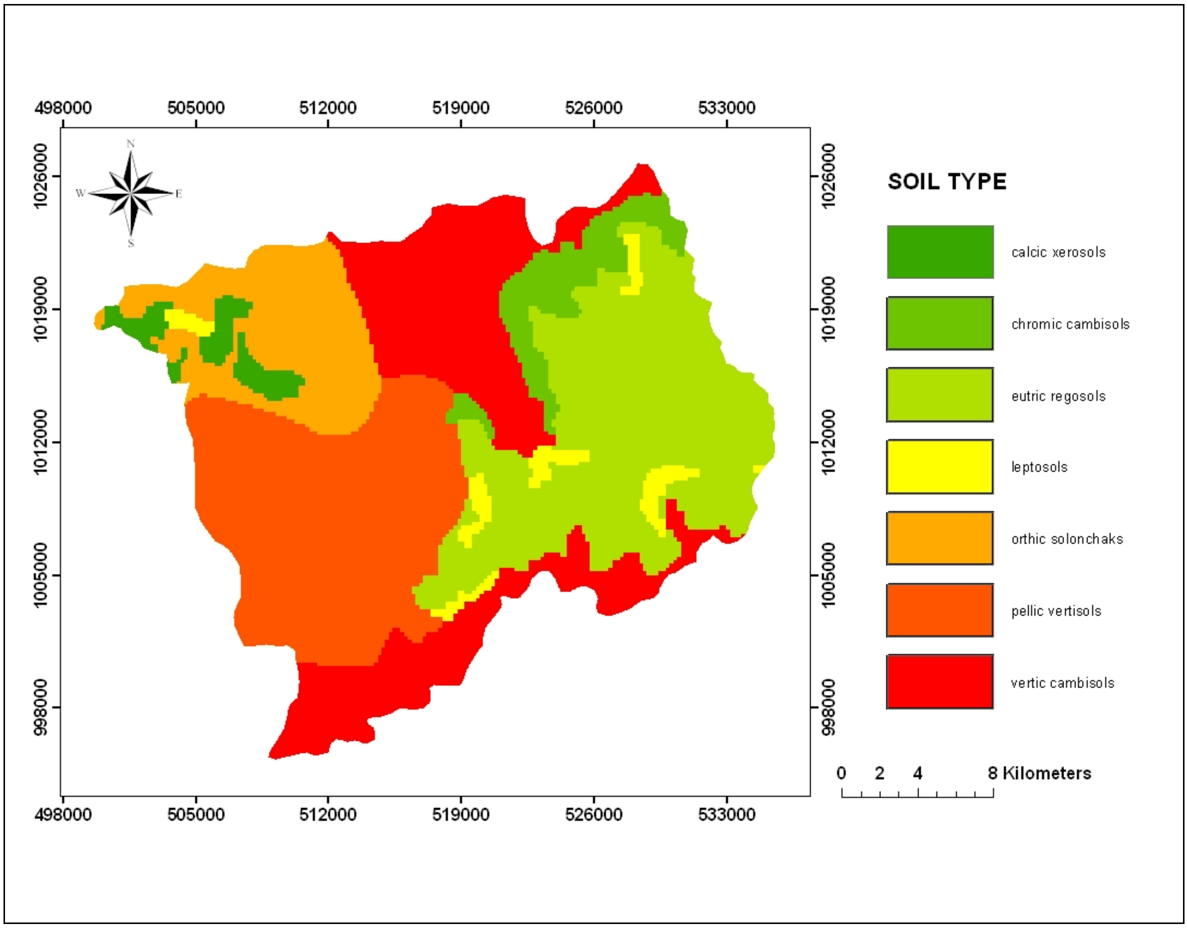


FIG 4.6 SOIL TYPE MAP OF THE STUDY AREA.

4.2.10 Present land use/ land cover

Land use map of the basin was derived from Land sat image taken in 2000. The image was used only to develop the land use map of the Upper Kesem. Land use and land cover influences on the cost of crop suitability and irrigation practice to prepare the land for agriculture. There fore it was taken as one input for the evaluation of land qualities for irrigation for the study area.

The type of land use/land cover in the study area includes cultivated land, forest land, grass land, fallow land, Bushes and shrubs, water (river and valleys), Built up area and Degraded area are the major ones (Fig 4.7).

Water land and villages are constraints for suitability analysis of both crop and irrigation because there is no irrigation practice or crop production in these land covers.

Most of the land as shown in the table (4.10) is cultivated land and Bushes and shrubs. Fallow land takes 13 % of the total are so; this shows that 41 % of the area is used for agriculture purpose.

Land use	Area in %
Built up area	17%
Water body	1%
Forest	8%
Cultivated land	28%
Bushes and shrubs	27%
Grass land	5%
Fallow land	13%
Degraded area	1%

Table 4.10 Land use (cover) types in percentage of the study area.

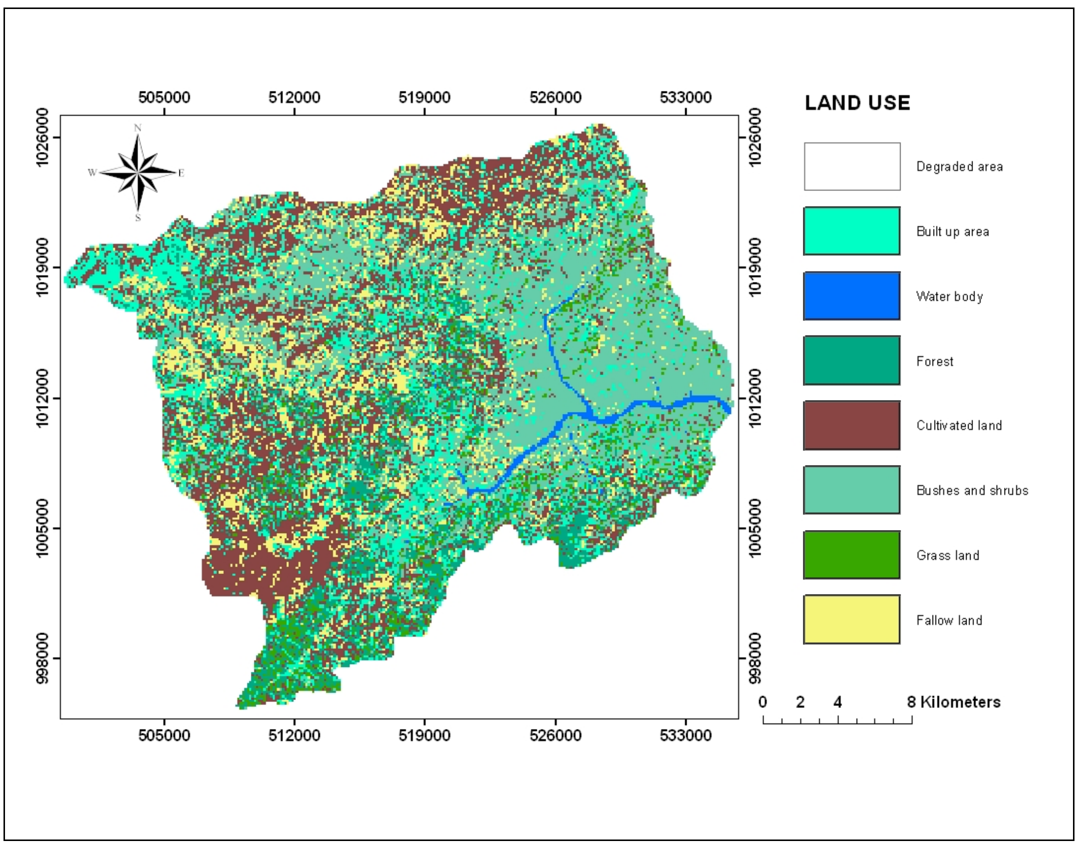


FIG 4.7 LAND USE MAP OF THE STUDY AREA.

Accuracy Assessment

The accuracy assessment is essentially a measure of how many ground truth pixels were classified correctly. An overall accuracy of *87.1% was* achieved with a Kappa coefficient of *0.81* for Landsat 2000 ETM image.

4.2.11 Climate

The characteristics of the soil, drainage conditions, distribution of native vegetation, and crop adaptation are related to climate. Thus, the physical environmental factors (including climate) determine what will or will not grow, while economic and social factors determine what is grown. Therefore, fundamental considerations in planning an irrigation project involve deriving a proper set of assumptions regarding the cropping pattern and management systems. Generally the climate of the study area was classified under moist climatic zone, with considerable annual rainfall. Temperature and rainfall were considered as factors for analysis of crops suitability in the study area because crops require an average amount of temperature and rainfall. However climate was taken as homogenous for irrigation suitability analysis in the study area because of there is considerable rain fall with optimum temperature.

4.3 Crops Requirements

The factors, which are mentioned above, are the major physical factors, which were considered to determine the production of crops and irrigation potential in a specified area. All these factors have not the same impacts on crops.
Some crops need one factor more than the others. However the factors bring different effects on production. There fore weight given for the two crops were different based on their requirements (Table 4.11).

The physical properties of soils such as depth, texture, soil drainage (permeability) are the important soil characteristics in land evaluation that affect the yields under specific climatic and site conditions.

TABLE 4.11 CRITERIA USED IN THE EVALUATION OF SOIL AND TERRAIN SUITABILITY FOR CROPS REQUIREMENT ADOPTED FROM FAO GUIDELINES MODIFIED FOR ETHIOPIAN CASES.

Crop	Depth (m)	Temperature	Water Requirement (mm)	Drainage	Soil
Teff	1-1.5	15-20(12-25)	100-600	Well	Silt to clay
Wheat	1-1.5	15-20(10-25)	450-650	Well	Loam to clay Loam
Barley	1-1.5	15-20(10-25)	400-600	Well	Light to medium texture
Sorghum	1-2	24-30(15-35)	450-650	Well	Light to medium texture

4.4 Land Suitability Class Specification

According to FAO standards, which are widely used to classify land suitability for specified objectives of land utilization types, a land can be divided in to five classes. These include very suitable (S1), suitable (S2), marginally suitable (S3), marginally not suitable (N1) and permanently not suitable (N2) (FAO, 1976).

Class-determining parameters are those factors, which affect the performance of the land utilization types on the land units under the study i.e. the irrigation potential evaluation in the Upper Kesem. These parameters are also called parameter maps, which were mentioned above. These parameters include slope gradient, soil drainage, soil depth, soil texture, soil type and land use of Upper Kesem. The parameters were selected based on the requirement of the surface irrigation potential and crop suitability of each crop requirement (Teff and Wheat). Amount of Temperature and rainfall are also added as a parameters for crop suitability analysis besides the above stated parameters.

4.5 Multi-Criteria Decision Evaluation

MCE is a set of procedures designed to facilitate decision-making. The basic purpose is to investigate a number of choice possibilities in the light of multiple criteria and conflicting objectives.

Decision Theory is concerned with the logic by which one arrives at a choice between alternatives. What those alternatives are varies from problem to problem. They might be alternative actions, alternative hypotheses about a phenomenon, alternative objects to include in a set.

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

$S = \sum WiXi$ where S = suitability

Wi = weight of factor i

Xi = criterion score of factor i

The above method mentioned was also used in this paper to develop the suitability map of physical land for surface irrigation potential, Land capability and crop suitability in the study area. In order to develop suitability map there are procedures to be followed which are mentioned in the literature reviews when using weighted linear combination technique.

4.6 Standardizing the Parameters

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

Since the matrix is symmetrical, only the lower triangular half actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half.
Based on Ethiopian condition which is extracted from FAO guidelines for Land Classification the parameters are weighted and ranked as follows.

Factors	Slope	Soil depth	Past erosion	Water logging	Infiltration	Texture	Stoniness	Weight
Slope	1							0.3547
Soil depth	1/2	1						0.2399
Past erosion	1/3	1/2	1					0.1587
Water logging	1/4	1/3	1/2	1				0.1036
Infiltration	1/5	1/4	1/3	1/2	1			0.0676
Texture	1/6	1/5	1/4	1/3	1/2	1		0.0448
Stoniness	1/7	1/6	1/5	1/4	1/3	1/2	1	0.0312

TABLE 4.12 ILLUSTRATES THE STANDARDIZED RESULTS AND WEIGHT OF ALL SEVEN PARAMETERTS FOR THE PHYSICAL LAND CAPABILITY OF THE STUDY AREA.

Consistency ratio = 0.02

Consistency is acceptable.

4.7 Establishing the Parameter Weights

This is the second step in MCDE to establish a set of weights for each of the factors. The technique described here and implemented in IDRISI is that of pair wise comparisons developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). In Saaty's technique, taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria can derive weights of this nature. The purpose of weighting is to express the importance or preference of each factor relative to other factor affect on crop yield and growth rate.

To avoid and reduce the individual biases of factor weighting, the weights in the study were determined by using a pairwise comparison method as developed by Saaty (1980) in the context of the analytical hierarchy process (AHP). Pairwise comparisons are based on forming judgments between two particular elements rather than attempting to prioritize an entire list of elements. A matrix is constructed, where each factor is compared with the other factors, relative to its importance, on a scale from 1 to 9. Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the pairwise comparisons. If the CR > 0.10, then some pairwise values needs to be reconsidered and the process is repeated till the desired value of CR < 0.10 is reached.

In this paper pair wise comparison was used for weighting the factors. All the seven factors, which were selected for the evaluation of Land Capability in the study area, were weighted using pair wise comparison.

After the pair wise comparison matrices were filled, the weight module was used to identify consistency ratio and develop the best-fit weights.

The consistency ratio (CR) was 0.02, which was acceptable for weighting the factors to evaluate the physical land capability of the area.

4.8 Land Capability (Classification) Analysis

4.8.1 Parameters used for Land Classification (Land Capability)

Land capability is set based on the agro climatic or agro ecological, topographic, physical and chemical (optional because it changes with time), past erosion, stoniness etc. FAO sets information needed for the land classification but in this study area ranges for each parameter is set based on Ethiopian conditions (Source: Mekele University, Department of Dry Land Crop science (unpublished)).

INFORMATION NEEDED FOR LAND CLASSIFICATION BASED ON FAO

Factors	RANGE OF CODES PERMITTED IN COLUMN								
Slope (S)	1	2	3	1-4	4	5	6	1-6	1-6
Soil depth (D)	1	1-2	1-2	1-3	1-4	1-3	1-4	1-5	1-5
Past erosion (E)	0	0	0-1	0-2	0-2		0-3	0-4	0-4
Water logging (W)	0	0	0-1	0-2	0-2		0-2	0-2	0-3
Infiltration (I)	0	0	0-1	0-2	0-2		0-2	0-2	0-2
Texture	3-5	3-6	3-7	2-7	2-7		2-7	1-7	1-7
Stoniness/Rockiness	0	0-1	0-2	0-2	0-3		0-3	0-4	0-4
Soil conservation requirement class	1	2	3	4	5		6	7	8
Land use suitability	Land suitable for annual crops			Land suitable for grazing or perennial crops			Land suitable for forestry	Land not suitable for agriculture	Swampy areas, river beds…

TABLE 4.13 LAND CLASSIFICTION (CAPABILITY) CODES.

*** Chemical properties are OPTIONAL

So the seven stated above parameters are weighted in table (4.10) and the capability of the land also done using the weight given to each parameters. Land capability map of the area is also shown in table (4.14) and figure (4.8) below.

Suitability Class	Area (in Sq.km)	Area (in %)
Annual crops	388.37	60
Grazing or perennial crops	118.48	18
Forestry	105.29	17
Land not suitable for agriculture	27.36	4
Swampy areas, river beds…	6.62	1

TABLE 4.14 LAND CLASSIFICATION SUITABILITY OF THE STUDY AREA (UPPER KESEM).

As shown in the table (4.14) 60 %(388.37 Sq.km) of the total area is highly suitable for annual crops. Suitability for Grazing or perennial crops 18% (118.48 Sq.km) and Forestry 17% (105.29 Sq.km) of the total area are almost in equal rate. Land not suitable for agriculture 4% (27.36 Sq.km) and Swampy areas, river beds etc1% (6.62 Sq.km) are the least in the study area.

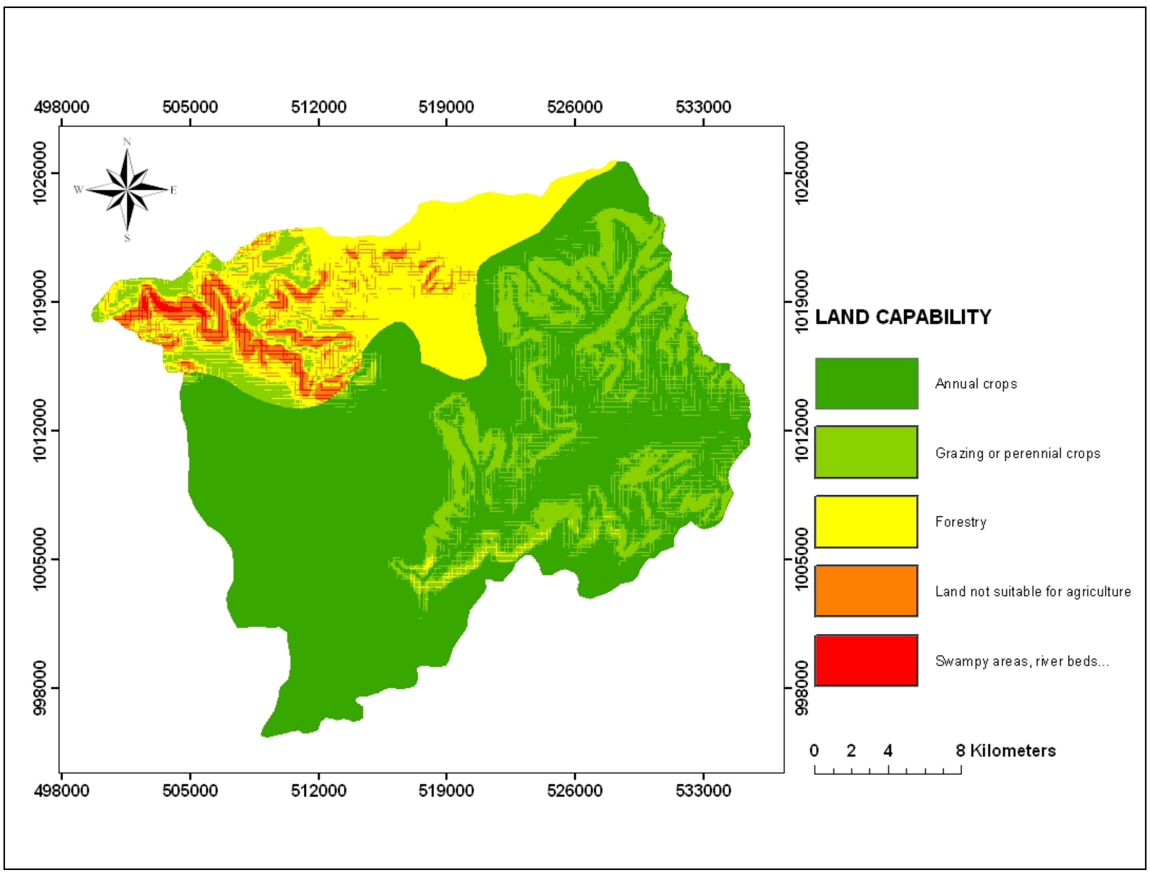


FIG 4.8 LAND CAPABILITY (CLASSIFICATION) MAP OF THE STUDY AREA.

4.9 physical suitability mapping for crops and irrigation

After evaluation of the physical land Capability of the area, it is necessary to examine the land suitability for crops production and irrigation potential in the study area. The base line to select types of crops, which are suitable for the land, was types of crops, which are widely grown in the area and used by many farmers as commercial crops. In addition types of crops, which are very necessary for export items and bring economic growth for the country in general.

Teff and wheat were selected in order to evaluate the suitability of the land under the study area based on the Land capability. Teff and wheat are widely grown in the study area and they are the major cereals with the area coverage of 8,608 and 1,286 ha respectively**.**

4.10 Teff suitability analysis

Teff is a high land crop which grows in an altitude of 1700-2800 m.a.s.l.It requires an annual rain fall up to 2500 mm and it has wide climatic adaptability with high tolerance to water logging. Weight and ranking are given based on the specific requirement of Teff and there is also involvement of experts, decision makers and farmers as well.

Parameters	Weight
Slope	0.307
Drainage	0.218
Depth	0.154
Texture	0.109
Rain fall	0.077
Temperature	0.064
Soil type	0.037
Water logging	0.026
Land use	0.019

TABLE 4.15 PARAMETERS WEIGHTS USED FOR TEFF.

Consistency ratio = 0.056

Consistency is acceptable.

Suitability Class	Area (in Sq.km)	Area (in %)
S1	84.32	16
S2	86.50	17
S3	168.95	33
S4	107.34	21
S5	68.65	13

TABLE 4.16 TEFF SUITABILITY AREAS UNDER DIFFERENT CLASS.

From the total land of the study area 84.32 sq km (16%) is highly suitable, 86.50 sq km (17%) moderately suitable, 168.95 sq km (33%) marginally suitable, 107.34 sq km (21%) not suitable and 68.65 sq km (13%) permanently not suitable for Teff (Table 4.16). **White colors** of the map are constraints for Teff suitability (Fig 4.10).

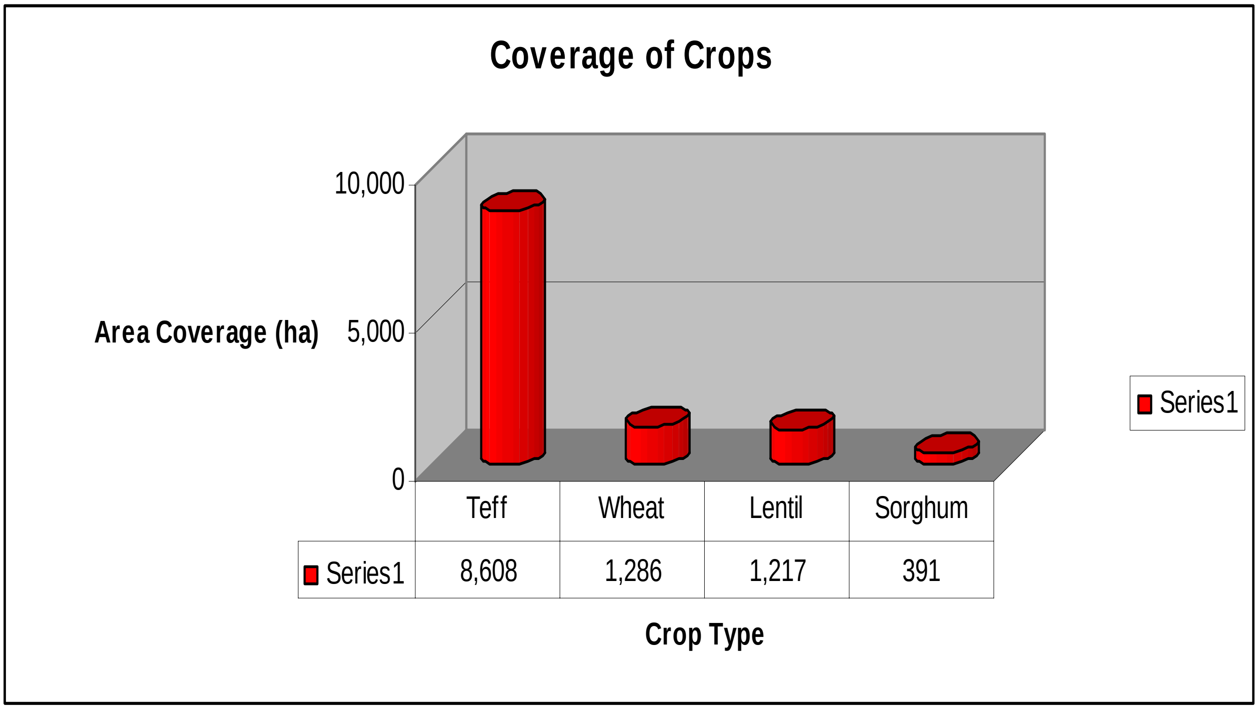
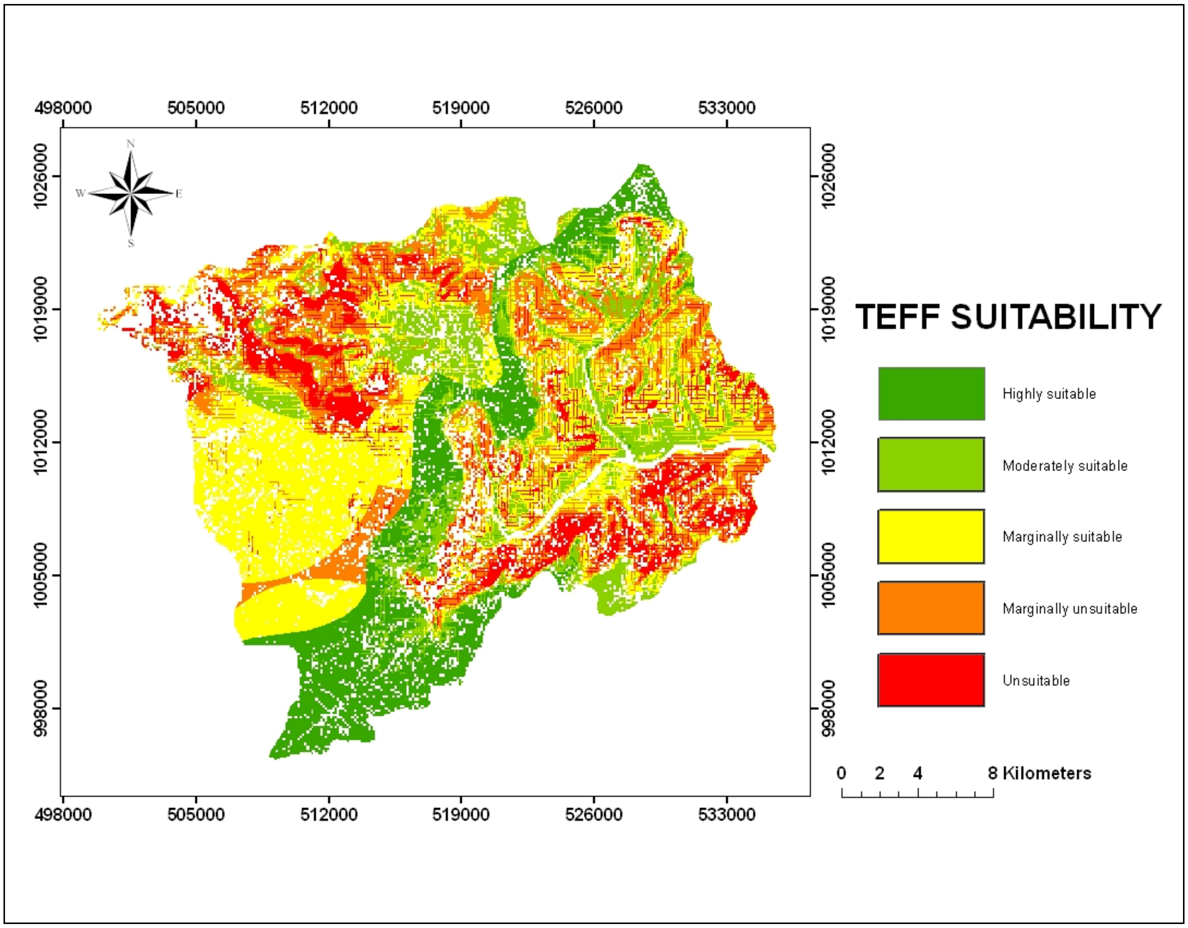


Fig 4.9 Area coverage (ha) of some crops in the woredas.
Source: Woreda Agricultural Bureau.



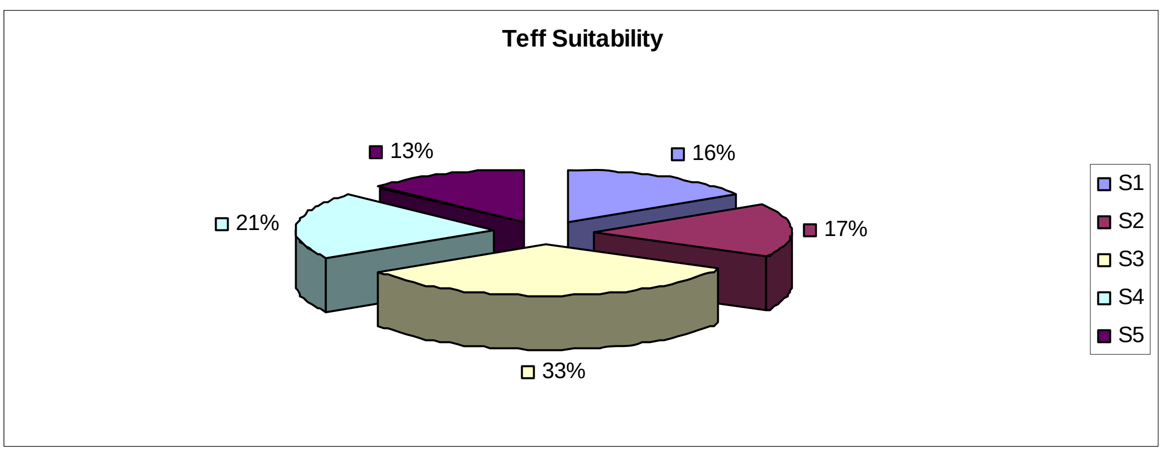


Fig 4.10 Teff Suitability map of the study area.

4.11 Wheat suitability analysis

Wheat is highly adapted to cool dry temperate region which grows in medium to high altitude. It requires an annual rainfall of 500-3000 mm and tolerance to high water logging problem. Weight and ranking are given based on the specific requirement of wheat and there is also involvement of experts, decision makers and farmers as well.

Parameters	Weight
Drainage	0.307
Depth	0.218
Slope	0.154
Texture	0.109
Rain fall	0.077
Temperature	0.064
Soil type	0.037
Water logging	0.026
Land use	0.019

TABLE 4.17 PARAMETERS WEIGHTS USED FOR WHEAT.

Consistency ratio = 0.056

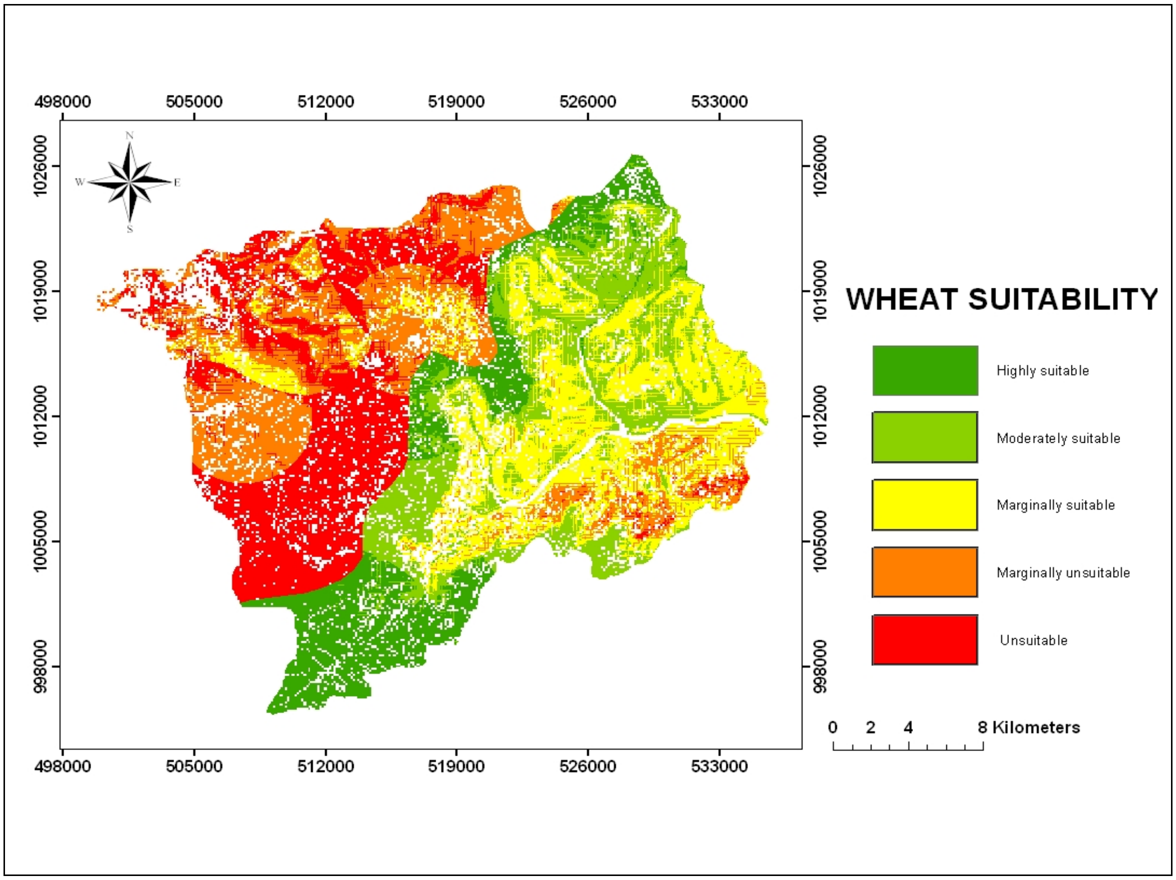
Consistency is acceptable

Suitability Class	Area (in Sq.km)	Area (in %)
S1	73.50	14
S2	96.71	19
S3	118.93	23
S4	106.60	21
S5	120.02	23

TABLE 4.18 WHEAT SUITABILITY AREAS UNDER DIFFERENT CLASS.

From the total land of the study area 73.50 sq km (14%) is highly suitable, 96.71 sq km (19%) moderately suitable, 118.93 sq km (23%) marginally suitable, 106.60 sq km (21%) not suitable and 120.02 sq km (23%) permanently not suitable for Wheat Table (4.18).

Constraints: These are lands which are not important to be a part of the suitability. Generally constraints are Infrastructures like towns, cities, Villages, Roads and water lands etc. White colors of the map below (Fig 4.11) are CONSTRAINTS for the Wheat Suitability.



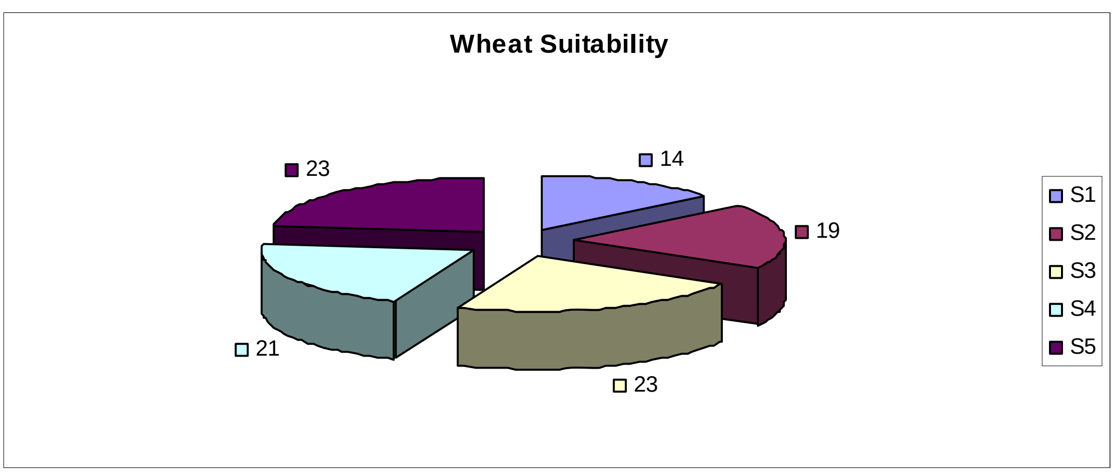


Fig 4.11 Wheat Suitability map of the study area.

4.12 Irrigation suitability analysis

The term 'surface irrigation' refers to a broad class of irrigation methods in which water is distributed over the field by overland flow. A flow is introduced at one edge of the field and covers the field gradually. The rate of coverage (advance) is dependent almost entirely on the differences between the discharge onto the field and the accumulating infiltration into the soil. Secondary factors include field slope, surface roughness, and the geometry or shape of the flow cross-section.

The practice of surface irrigation is thousands of years old. It collectively represents perhaps as much as 95 percent of common irrigation activity today. The first water supplies were developed from stream or river flows onto the adjacent flood plain through simple check-dams and a canal to distribute water to various locations where farmers could then allocate a portion of the flow to their fields. The low-lying soils served by these diversions were typically high in clay and silt content and tended to be most fertile. The land slope was normally small because of the structure of the flood plain itself.

The type of irrigation system selected is an important economic decision. Some types of pressurized systems have high capital and operating costs but may utilize minimal labour and conserve water. Their use tends toward high value cropping patterns. Other systems are relatively less expensive to construct and operate but have high labour requirements. Some systems are limited by the type of soil or the topography found on a field. The costs of maintenance and expected life of the rehabilitation along with an array of annual costs like energy, water, depreciation, land preparation, maintenance, labour and taxes should be included in the selection of an irrigation system.

The quality and quantity of the source of water can have a significant impact on the irrigation practices. Crop water demands are continuous during the growing season. The soil moisture reservoir transforms this continuous demand into a periodic one which the irrigation system can service. A water supply with a relatively small discharge is best utilized in an irrigation system which incorporates frequent applications. The depths applied per irrigation would tend to be smaller under these systems than under systems having a large discharge which is available less frequently. The quality of water affects decisions similarly. Salinity is generally the most significant problem but other elements like boron or selenium can be important. A poor quality water supply must be utilized more frequently and in larger amounts than one of good quality.

With the advent of modern equipment for moving earth and pumping water, surface irrigation systems were extended to upland areas and lands quite separate from the flood plain of local rivers and streams. These lands tend to have more variable soils and topographies, are usually better drained, and may be naturally less fertile. Thus, these lands usually require greater attention to design and operation. Weight and ranking are given based on literatures, experts, and farmers' knowledge and there is also involvement of decision makers.

Parameters	Weight
Slope	0.3547
Drainage	0.2399
Depth	0.1587
Texture	0.11036
Water logging	0.0676
Land use	0.0448
Soil type	0.0312

TABLE 4.19 PARAMETERS WEIGHTS USED FOR IRRIGATION POTENTIAL OF THE STUDY AREA.

Consistency ratio = 0.02

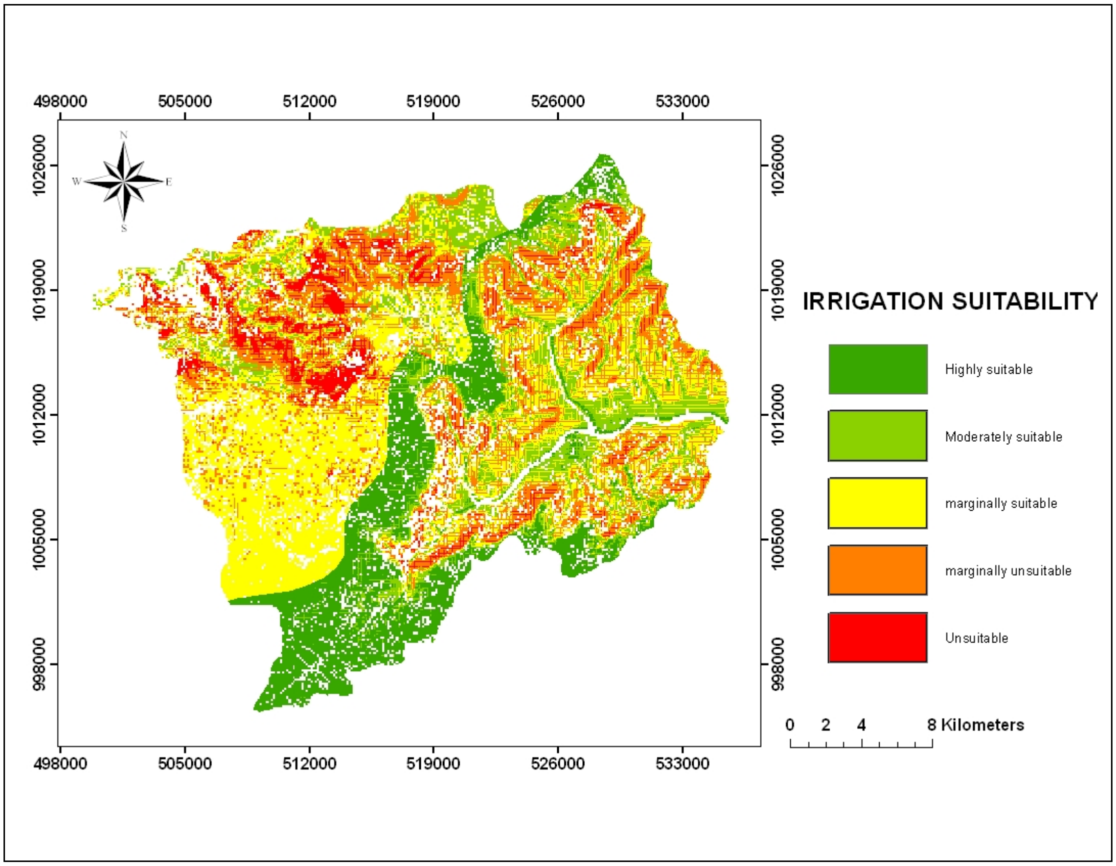
Consistency is acceptable

Suitability Class	Area (in Sq.km)	Area (in %)
S1	93.87	18
S2	85.63	17
S3	176.93	34
S4	126.13	25
S5	33.20	6

TABLE 4.20 IRRIGATION POTENTIAL SUITABILITY AREAS UNDER DIFFERENT CLASS.

From the total land of the study area 93.87 sq km (18%) is highly suitable, 85.63 sq km (17%) moderately suitable, 176.93 sq km (34%) marginally suitable, 126.13 sq km (25%) not suitable and 33.20 sq km (6%) permanently not suitable for Irrigation Table (4.20).

Constraints: These are lands which are not important to be a part of the suitability. Generally constraints are Infrastructures like towns, cities, Villages, Roads and water lands etc. White color of the map below (Fig 4.12) are CONSTRAINTS for the Irrigation Suitability.



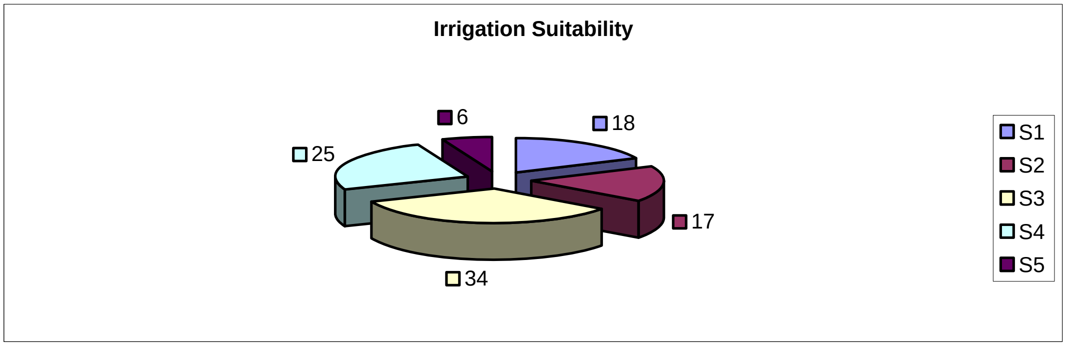


FIG 4.12 IRRIGATION SUITABILITY MAP OF THE STUDY AREA.

CONCLUSIONS

- ✓ Land Capability Classification is grouping or classifying of areas with the "same" capability to support sustainable agriculture. It is important for soil conservation i.e. to analyse biophysical conditions but Land suitability highly considers socio-economic conditions. The parameters which were considered for evaluation of the Land capability are Slope, Soil depth, past erosion, Water logging, Infiltration and stoniness (FAO). Most of the parameters used in this study are essential but slope has high influence in determining the Land capability of the area rather than the others. Based on the result obtained from Land Capability (Classification) 60 % of the area highly suited for production of annual crops (are those that are planted and harvested during the same production season). Grazing or perennial crops are also taking 18 % of the total area while forests are highly suited in 17 % of the study area.

- ✓ The FAO (1976) has given a framework for land suitability analysis for crops in terms of suitability classes from highly suitable to not suitable based on the crop specific soil, climatic and topographic data. The same framework has been incorporated in the study with some modification in order to make the situation more compatible to Ethiopian cases.

- ✓ Land suitability evaluation requires involvement of experts, local farmers and decision maker's knowledge. Crop suitability also highly dependent on specific crop requirement and expert's knowledge. Parameters used for analysis of crop suitability are slope, drainage, depth, texture, rain fall, temperature, soil type, water logging and present land use (land cover). These parameters ranked and weighted based on the selected crop i.e. Teff and Wheat (which are highly cultivated in the study area) requirement. There may be over lap in area of suitability for both crops this is because of there may be equal requirement in any one of the given parameters.

- ✓ The total land under the study area which is suitable for Teff and Wheat is 339.78sq km (66 %) and 289.15 sq km (56 %) respectively. The other 175.99 sq km (34 %) for Teff and 226.62 sq km (44 %) for Wheat is not suitable for both of them.

- ✓ Topography is a major factor affecting irrigation, particularly surface irrigation and the most critical factor that determines gravity (surface) irrigation is slope gradient Field slope and its uniformity are two of the most important topographical factors. Surface systems, for instance, require uniform grades in the 0-5 percent range. Most of the land of the study area is characterized by gentle slope; this indicates that most of the area is classified under suitable for surface irrigation.

- ✓ The yields of many crops may be as much affected by how water is applied as the quantity delivered. Most types of crops require deep soil depth for their growth. Soil depth of the study area varies from place to place. Its depth is between less than 25cm up to 150cm. Those places having soil depth greater than 100cm is very suitable for crops. Some crops have high economic value and allow the application of more capital-intensive practices. Deep-rooted crops are more amenable to low frequency, high-application rate systems than shallow-rooted crops.

- ✓ Soil texture affects the infiltration rate of the soil. Sandy soils typically have high intake rates and low soil moisture storage capacities and may require an entirely different irrigation strategy than the deep clay soil with low infiltration rates but high moisture-storage capacities. Sandy soil requires more frequent, smaller applications of water whereas clay soils can be irrigated less frequently and to a larger depth. Clay texture is the dominant type of soil texture in the study area and clay texture soil has great retention (water holding capacity) or less infiltration rate. There fore, more than half of the land of the study area is characterized by less infiltration rate. The other type of soil texture found in the study areas that determine the physical land suitability of land for surface irrigation and crops suitability is clay loam. This type of soil is suitable for many crops next to loam texture soil.

- ✓ Vertisols is the most dominant soil type in the Upper Kesem. This type of soil is black in color and reach in chemical properties of soil. As it was evaluated the physical land for irrigation and crops suitability, the drainage properties of the study area are classified in to well, moderately well and imperfect drained area. The dominant drainage type found in the study area is well drained area. Such type of drainage property is suitable for surface irrigation and growth of plants.

- ✓ Generally the parameters used for analyzing surface irrigation are slope, soil drainage, soil depth, texture, waterlogging, present land use (land cover) and soil type of the study area. The total land under the study area which is suitable for surface irrigation is 356.438043 sq km which is 69 % of the total area. The other 31 % (159.33096 sq km) is not suitable for surface irrigation.

RECOMMENDATION

- ✓ In this paper only physical characteristics of the parameters are used to analyse the land suitability and capability of the study area. But chemical properties (which vary continuously over the space and it is not possible to model as it is) of the soils are also very necessary for Land Capability, crops suitability and irrigation in a specified area. There fore, a research should be conducted on the evaluation of chemical properties of the soil such as Ph, soil fertility etc. under the study area.
- ✓ Physical suitability based on topography, climate and crop specific requirement is more focused in this paper. But other parameters like socio-economic, market infrastructure etc are recommended to be included.
- ✓ The potential negative environmental impacts of irrigation include water logging and salinization of soils, increased incidence of water-borne and water-related diseases. So potential suitability for irrigation has noting to do with out considering or avoiding the above problems.
- ✓ In order to have sustainable agriculture policy makers and decision makers should be aware of which area is highly suitable for which purpose. The critical importance of land for specified uses should be known either physically or economically.
- ✓ 85 % of Ethiopian people highly dependent on agriculture. But most of the farmers have small plots of land with poor management and investment level. As a result, the growth of production doesn't much with the growth of population. So Land capability and suitability analysis becomes more important in order to avoid poverty and improving the quality of life for rural populations and economic for the country in general.
- ✓ Ethiopia has a lot of rivers with high amount of rainfall annually. So irrigation suitability should be considered as an important investment for improving rural income through increased agricultural production in the country.

REFERENCES

Beek, K. J., P. A. Burrough and D. E. McCormack (1987). “Quantified land evaluation procedures: Proceedings of the international workshop on quantified land evaluation procedures held in Washington, DC 27 April - 2 May 1986”. International workshop on quantified land evaluation procedures, Washington, DC.

Belton, V. and T. Gear (1983). "On a short-coming of Saaty's method of Analytical Hierarchies." Omega **11**: 228-230.

Ceballos-Silva, A. and J. Lopez-Blanco (2003). "Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: a case study in Central Mexico.” Agricultural Systems **77**(2): 117-136.

D.W. Thorne and H.B. Peterson, 1949 Irrigated Soils, their fertility and Management, New York The Blackstone Company, Inc. Toronto.

FAO1976. A framework for land evaluation. Soils Bulletin, No. 32.

FAO1986. Irrigation in Africa south of the Sahara. FAO Investment Center Technical Paper 5. Rome.

FAO1988. Irrigation and water resources potential for Africa. FAO report AGL/MISC/11/87. Rome.

FAO.1995. A note on small-scale irrigation in Ethiopia. Rome.

FAO 2003.theoretical framework for land Evaluation. Geoderma 72: 165-190

Foote, K. E. and M. Lynch (1996). Geographic information systems as an integrating technology: context, concepts and definition. Austin, University of Texas.

Ghafari, A., H. F.Cook and H. C. Lee (2000). Integrating climate, soil and crop information: a land suitability study using GIS. 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs, Banf, Alberta, Canada.

Jankowski, P. (1995). "Integrating geographical information systems and multiple criteria decision making methods." international Journal of geographic Information System **3**(2): 251-273.

Jiang, H. and J. R. Eastman (2000). "Application of Fuzzy Measures in Multicriteria evaluation in GIS." International journal of Geographic Information Science **14**(2): 73-184.

Lai, S. (1995). "A preference-based interpretation of AHP." Omega **23**: 453-462.

Leingsakul, M., S. Mekpaiboonwatana, P. Pramojanee, K. Bronsveld and H. Huizing (1993). "Use of GIS and remote sensing for soil mapping and for locating new sites for permanent cropland -a case study in the highlands of northern Thailand." Geoderma **60**(1-4): 293-307

Malczewski, J. (1999). GIS and Multicriteria decision Analysis. USA and Canada, John Wiley &Sons.

Marble, D. H., H. W. Calkins and D. J. Pequet (1984). Basic Readings in Geographic Information Systems. Williamsville, NY. SPAD Systems Limited.

Masuda, T. (1990). "Hierarchical sensitivity analysis of the priorities used in the Analytic Hierarchy Process." Systems Science **21**(2): 415-427.

Mikhailov, L. (2003). "Deriving priorities from fuzzy pairwise comparison judgements." Fuzzy Sets and Systems **134**(3): 365-385.

Pereira, J. M. C. and L. Duckstein (1993). "A multiple criteria decision-making approach to GIS based land suitability evaluation." International Journal of Geographical Information Science**7** (5): 407-424

Saaty, T. L. (1977). "A Scaling Method for Priorities in Hierarchical Structure." Journal of Mathematical Psychology **15.3**.

Saaty, T. L. (1980). The Analytic Hierarchy Process. New York, McGraw-Hill International.

Saaty, T. L. and L. G. Vargas, Eds. (2001). Models, Methods, Concepts & Applications of Analytical Hierarchy Process. International Series in Operations Research and Management sciences.

Tkach, R. J. and S. P. Simonovic (1997). "A New Approach to Multi-criteria Decision Making in Water Resources." Journal of Geographic Information and Decision Analysis **1**(1): 25-44.

Triantaphyllou, E. (2001). "Two New Cases of Ranking Reversals When the AHP and Some of Its Additive Variants Are Used that do not occur with the Multiplicative AHP." Journal of Multi-Criteria Decision Analysis **10**: 11-25.

Triantaphyllou, E. and S. H. Mann (1994). Some Critical Issues in Making Decisions with Pairwise Comparisons. Proceedings of the Third International Symposium on the Analytic Hierarchy Process, Washington, D.C.

Triantaphyllou, E. and A. Sanchez (1997). "A Sensity Analysis Approach for some Deterministic Multi-Criteria Decision Making Methods." Decision Sciences **28**(1): 151-194.

D E C L A R A T I O N

I here by declare that the dissertation entitled "Land Capability, Irrigation Potential and Crop Suitability Analysis Using GIS and Remote Sensing in Upper Kesem (Awash Basin)"has been carried out by me under the supervision of Dr. K. V. Suryabhagavan, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2007-2008 as a part of Master of Science programme in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Place: Addis Ababa
Date: July 16, 2007

(Slehak Melak)

CERTIFICATE

This is certified that the dissertation entitled "Land Capability, Irrigation Potential and Crop Suitability Analysis Using GIS and Remote Sensing in Upper Kesem (Awash Basin)" is a bonafied work carried out by Slehak Melak under my guidance and supervision. This is the actual work done by Slehak Melak for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University. Addis Ababa.

Dr. K. V. Suryabhagavan

Lecturer

Department of Earth Sciences
Addis Ababa University
Addis Ababa