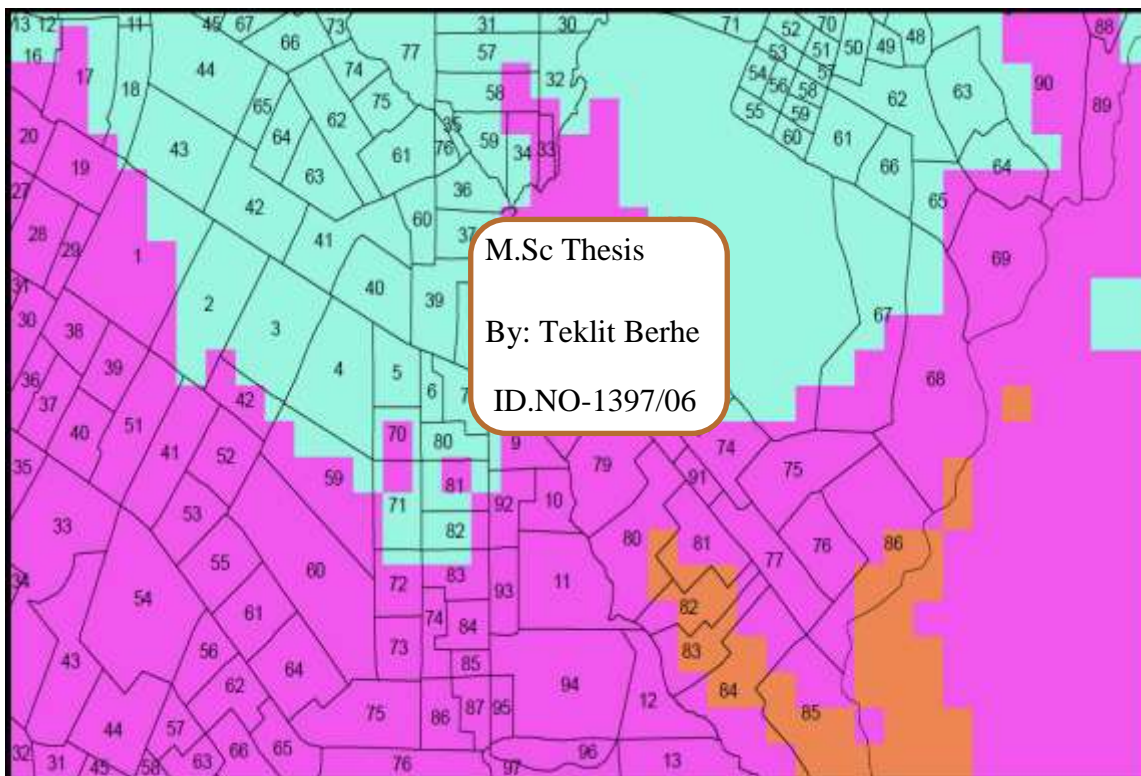


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SCHOOL OF EARTH SCIENCES
REMOTE SENSING AND GIS STREAM

**REMOTE SENSING AND GIS BASED URBAN LAND SUITABILITY MODELING AT PARCEL
LEVEL USING MULTICRITERIA DECISION ANALYSIS; A CASE STUDY OF BOLE SUB CITY,
ADDIS ABABA, ETHIOPIA**



Advisor: Dr. Getachew Berhan (PhD)

June, 2015

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ADDIS ABABA, ETHIOPIA**

By: Teklit Berhe

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA
UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN REMOTE SENSING AND GEOGRAPHICAL INFORMATION
SYSTEMS (GIS)**

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This is certified that the dissertation entitled “Remote Sensing and GIS Based Urban Land Suitability Modeling at Parcel Level Using Multicriteria Decision Analysis; A Case Study of Bole Sub City, Addis Ababa, Ethiopia” is bonafied work carried out by Teklit Berhe under my guidance and supervision. This is the actual work done by Teklit Berhe for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and GIS from Addis Ababa University,
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How can I Replay the Lord for All His Acts of Kindness to Me? Ps 116:12

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Abstract

This research was carried out to evaluate the suitability of the land for urban development activities using remote sensing and GIS applications with the integration of MCDA approach. Evaluation of urban land in terms of suitability classes based on the method described in FAO guide line for land evaluation the parameters used for the evaluation of land suitability for urban development activities were slope, soil type, rivers and streams, soil depth, geology, road network, ground water prospect .This research aimed at assessing urban land suitability modeling of the study area through Geographic Information System and remote Sensing based urban land suitability modeling techniques, by preparing maps that enhance proper urban land use for sustainable urban land development and management. Spatial Data was processed and generated from these specified parameters to generate urban land suitability model map at parcel level finally. IDRISI was applied to generate weight for each parameter according to their level of importance. By the help of ArcGIS weight was given for each parameter and finally With spatial analytic capability of Geographic information system weighted overlay method was used to generate the final urban land suitability model map from which urban land suitability maps were developed. Accordingly the final result of this research shows 72.09% of the total area was suitable for urban development activities and 29.33% was unsuitable for urban development activities the current urban development activities of the study area were in the area which was identified as suitable area. Finally this research recommends that areas identified us unsuitable area needs additional improvements after urban development activities made.

Keywords: Remote sensing, Geographic Information System, suitability modeling, Analytic Hierarchy process

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ACRONYMS

AA	Addis Ababa
CAD	Computer Aided Designing
CSA	Central Statistical Agency
CR	Consistency Ratio
CBD	Central Business District
DEM	Digital Elevation Model
DN	Digital Number
FAO	Food Agricultural Organization
GIS	Geographic Information System
GPS	Global Positioning System
MCDA	Multi Criteria Decision Analysis
NCGIA	National Center for Geographic Information and Analysis
NMA	National Metrological Agency
SDSS	Spatial Decision Support System
SUR	Sub Urban
SRTM	Shuttle Radar Topographic Mission
RS	Remote Sensing
SDSS	Spatial Decision Support System
TRZ	Transitional Zone
MCDA	Multi Criteria Decision Analysis
UTM	Universal Transverse Mercator
WLC	Weighted Linear Combination

1. INTRODUCTION

1.1 General Background

Urbanization is one of the most influential socio economic issues now a day's and major challenge to policy makers planners and city managers. Urban area in developing countries like Ethiopia has fast changes due to high population growth and rapid urbanization. Urban land suitability modeling is the first step whether a land is likely to be suitable or not for sustainable urban development for an intended purpose or use.

Land suitability refers to the ability of a specific type of land for specific purpose and this involves the process of grouping of a particular land in terms of their suitability for a defined use (Parakash,2003) in other words it is the process to determine whether the land resource is suitable for a specific use it is also under take to determine the suitability level in order to evaluate the most suitable area for urban development activities urban land suitability should be carefully examined with the help of different parameters. Suitability analysis techniques integrate three factors of the study site location, development activities, biophysical and environmental factors (Miller et al., 1998) land suitability aims at an identifying the most appropriate spatial pattern for future land use.

The most useful applications of remote sensing and Geographic Information System for urban land use planning and management is land suitability mapping and analysis based up on the parameters identified. (McHarg, 1969; Collins et al., 2001).Land suitability analysis aims at identifying the most appropriate suitable urban land for future and current urban development according to the specific parameters, preferences, or predictors of some activity Collins et al., 2001). Geographic Information System based land suitability analysis has been applied in a wide variety of situations including land suitability approaches for defining land suitability (Pereira and Dickstein, 2001), hydro-geological suitability of land for urban development activities land evaluation and planning (Miller et al., 1998), environmental impact assessment (Moreno and Seigel, 1988), selecting the best site for urban land suitability modeling activities (Eastman et al., 1993).This Thesis focuses on land suitability analysis and modeling as applied to urban planning and land management.

1.2 Problem Statement

Urban Land suitability modeling can be done using various methods and by using different parameters according to the nature of the urban area. However, the diversity of residents and intensive use of land resources through the increasing number of population coupled with economic activities and global market drive unprecedented land use and land cover changes in urban and rural environment for further environmental protection and wise use. (Ezeaka and Davidson, 2003).

These changes lead to transformations in the hydrological, ecological, geomorphologic and socioeconomic systems and which are often neglected by both rural and urban administrations. Thus, special attention and continuous assessment are required for monitoring and planning urban environment. It is believed that institutional weakness and lack of experienced professionals can be considered as one reason for the improper urban land use of the study area. However the gap is not large but parameters like Geological and Hydrological factors were not used in the existing urban land suitability modeling and analysis.

The second issue is related to the procedural approach on how urban land suitability modeling prepared and implemented. Evidences and literatures show that urban land suitability modeling of the study area was done on a traditional way. It lacks the consideration of parameters like soil depth and ground water potential, geology etc. To fill this gap this research shows the overall main parameters with Geographic Information System and remote sensing techniques as well as Analytic Hierarchy Process approach by comparing the parameters by giving weights for each. This thesis attempts to evaluate the suitability of the study area using remote sensing and Geographic Information system with the integration of MCDA approach which could benefit decision makers, stakeholders and city administration in general.

1.3. Objective of the Study

1.3.1 General Objective

The general objective of this research is to use Remote sensing and Geographic Information System techniques for urban land suitability modeling at parcel level using multi criteria decision making analysis approach for Bole sub city.

1.3.2 Specific Objectives

- To investigate and identify the parameters used for urban land suitability modeling in the study area.
- To prepare land use land cover map of the study area.
- To combine the existing cadastral map with the new urban land suitability model result map in order to show the suitability of each parcel in the study area.
- To develop urban land suitability model of the study area for urban development activities which used as a bench mark for other researchers and decision makers

1.4 Research Questions

To realize the above sated objectives the following research Questions have been formulated.

- What are the main influencing Factors or parameters used for urban land suitability modeling in the study area?
- What are the similarities and differences between the existing urban land use and urban land suitability model result and what are the main reasons contributing for the difference?
- How much percent of the study area was unsuitable for urban development?
- How much percent of the study area was suitable for urban development?

1.5. Significance of the Study

This research is expected to produce urban land suitability model map of the study area that demarcates the study area into different urban land use classifications according to their suitability level for different urban land use purposes based up on the parameters used.

- A properly organized urban land suitability modeling data is expected with an importance to decision making by the responsible persons and review by concerned stakeholders and subsequent researchers.
- A complete report with strong recommendations based the up on findings is the other main output expected from this thesis with comparison of the existing urban land use of the study area.
- The thesis will have a paramount importance to the government, municipal authorities and the community in the sub city for the need for improvements and urban land use planning & suitability modeling.
- This thesis can also use as one source of information for those institutions concerned with urban land management and helps to improve the quality of decision making in urban planning and management using GIS and RS.
- It will also use as a benchmark information to those scholars, who want to conduct future studies on urban land suitability modeling analysis using GIS and RS by integrating Multicriteria decision analysis approach,

1.6. Scope of the study

This thesis focuses on remote sensing and Geographic Information System based urban land suitability modeling at a parcel level using multi criteria decision analysis in Bole sub city of Addis Ababa, Ethiopia using GIS and Remote Sensing Multi criteria Decision Analysis techniques. It is necessary to define the scope of the study so that the untreated areas could be left for other Researchers. Accordingly, the scope of this study was limited in Bole sub city of Addis Ababa Administration. Addis Abeba, Ethiopia

1.7. Limitation of the study

Many researches and articles have been published about the factors that influence urban land suitability modeling. All the studies considered different parameters but some of the factors appear in all studies as a common. Like slope, soil type, Road network etc. However, this study lacks to obtain fully completed data related to urban land use suitability modeling. Organized and well urban cadastral base maps prepared based up on parameters rather on the centrality of the city; in addition it is also difficult to obtain high resolution satellite images used to identify urban land use exactly instead the researcher used existing urban land use land cover map of the city.

The second limitation is number and types of factors aggregated to generate urban land suitability model numbers of different factors have been included in this study because the researcher was not able to get data to add more factors, Therefore the way the researcher analyzed the urban land suitability model of the study area is based on spatial factors with mostly GIS based system live room for other research to consider all these limitations and include other physical and socio economic factors.

1.8. Structure of the research

This research is organized into six chapters. As in the following way:

Chapter one, deals with the general context of the study including introduction, back ground problem statement, objective, research question, significance of the study, scope of study, limitation of the study and finally structure of the research.

Chapter two, gives a comprehensive review of literature on the theory of urban land suitability modeling which includes identification and explanation of the main influential factors that influence urban land suitability modeling at parcel level using multi criteria decision making analysis and Geographic Information System and remote sensing approach.

Chapter three, deals with description of the study area, physiography and drainage, population, climate, land use, geology, soil, methodological approach, data source, data collection, data's analyzed and organized in to meaning full result can be used in the suitability model the general concept of urban land suitability modeling and its application in GIS environment is explained and based on the analysis methodology flow chart also developed to show the overall research process going on.

Chapter four, deals with results processed from all parameters used to generate urban land suitability model of the study area.

Chapter five, deals with Discussions on the results of urban land suitability modeling of the study area at Parcel Level using Multi criteria Decision Analysis with GIS and RS techniques.

Chapter six, deals with conclusion and recommendations and its findings in general and conclusions are drawn from the research results and findings obtained recommendations including suggestions for further research are forwarded.

2. LITRATURE REVIEW

2.1 Definition of Urban Land Suitability

Urban Land suitability can be defined as a fitness of a given use of urban land for a defined purpose based up on a scientific study and defined parameters. Land may be considered in its present situation or after some arrangements made on it. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined purpose to be used” (FAO 1976). In general, urban land area can be classified as “Suitable” or “Not Suitable” for a specific use: Suitable areas can be divided in to three classes, which reflect the degree of suitability, one from the other. The number of classes can vary but it should be kept to the minimum necessary and should never exceed the number of classes from five. The lowest number always represent the most suitable and the highest number the least suitable area. FAO recommends three suitability classes with the following demonstrations bellow;

Table 2.1 Land suitability classification

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

Sub-Class N1: Currently not suitable but may be suitable with some arrangements made

Sub-Class N2: Permanently not suitable not suitable permanently by any arrangement made

(Source, FAO 1976)

There can be a number of reasons why an area classified as suitable and not suitable, for example technical considerations like slope, soil fertility, soil type, ground water potential, urban infrastructure, soil depth, road network etc. It depends up on the purpose of urban land use needed; environmental considerations also should be considered potential damage of cultivation to biodiversity, aquifers, etc. or economic considerations investment costs and revenues. Within the class “Not Suitable”, there are normally two sub classes. Currently not suitable but may be suitable after some arrangements made on it and permanently not suitable by any arrangements made to it.

2.2 Land Evaluation Modeling and Suitability Mapping In General

Urban land evaluation modeling and suitability mapping can be used in a broad field of disciplines for different purposes. However, most land evaluation methods are emphasizing from soil science context. According to Rossiter’s theoretical framework for land evaluation (1996), the reason for this is mainly because FAO land evaluation methodology was initially developed by soil scientists initially. But the aim is common for every intended use. Land evaluation is a tool for strategic land use planning and suitability modeling. It predicts land performance, both in terms of the expected benefits from and constraints to productive land use, as well as the expected environmental degradation due to these uses (Rossiter 1996, 165). According to Rossiter (1996), there are 3 different modeling approaches for land suitability evaluation in General. They are classified depending on how they take time and area into account;

1) Non-spatial models of single-area land suitability evaluation

In these models, the suitability of a single small and homogenous area on the earth’s surface is determined. The influence from surrounding areas is neglected, and the geographic location is not taken into account. This type of analysis is only valid for mapping unit consisting of small areas, which share the same set of land characteristics of the area. The evaluation units must be “small enough” and “homogeneous enough” for the objectives of the land evaluation, and must not exceed the precision of the natural resource inventory from which land characteristics are derived.

2) Spatial models of single area land suitability evaluation

These models consider the suitability of an area for a certain land use that is dependent on its geographic location. Such models require GIS operations to implement them. In these operations, one computes a new value for each location as a function of existing data explicitly associated with that location, or as a function of its neighborhood, or as a function of values associated with a zone containing the location.

3) Models of multi area suitability and the land allocation problems evaluation

A set of land mapping units that are to be planned together, for example, fields managed global constraints on the land use that apply to entire management or planning unit. Examples include a maximum or minimum land area to be allocated to each land as part of the same urban or management parcels of a block, there are often evaluating use type, maximum or minimum evaluation levels of each output, and a limited supply of labor, capital, or inputs. There may be one overall goal, e.g. to maximize economic return over the entire project, or, more typically, multiple goals corresponding to the different land users or to a variety of societal objectives of the study area (Rossiter 1996).

2.3 Land Evaluation Procedures

The main activities one can perform in a land evaluation procedure are discussed as bellow:

Initial consultations, concerned with the objectives of the evaluation, and the data and assumptions on which it is to be based on,

- Description of the kinds of land use to be considered, and establishment of their requirements
- Description of land mapping units, and derivation of land qualities
- Comparison of kinds of land use with the types of land cover present in the study area
- Economic and social impact analysis
- Land suitability classification qualitative or quantitative
- Presentation of results of the evaluation

A schematic and simplified representation of land evaluation procedure activities is shown in Figure 2.1 below as in spatial and non-spatial aspect.



Figure 2.1 Schematic illustrations of activities in land evaluation procedure

Within the Framework, considerable freedom exists in choice of the approach and procedures that are most appropriate in any set of circumstances. This choice is made on the basis of the objectives and assumptions of the study.

2.4 Basic Concepts of Geographic Information System as a Tool

Geographic Information Systems is a computer based system that provides four sets of capabilities to geo referenced data, data input, data management storage and retrieval, manipulation and analysis, and finally data output Arnoff (1989).GIS is a set of tools for collecting, storing, retrieving as well as transforming and displaying spatial data from the real world for a particular set of purposes (Burrough, 1986). Furthermore, Geographic Information Systems is a computer based system which is used to digitally reproduce and analyze the future at present on earth surface and the events that take place on it. In the light of the fact that almost 80% of the data has geographical reference as its denominator, it becomes imperative to underline the importance of a system which can represent the given data geographically. In order to utilize the land resources in sustainable way, a land use planning that incorporates the different land characteristics has a paramount importance. To incorporate the different land attributes that differ spatially and to identify the best suitable urban land use for urban planning, GIS is a vital tool. Geographic Information System incorporates database systems for spatial data.

Moreover, the surface and overlay analysis capabilities in GIS can effectively facilitate in handling vast amount of spatial information (Dayawansa, 2003).It is estimated that 80% of data used by managers and decision makers is related to spatial data. Data are of little value in and of themselves. To be useful, they must be transformed in to information. When data are organized, presented, analyzed, interpreted, and considered useful for the decision making, they become information. Accordingly, geographical information can be defined as geo referenced data that has been processed in to a form that is meaningful to the decision makers and it is of real or perceived value in the decision-making process. Information is used by the decision maker and is derived from data (Malczewski,1999). Traditionally, spatial data has been acquired and rendered in to pictorial form to accomplish variety of activities related to land suitability analysis, with the introduction and dissemination of high speed computers, data capture and display devices. The importance of efficient and cost effective land resource data management was emphasized. As a result, database systems for spatial data, commonly named as a Geographic Information Systems were designed and developed enabling the acquisition, compilations, analyzing and display of topographical interrelations. And to analyze different spatial features using different methods or approaches of GIS techniques.

2.5 Basic Concepts of Remote Sensing as a Science

Remote sensing can be defined as a science and art of acquiring information spectral, spatial, and temporal information about material objects, or phenomenon above and below the earth surface, without coming in to physical contact with the objects or phenomenon under investigation (Lillesand and Kiefer, 2004). Without direct contact, some means of transferring information through space must be utilized. In remote sensing, information transfer is accomplished by use of electromagnetic radiation (Lillesand and Kiefer, 2004). Image processing and analysis can be defined as the “act of examining images for the purpose of identifying objects and judging their significance”. Image analyst study remotely sensed data and attempt through logical process in detecting, identifying, classifying, measuring and evaluating the significance of natural and manmade objects, their patterns and spatial relationships.

Digital image consists of discrete picture elements called pixels (picture element). Associated with each pixel is a number represented as DN (Digital Number) that depicts the average radiance relatively small area within a scene. The range of DN values normally from 0 to 255. The size of this area affects the reproduction of details within the scene. As the pixel size is reduced more scene detail is preserved in digital representation (Lillesand and Kiefer, 2004). Digital image analysis is usually conducted using raster data structure each image is treated as an array of values. It offers advantages for manipulation of pixel values by image processing system, as it is easy to find and locate pixels and their values from images for further analysis.

2.6 An over view of urban land Suitability Modeling and Analysis

2.6.1 Land Suitability Assessment Methodology

The methodology adopted in this thesis for urban land suitability evaluation and modeling was based on FAO's 1976 methodology it contains land characteristics against land suitability by determining deferent parameters' specific to the study area . In order to evaluate urban land suitability modeling of an area based up on the intended factors and parameters for the proposed use. Based on this the researcher prepared a method and by identifying various parameters of the study area those are spatial data from field survey, Arial photo, and RS and GIS technologies

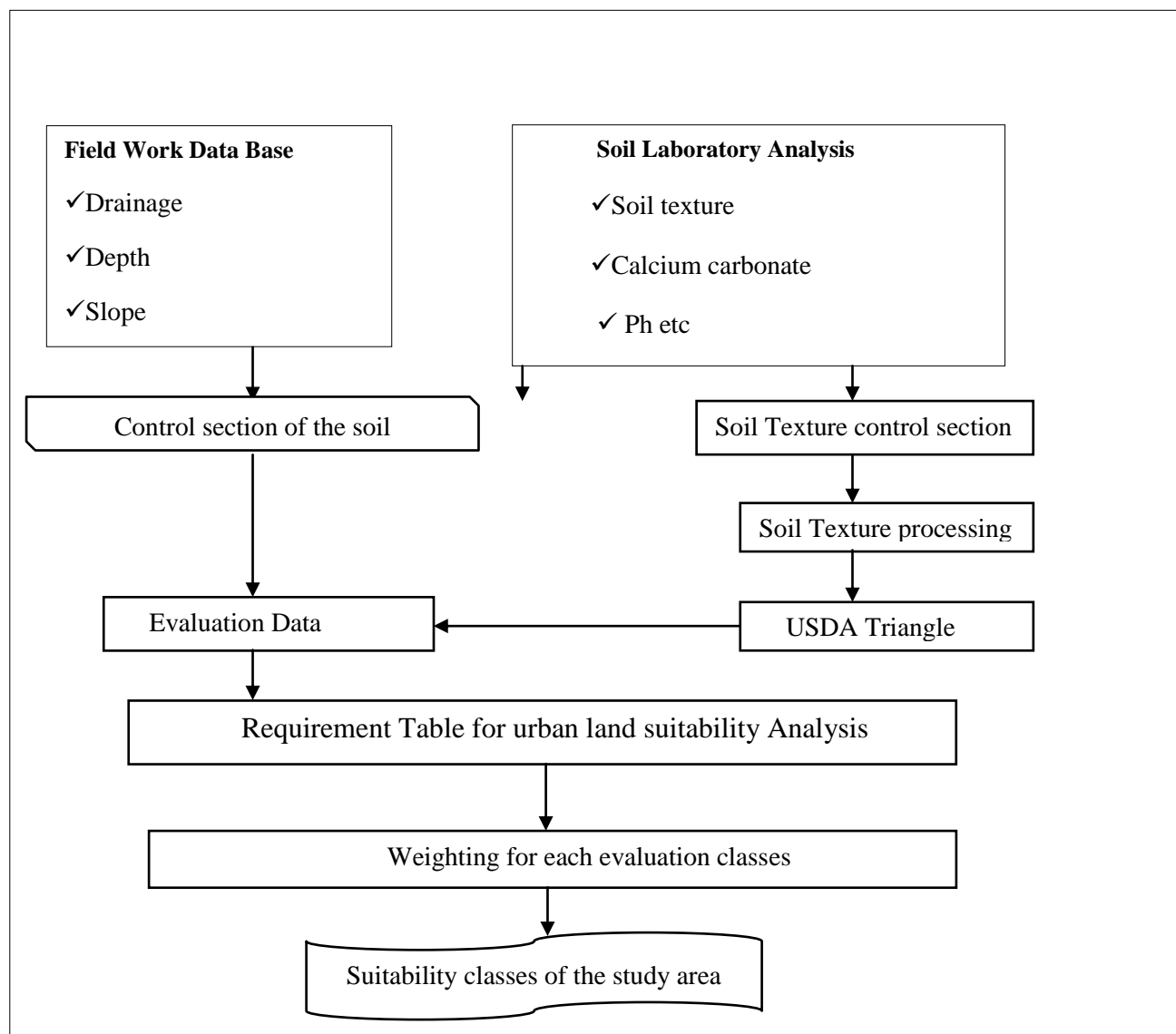


Figure 2.2 FAO, 1976 Methodology for land suitability evaluation and modeling analysis.

2.6.2 Level of Suitability Assessment

Although the procedures of land suitability mapping are common to all types of land suitability assessment, there are different levels at which the assessment can be done. There are three levels which can be distinguished depending on intensity of the surveys and studies carried out. These are reconnaissance, semi-detailed and detailed. These are usually reflected in the scale of the suitability analysis maps produced. Reconnaissance surveys are concerned with broad inventory of resources and development possibilities at regional and national level at large scale. Economic analysis is only in very general terms and land suitability assessment is qualitative. The results contribute to national plans, permitting the selection of development areas and priorities for urban planning.

Surveys at the semi-detailed level are concerned with more specific aims such as feasibility studies of development projects in a small area. Economic analysis is considerably more important and suitability assessment is usually quantitative. This level provides information for decisions on the selection of projects or whether a particular development or land use change is to go ahead. The detailed level covers surveys for actual planning and design or farm planning. It is often carried out after the decision to implement a project has been made. Land suitability mapping is the process of assessing land for the specific kinds of use (Dent and Young 1981). The basic feature of the process is the comparison of the requirements of land use with the resources offered by the land. Fundamental to the assessment process, is the fact that different kinds of use have differing requirements. Land suitability mapping requires information from three main sources land, land use and socio-economics. This is because considerations of economic, social consequences for the people concerned and consequences beneficial or adverse for the environment have to be taken into account in the process of evaluation.

Successful land assessment is a necessarily multi-disciplinary process and therefore, the use of a standardized framework is essential to ensure logical, and quantitative analysis of the suitability of the land for a wide range of possible land uses. Suitability mapping does not involve the determination of land use changes or proposals but rather provides information on which decisions on land use interventions can be made. To be useful in this role, the products of suitability mapping should provide information on two or more potential alternatives for use for each area of land including the consequences, beneficial and or adverse of each.

2.6.3 Advantages of Urban Land Suitability Modeling

Urban Land suitability modeling becomes important where change is anticipated. This may be a change in kind of land use such as bringing into suitability land formerly under another use. Prediction is needed for the suitability of the land for different forms of needs, or other benefits and the consequences of such change on the environment. These include adverse consequences such as the warning that certain land should not be cultivated owing to severe hazard of soil erosion. Land suitability mapping has high potential for the management of environment by providing resource inventory and project feasibility information to developers and investors. Resource inventory enables developers to see for example, where the best areas for business, industry, and to be. Identification of alternative development projects can then follow. Project feasibility is required before a decision to invest is taken place. Urban Land suitability modeling provides one of the sources of data for land use planning purpose.

Land use planning has immense usefulness in the management of the urban land management

A land use plan would provide the following advantages.

- Enhance environmental sustainability
- Create harmony in various land uses
- Reduce regional development imbalance
- Optimize resource utilization for maximum returns
- Manage land as a scarce natural resource

If the above objectives are achieved, it would lead to orderly, coordinated and harmonious development in the urban land management and administration in order to promote, safety, efficiency, social equity, social choice and environmental conservation and efficient land management system.

2.6.4 Procedures Used For Urban Land Suitability Modeling

Procedures and main activities used in suitability mapping and suitability modeling are shown as in Figure 2.3 below. The first step is that of setting the objectives of the assessment. This is done through consultations with stakeholders such as land owners, government departments, NGOs and the private sector and Experts. The objectives are specified activities to be carried out on the land for purposes of attaining defined goals which are in most cases have quantifiable outputs. The next step is the

identification and description of the kinds of land use to be considered and establishment of the requirements. Land qualities required for particular land uses are determined. Land qualities are measurable attributes of land on which decisions on suitability of land for specific uses can be made. Land quality determination should be done by a multi-disciplinary group of experts representing all considered land use objectives. Such experts include, among others, agriculturalists, GIS Experts, foresters, nutritionists and planners.

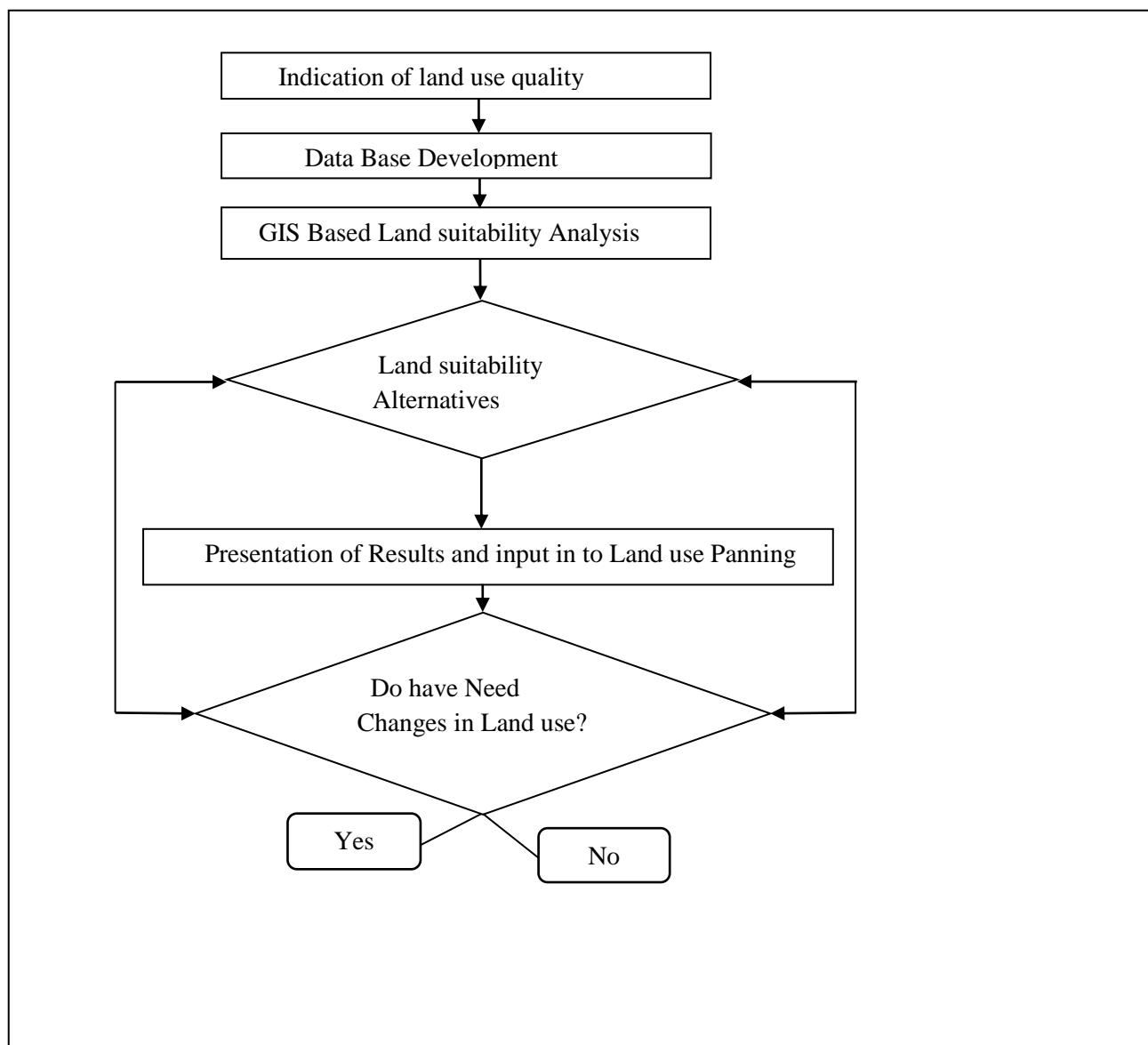


Figure.2.3 Flow chart for land suitability modeling processes

Figure 2.3 gives examples of land qualities related to various production systems and management practices. Examples of land qualities for specific land uses are given in Table 2.5 database development involves collecting background data on the physical, economic, and social and environment parameters to give the context of the study area. These data include:

- Location and accessibility
- Climatic zone
- Relief
- Present state of land improvements e.g. reclamation, drainage
- Population and its rate of change
- Level of living e.g. gross domestic product per capita income
- Education
- Basis of the present economy
- Economic infrastructure e.g. roads, urban services
- Government subsidies
- Size of farms or other landholdings
- Land tenure system
- And Political system

This database creation involves the development of a digital database which is used in the next stage of land suitability analysis which is most efficiently done in a Geographic Information System environment. GIS is a computer based information system that enables capturing, modeling, manipulation, retrieval, analysis and presentation of geographically Geo referenced data. It is a facility for preparing, presenting, and interpreting facts that pertain to the surface of the earth. All the above data are brought together spatial layers and analyzed systematically. GIS integrates the land qualities from the physical, biological and socio-economic aspects and supports decision making through Decision Support System approach.

Decision Support System is a mechanism that can be used to provide information needed to make effect decisions on the land use to be allocated to a particular piece of land. Figure.6 illustrates the land suitability analysis process in a GIS environment. In the DSS land under consideration is ranked according to its suitability in the performance of specific land uses on the basis of simultaneous evaluation of all land qualities known to affect the specific land use. The output from this process should provide guidance for land use allocation decisions. If there was only one objective the allocation decision would simply involve identifying the highest ranked sites and allocating them until the projected demand area is satisfied. With multiple objectives, it is likely that some objectives will pick the same land units as the most suitable. In such circumstances, decisions have to be made on which objectives to allocate to which land units.

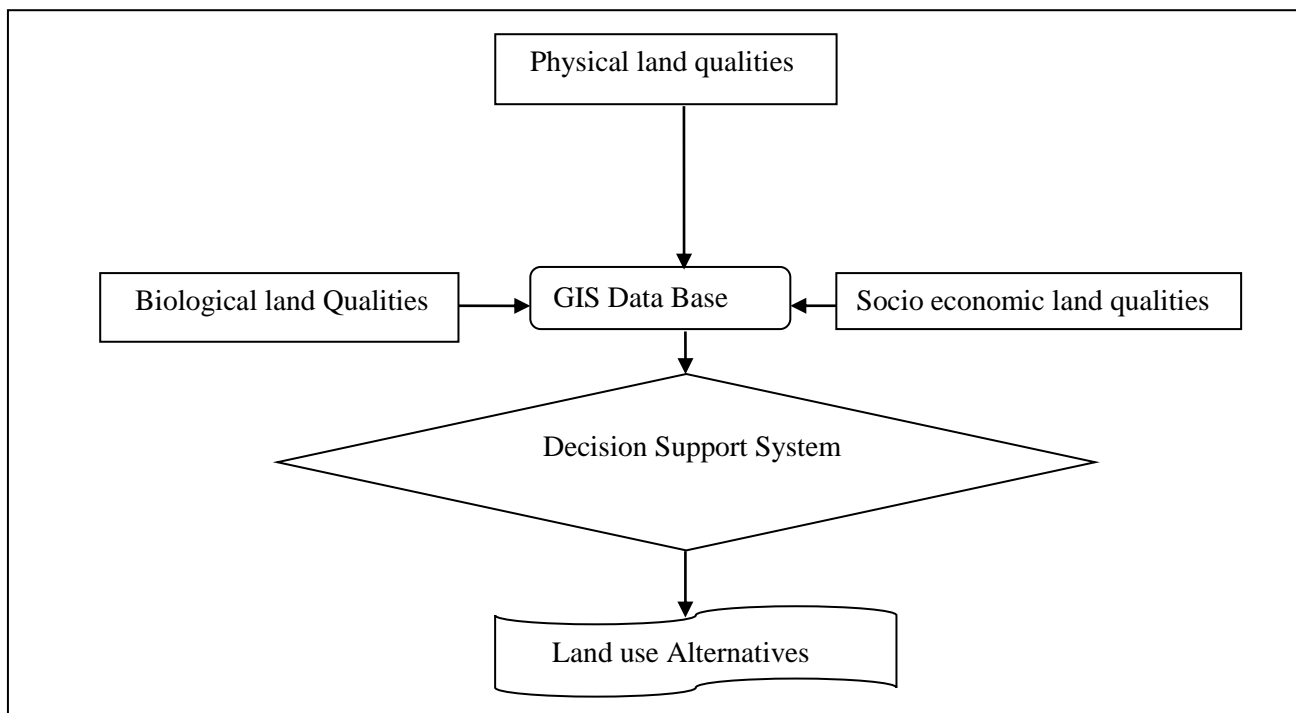


Figure 2.4 Land suitability determination process

Although the procedure indicates that the activities are undertaken successively, there is considerable amount of iteration in the procedure followed. For example some revision of the activities may become necessary upon findings in the later activities. More specifically if there are changes in objectives during the land suitability process or land use planning due to changes in socio-economic characteristics or identified land qualities then the whole process has to be repeated as shown in Figure 2.4 above.

2.6.7 Urban Land Suitability Classification

Table 2.2 Illustrate the structure of urban land suitability classification. The suitability of urban land for a particular use is categorized as most suitable, suitable, moderately suitable, marginally suitable and not suitable. In some cases, classes may be specified in terms of yield like Agricultural land, for example S1 >80% optimum yield, S2: 40-80%, S3: 20-40%. N: yield < 20% of optimum yield where this is the breakeven point. According to Food and Agricultural organization (FAO) soil classification.

Table 2.2 Structure of land suitability classification Based on (FAO, 1985)

Classification	Description
Class S	Land that can support the land use type without degrading its productive capacity and yielding benefits that justify the inputs
Class SI Most Suitable	Land without limitations or with only minor limitations that will not significantly reduce productivity nor require extra inputs.
Class S2	Land having limitations that will reduce productivity or increase the inputs required to maintain productivity compared to S1 but still clearly suitable and offering attractive benefits for use.
Class S3	Land having limitations so severe those benefits are reduced and/ or require inputs increased so that this expenditure is only marginally justified.
Not Suitable N	Land that cannot support a specified land use type on a sustained basis. Either the Land use is technically impractical or cannot be sustained because it leads to progressive destruction of land and water resources or is financially unprofitable.

Source FAO, 1985

The suitability classification is based on land qualities and land characteristics. A land quality is an attribute of that land that has a specific effect on land use suitability. Examples are water availability, nutrient availability drainage, flood hazard and erosion hazard. Land quality can rarely be measured directly because they are determined by the interaction of several land characteristics. However, they are frequently described by land characteristics. Erosion hazard as land quality is for example determined by rainfall intensity, ground cover, soil permeability and structure, slope angle and length, which are all land characteristics.

Individual characteristics are usually unsuitable for assessing land suitability. Sometimes they act in opposing directions for example slope must be used to assess erosion hazard. The steeper the slope the worse the hazard but slope also determines drainage, the steeper the slope the quicker the drainage. There is numerous land qualities required for any particular land use types. However, in practice only a few critical ones have major influence on suitability. The suitability classification is based on land qualities and land characteristics. A land quality is an attribute of the land that has a specific effect on land use. Examples are water availability, nutrient availability drainage, flood hazard and erosion hazard. Land quality can rarely be measured directly because they are determined by the interaction of several individual land characteristics. However, they are frequently described by land characteristics. Erosion hazard as land quality is for example determined by rainfall intensity, ground cover, soil permeability and structure, slope angle and length, which are all land characteristics. Individual characteristics are usually unsuitable for assessing land suitability.

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- a) Land units: areas of land with distinctive land qualities. These may be soil series, soil associations or landscapes, land systems or facets, depending on the scale of the surveys and the time and money available for the mapping,
- b) Present land use: current spatial land use patterns of the area
- c) Tables and textual material showing degree of land suitability: sharing the suitability of each land unit for each alternative land use type.
- d) Land use problems: for example flood hazard, soil erosion hazard, drainage problems and soil salinity.

2.7 Role of Remote Sensing and Geographic Information System in Urban Land Suitability Modeling

Geographic Information System is used as a tool for input, storage and retrieval, manipulation and analysis, and output of spatial data (Marble et al. 1984). GIS functionality can play a major role in spatial decision making by data analysis by applying various parameters and approaches. Considerable effort is involved in information collection for the suitability analysis of urban land suitability modeling. This information should present both opportunities and constraints for the decision makers (Ghafari et al. 2000). GIS have the ability to perform numerous tasks utilizing both spatial and non-spatial data stored in it. It has the ability to integrate variety of geographic technologies like Global Positioning System and Remote Sensing technologies. The ultimate aim of Geographic Information System is to provide support for spatial decisions making process (Raguntah,2006). In Multi-criteria evaluation many data layers are to be handled in order to arrive at the suitability level, which can be conveniently achieved using GIS. Remote sensing provides the information about the various spatial criteria or factors under consideration. Remote sensing can provide us the information like land use or land cover, drainage and topography of our area of interest.

Many of the non-spatial parameters can also be inferred by looking the various spatial parameters. Remote sensing in combination with Geographic Information System will be a powerful tool to integrate and interpret real world situation in most realistic and transparent way. Integrated GIS and Remote Sensing technology apart from saving time and providing good data quality have the ability to locate potential new urban land use sites (Leingsakul et al. 1993).physical parameters which used for urban land suitability modeling for this study are soil, drainage, physiographic, land use land cover, ground water prospect, road network and land value with their detail properties and types. By integrating this spatial data with the help of GIS and RS this thesis tries to evaluate the urban land suitability modeling of Bole sub city at parcel level using Multi criteria Decision analysis. The physical parameters used for this thesis are listed below in table 2.3

Table 2.3 List of physical parameters and their importance in land suitability for urban land development

R.No	Parameter	Category	Constraint	Development considerations
1	Soil	Soil depth	Foundation inadequacy	Very deep to deep soils are required for urban development from the foundation point of view as well as providing infrastructural facilities like construction, water, electricity etc.
		Soil type	Foundation inadequacy	Areas with un suitable foundation materials such as swelling or shrinking soils, compressive soils etc. expensive for construction.
2	Physiographic	Slope Aspect	Steepness and suitability	Land where high and medium slopes more than 7 percent provide constraint for urban land use planning and urban development.
3	Land use land cover	Greenery, field crop and residencies	Productivity	Productive agricultural and forest land should not be considered for development as they are essential for producing food and fiber as well wood etc.
4	Ground water prospect	High ground water potential zone Low ground water potential zone	Null	These are areas to be conserved for the purpose of feature requirements and not to be taken up for the development as water has already been over exploited.
5	Drainage	Rivers and streams	Poorly or excessively drained	Land where the drainage status is in a problem
6	Road	Road net work	Infrastructure	Areas near to transportation network have higher potential for development. Areas far away from road network require infrastructural development facilities have low opportunity for urban development.

2.7.1 Principles of Land Suitability Assessment

Principles that are fundamental to the methods used in land suitability assessment based on: (FAO, 1976) Land suitability is assessed and classified with respect to specified kinds of land use. This principle gives recognition to the fact that different land uses have different requirements. The concept of land suitability is only meaningful in terms of specific kinds of land use, each with their own requirements, e.g. for soil depth and soil texture among others. The qualities of each type of land, such as moisture availability or liability to flooding, are compared with the requirements of each land use. Thus the land itself and the land use are equally fundamental to land suitability assessment.

2) Assessment requires a comparison of the benefits obtained and the inputs needed on. Different types of land. Suitability for each use is assessed by comparing the required inputs, such as labor, fertilizers or road construction, with the goods produced or other benefits obtained.

3) A multidisciplinary approach is required. The process requires contributions from the fields of natural science, appropriate land use technologies; suitability modeling always incorporates economic considerations to a greater or lesser extent. The comparison of benefits and inputs in economic terms plays a major part in the determination of suitability. The comparison of benefits and inputs in economic terms plays a major part in the determination of suitability.

4) Evaluation is made in terms relevant to the physical, economic and social context of the area concerned. The assumptions underlying suitability evaluation differ from one country to another and, to some extent, between different areas of the same country. Many of these factors are often implicitly assumed; to avoid misunderstanding and to assist in comparisons between different areas, such assumptions should be explicitly stated.

5) Suitability refers to use on a sustained basis. The aspect of environmental degradation is taken into account when assessing suitability. There might, for example, be forms of land use which appear to be highly profitable in the short run but are likely to lead to soil erosion, progressive pasture degradation, or adverse changes in river regimes downstream. Such consequences would outweigh the short-term profitability and hence such land is classed as not suitable for such purposes.

2.7.2 Analytic Hierarchy Process and Suitability Modeling Analysis

This thesis proposes an alternative approach to land suitability analysis. Most of the suitability analysis techniques described above rely on significant amount of information to be useful, applicable, and effective. Regression analysis, for example, will require a cross-sectional database covering the wide range of suitability conditions as affected by different factors individually and collectively. If such data are available, formal analysis of the composite function such as regression analysis is warranted and also offers an accurate way to evaluate site suitability. On the other hand, if data are incomplete, or if significant information gaps exist in the cross-sectional database, then it may be more appropriate, practical, or convenient to adopt an alternative approach that does not rely on complete or comprehensive databases. One such approach is the Analytic Hierarchy Process (Malzewski, 2004).

AHP offers some advantages over the classical site suitability analysis techniques. First, it provides a structured approach to measuring suitability by “decomposing” the suitability analysis problem into hierarchical units and levels. This allows a systematic and more in-depth analysis of the factors which may be better understood when “de-coupled” or “deconstructed” into their lower and more specific forms or indicators. Second, AHP relies less on the completeness of the data set, and more on “expert” opinions or observations about the different factors and their perceived effects on land suitability. Third, the approach is more transparent and hence more likely to be accepted especially when the suitability analysis will ultimately serve as a basis for land allocation. Fourth, AHP allows for the participation of both experts and stakeholders in providing the suitability measure of a land relative to a proposed land use. Urban land suitability analysis deals with large amount of data on different dimensions. (AHP) is a classical land use approach in making decisions for best site selection and site allocation of lands for different uses. Integration of GIS for land suitability analysis serves three objectives.

1. To provide an introduction to GIS technology along Geographic Information System in Urban Planning.
2. To over view relevant methods and techniques for GIS based land use suitability mapping and modeling
3. To identify trends, challenges and prospects of GIS in land suitability analysis and modeling

2.7.3 Frame Work of Land Suitability Modeling Decision Making Process

The Decision making problem of land suitability modeling and analysis for urban planning is shown in the figure 2.5 which depicts the conceptual frame work of this thesis particularly in land suitability analysis and modeling.

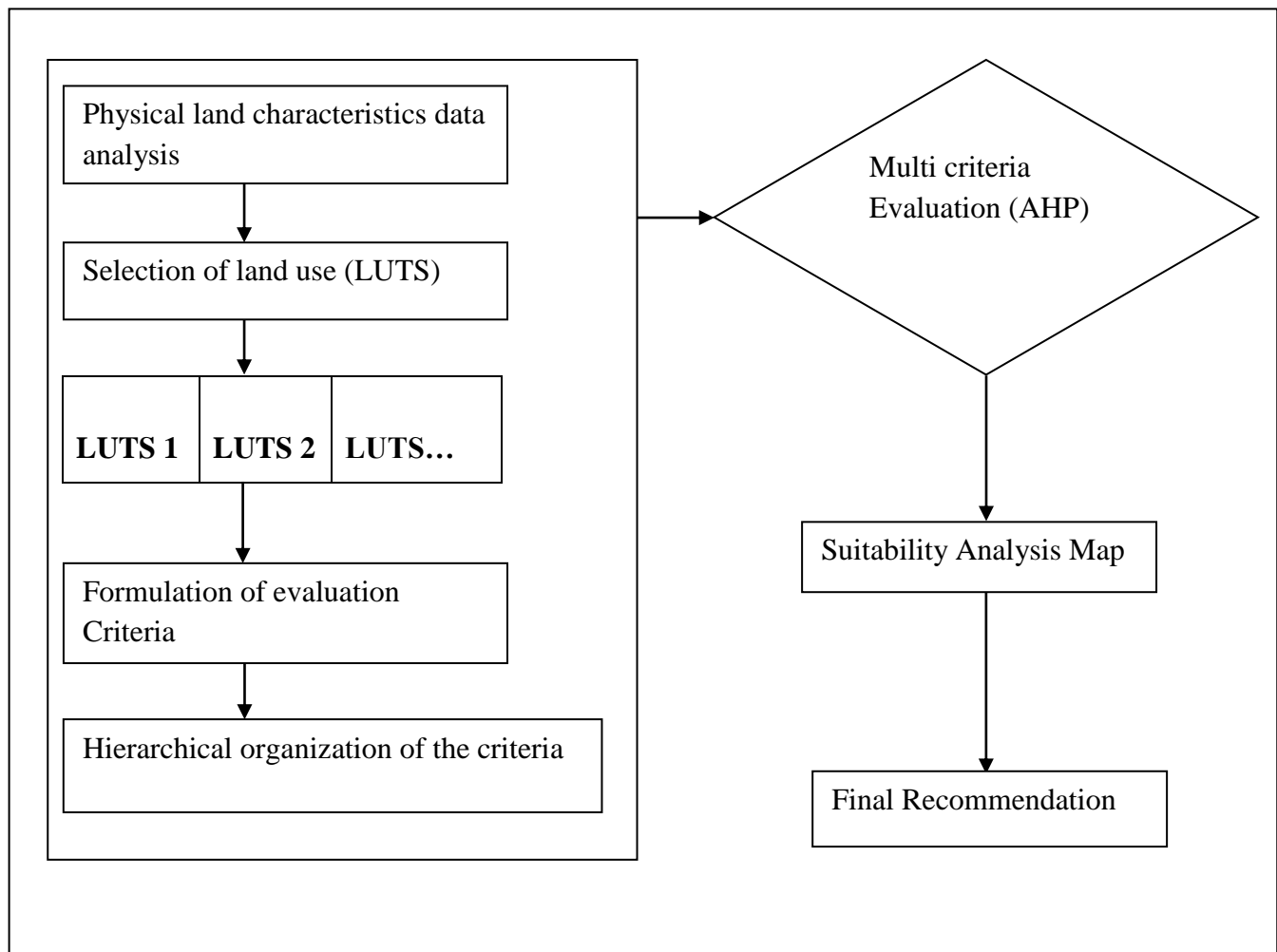


Figure 2.5 conceptual frame work of land suitability in decision making process

2.8 Geographic Information System in Urban Land Suitability Modeling

2.8.1 Urban Land Suitability Modeling Using Weighed Over Lay Techniques

Weighted Overlay is a technique for applying a common measurement scale of values to diverse and different inputs to create an integrated analysis in GIS environment. Geographic problems often require the analysis of many different factors.

2.8.2 Estimating Weights

The next step before running the model using weighted overlay method; weight is estimated to the input raster's. Accordingly each model parameters is weighted as a percentage influence, based on its importance to the model objective. Multi criteria Decision Making problems typically involve criteria of varying importance to decision makers. The derivation of weights is a critical step in eliciting the decision maker's performance preferences. A weight is a critical step in eliciting to an evaluation criterion that indicates its importance relative to other criteria under consideration. The larger the weight shows the more important criterion in the overall analysis process. Assigning weights of importance to evaluation criterion accounts for two most important reasons.

It is meant for changes in the range of variation for each evaluation criterion, and the different degrees of importance being attached to those ranges of variation. To this end, it is misleading to interpret the weights as general measurements of importance of evaluation criteria. The weight is dependent on the difference between the minimum and maximum value for given criterion. A criterion weight can be made arbitrarily large or small by increasing or decreasing the range. The weights are normalized to sum to 1. Assigning weights of importance to evaluation criterion accounts for two most important reasons. It is meant for changes in the range of variation for each evaluation criterion, and the different degrees of importance being attached to those ranges of variation. To this end, it is misleading to interpret the weights as general measurements of importance of evaluation criteria. The weight is dependent on the difference between the minimum and maximum value for given criterion. A criterion weight can be made arbitrarily large or small by increasing or decreasing the range. The weights are normalized to sum = 1.

3. MATERIALS AND METHODS

3.1 General Description of the Study Area

3.1.1 Geographic Location and Extent

Addis Ababa is the capital city of Ethiopia founded in 1887 and its geographic location is between $9^{\circ} 0' 8.64''$ - $9^{\circ} 1' 8.30''$ N and $38^{\circ} 46' 30''$ - $38^{\circ} 54' 59.0''$ E. The city is located in the central highlands of Ethiopia covering an aerial extent of about 527km^2 with an average elevation of 2600m above sea level, The administration of the city is divided in to ten subcities and 116 weredas. The study Area Bole sub city located between $8^{\circ} 36' 30''$ - $9^{\circ} 1' 0''$ N $38^{\circ} 46' 0''$ - $38^{\circ} 54' 0''$ E UTM Coordinate system covers an area of 140.52 km^2 (Figure 3.1) out of the total area of the city which is 26.6%.With an elevation ranges from 2120 m.a.s.l to 2408 m.a.s.l.

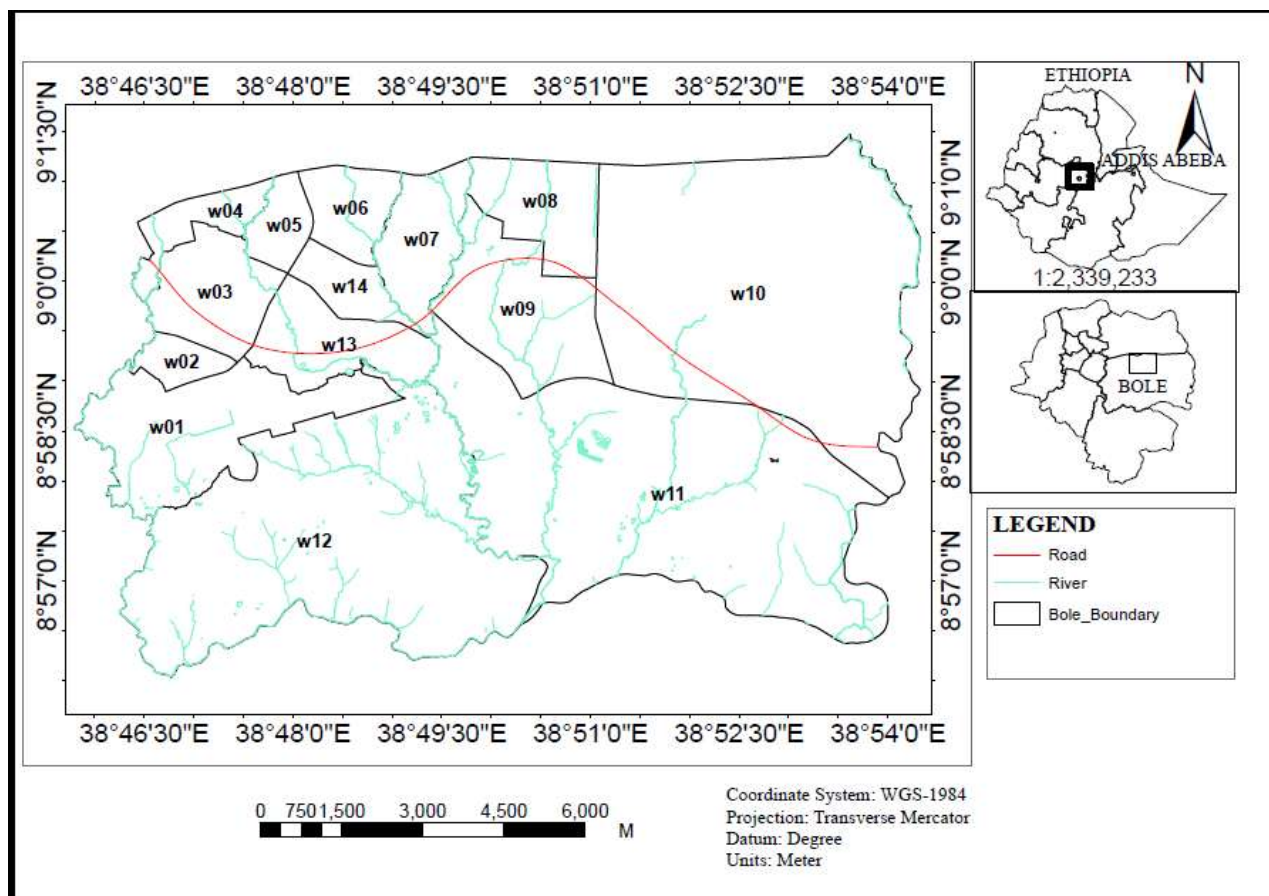


Figure 3.1 Location map of the study area

3.1.2 Physiography and Drainage of the Study Area

Addis Ababa was founded on the southern flank of Entoto ridge (3139m.a.s.l.) and expanded in all directions. Other prominent volcanic features surrounding the city are Mt. Wochacha in the west (3385m.a.s.l.), Mt. Furi (2839m.a.s.l.) in the southwest and Mt. Yerer (3100m.a.s.l.) in the southeast. These typical volcanic features are mainly built-up of acidic and intermediate lava flows. Thus, they are characterized by rugged landscapes and steep slopes. The topography slopes down from the Entoto Mountain in the north to the southern border of the city, with a number of steep-sided valleys, rivers and streams. The center of Addis Ababa lies on an undulating topography with some flat land areas. The topography is undulating and form plateau in the northern, western and south-western parts of the city. However, Bole and south western part of the city are characterized by gentle morphology and flat land areas. As a result, the stream drains towards south from the Entoto ridge; southeast direction from Mt. Wechecha and Mt. Furi and towards southwest direction from Mt. Yerer and other elevated areas of the eastern outskirts of the city.

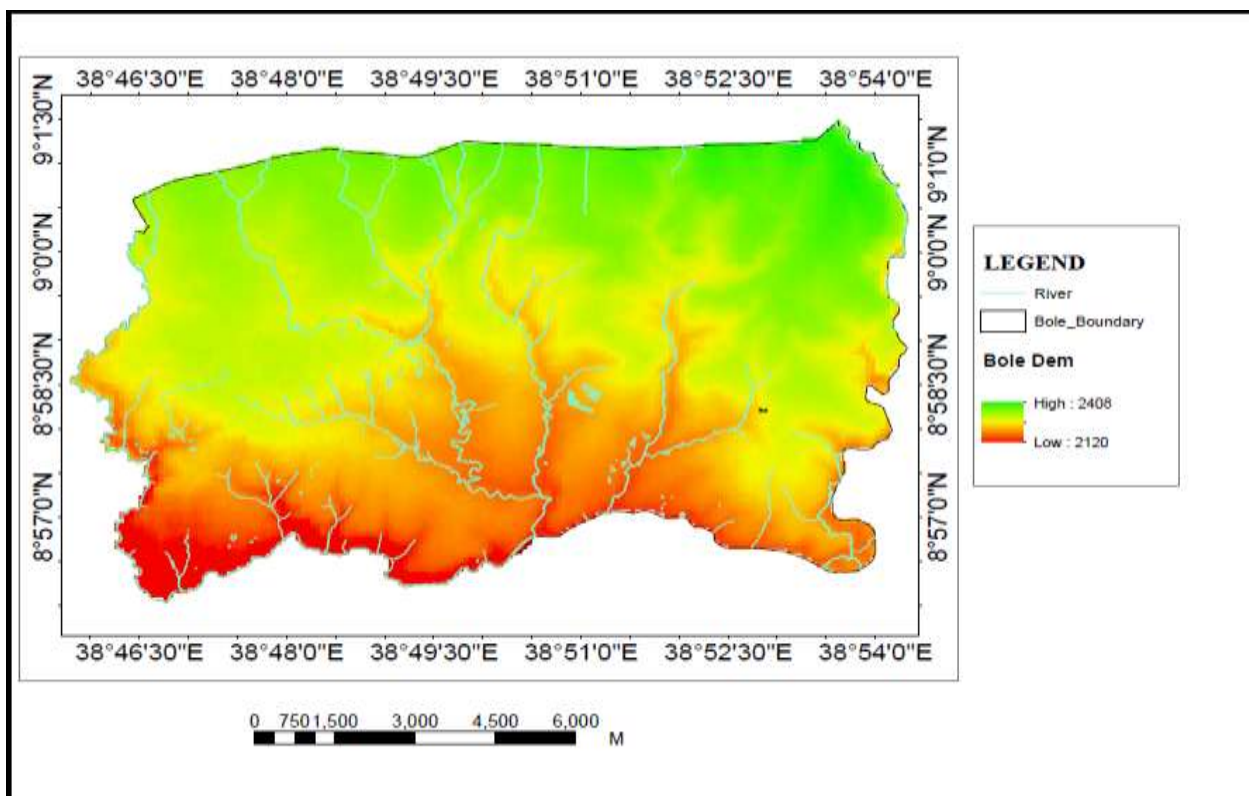


Figure 3.2 Physiography and drainage map of the study area

3.1.3 Population

The annual population growth of Ethiopia is at the rate of around 2.6 percent per year. The high growth rate is a result of the country's birth rate, which is 4.5 percent and is also among the highest in Sub Saharan Africa. By contrast, the death rate has been falling from 3.1 in 1950 to 2.3 in 1975 and to 1.5 in 2000. The country's population will continue to grow for several decades as the large portion of the population is relatively young. Population forecast indicates that over the next 15 years the country's population will double. This means that the population will double from 73 million today to 146 million by the year 2025. Currently, about 3.7 percent of the country's population is living in Addis Ababa city. During the last 40 years, the population in Addis Ababa has increased dramatically. The total population increased from 644,190 in 1967 to 1,423,182 in 1984. From 1984 to 2001, the population increased to 2,570,000 and has reached 2,805,000 in 2004. However, according to the Central Statistical Authority (CSA, 2007), the current population of the city is slightly decreased to 2,738,248. This decrease is due to the migration of the people of Addis Ababa to nearby towns such as Burayu, Sebeta, Legatafo and Sendafa. The total population of the sub city according to CSA, 2007 was 308,714.

Table 3.1 shows the population distribution of each wereda in the sub city.

Wereda	Area(km ²)	Total population	Population density (popu/hect)
w 01	825.35	28153	33.99
w 02	117.22	8132	69.37
w 03	408.05	31679	77.64
w 04	193.96	29839	153.84
w 05	152.54	20208	132.48
w 06	241.85	23507	97.20
w 07	249.24	27122	77.66
w 08	385.30	27122	70.39
w 09	656.79	27124	41.30
w 10	2752.31	15046	5.47
w11	2712.76	7510	2.77
w12	2457.87	12590	5.12
w13	413.31	32255	78.04
w14	179.73	18429	102.42
Total	140.52	308,714	947.68

Source: CSA, (2007)

3.1.4 Climate

The study area is located at high altitude and the climate is comfortable with optimum temperature and rain fall Metrological data recorded in the last 10 years from the two stations of the city. From Bole station shows the average rain fall of Addis Ababa and the study area is about 1185 mm annually. With the major rain fall occurring between Julys to September.

Table 3.2 .Shows the amount of rain fall recorded in bole station in the last 10 years.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1995	0.0	69.0	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0.0	0.0	48.4	1145.6
1996	28.1	5.2	106.8	128.2	122.0	258.5	266.4	338.7	294.2	0.2	0.2	0.0	1548.5
1997	39.2	0.0	24.5	51.3	38.5	104.0	272.6	194.3	113.8	62.4	50.3	1.5	952.4
1998	55.2	20.5	43.0	48.5	154.2	124.4	258.4	260.0	213.6	116.9	0.0	0.0	1294.7
1999	2.9	0.3	28.8	16.3	23.8	119.6	268.6	305.3	88.4	55.4	0.0	0.0	909.4
2000	0.0	0.0	2.4	58.7	110.0	144.5	244.8	306.2	250.6	46.4	21.1	0.0	1184.7
2001	0.0	12.2	213.5	25.0	168.0	213.5	428.0	246.4	130.7	14.6	0.0	0.0	1451.9
2002	14.7	21.0	90.2	56.5	63.1	172.5	255.2	215.9	108.8	0.2	0.0	16.5	1014.6
2003	10.5	53.3	62.6	99.9	20.2	151.8	291.8	233.3	214.1	0.8	1.5	54.9	1194.7
2004	24.8	20.3	49.5	139.9	30.1	141.9	248.5	268.6	164.0	76.9	0.0	0.0	1164.5
Monthly	15.5	38.7	66.8	89.4	83.0	130.7	259.5	276.5	170.9	36.5	7.9	9.5	1185.0
Max	75.7	155.9	236.5	229.5	257.0	258.5	428.0	426.5	294.2	272.5	62.3	54.9	
Min	0.0	0.0	2.2	8.4	0.5	31.9	180.1	123.6	88.4	0.0	0.0	0.0	
STDEV	18.9	37.6	58.7	51.9	62.1	46.7	51.7	64.5	51.1	48.8	16.1	16.3	
75%	2.7	13.4	27.2	54.4	41.1	99.2	224.6	233.0	136.4	3.6	0.0	0.0	835.7
85%	0.0	0.0	5.9	35.7	18.7	82.3	205.9	209.6	117.9	0.0	0.0	0.0	676.0

Source, NMA, 2007

The minimum mean monthly temperature of the region ranges between 8 °cto12 °c while the maximum mean temperature varies between 20°c to 25°c throughout the year.

3.1.5 Land Use Land Cover

The study area consists of 14 weredas having many types urban land use categories the total area of the sub city is 140.52 km² of which 39% field crop, 19% Residential, 13.4%, open space ,4.47% plantation, transport terminal 4.35 % ,open space 13.4% and others each land use category and area coverage are listed in Table 3.3.

Table3. 3 Land use type and area coverage of the study area

Land use Type	Area coverage in (Hectare)	Percentage %
Administration	98.019	4.471
Commercial	119.29	1.00666
Cultural and social welfare	7.455	0.0629
Education	67.4299	0.5690
Field crop	4636.482	39.1299
Health	14.20921	0.11992
Infrastructure and Utilities	0.4058	0.00343
Manufacturing and Storage	158.615	1.3386
Mixed Residential	61.4498	0.5186
Municipal service	31.4882	0.2657
Open space	1557.1743	13.149
Plantation	529.8550	4.4717
Recreation	27.2834	0.23027
Religious institution	112.7469	0.9515
Residential	2322.6730	19.6024
River	265.26525	2.23873
Riverine	2.114633	0.01784
Road network	948.43630	8.00441
Special use	0.323490	0.002730
Transport Terminal	516.4126	4.35830
Under construction	243.16188	2.05218
Vegetable farm	19.95816	0.168439
Mixed forest	108.68547	0.91726

Source: Master plan of Addis Ababa city, computed by the Researcher

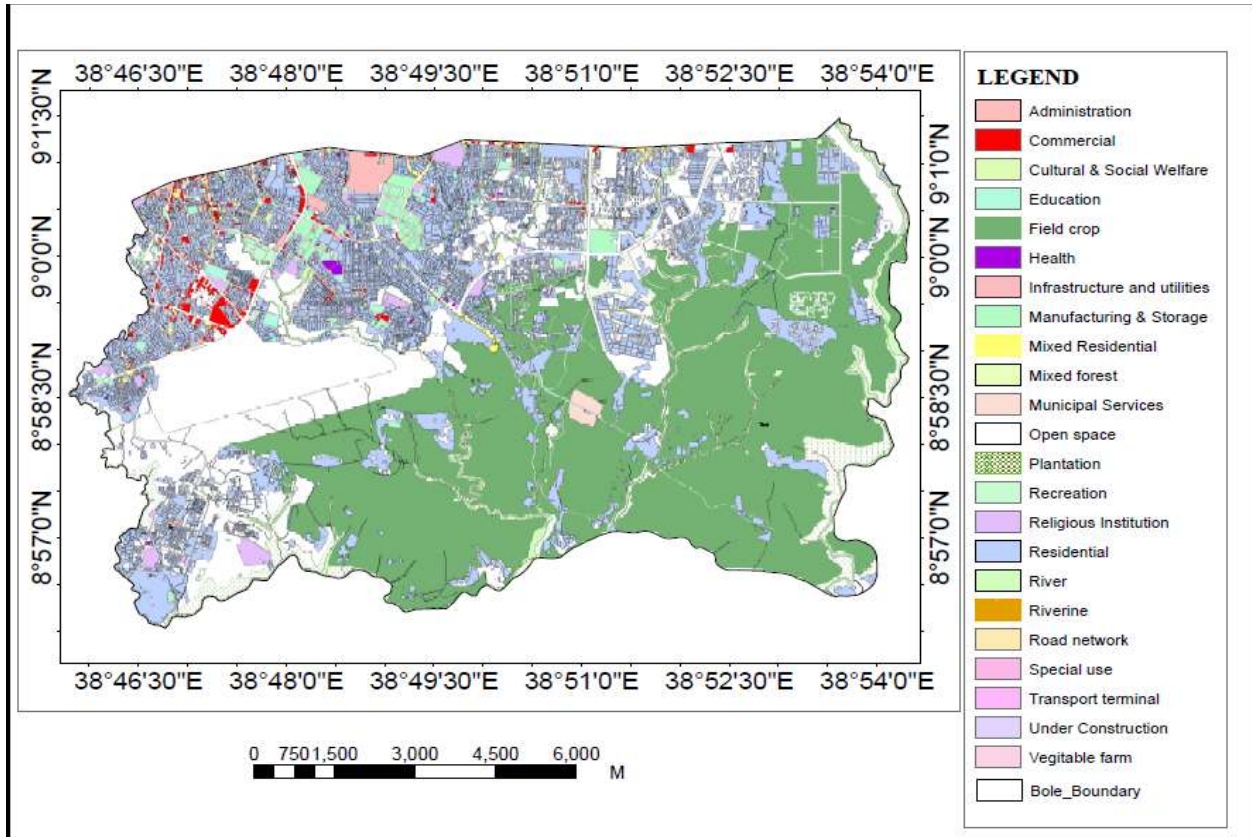


Figure 3.4 Land use map of Bole sub city. Source, Addis Ababa city Administration land management office

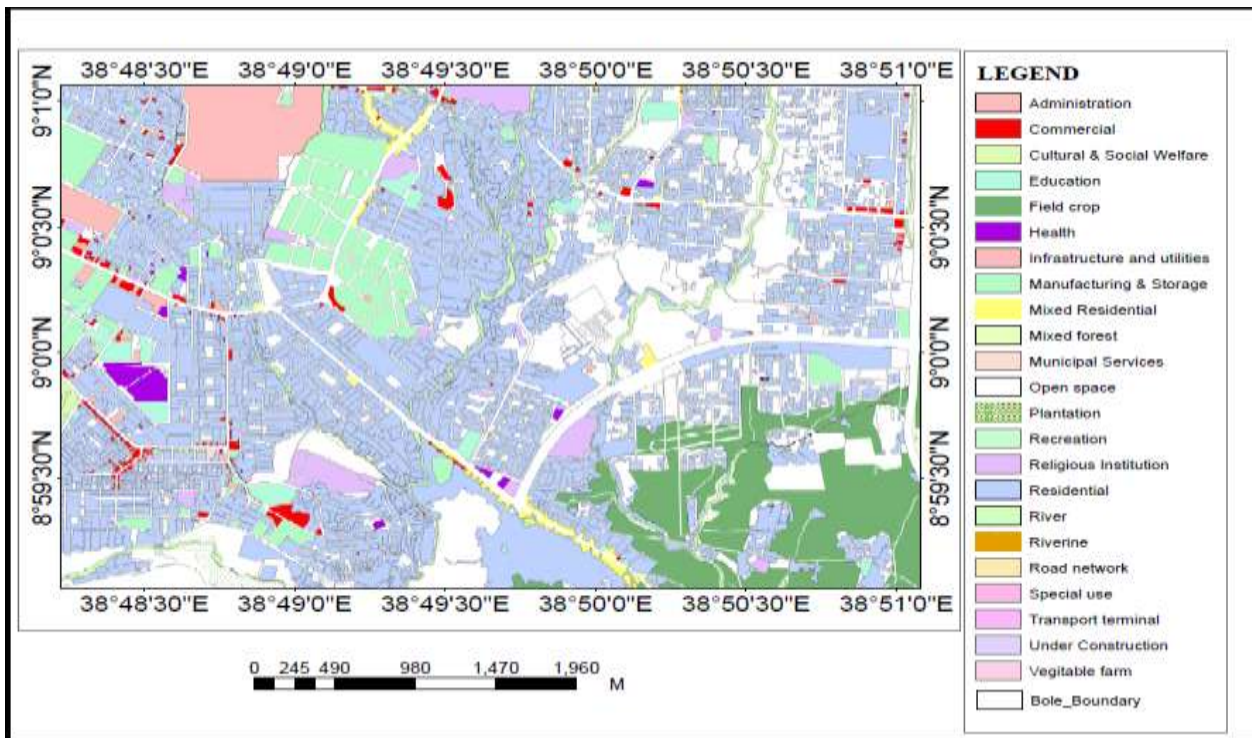


Figure 3.5 Land use map of Bole sub city. Source, Addis Ababa city Administration land management office

3.1.6 Geology

The geology of Addis Ababa and its surroundings has been studied by several researchers both locally and at the regional scale. The sequence of the rock units reveals the Miocene-Pleistocene volcanic succession ranging from older plateau volcanic to younger rift volcanic where from bottom to top are: Alaji basalt, Entoto silicics, Addis Ababa basalts, Nazareth group, and Bofa basalt (Tamiru et.al, 2005).

A) Alaji Basalt: group of volcanic rocks (Alaji rhyolite and Basalt) and parts of the escarpment were out poured from the end of Oligocene until middle Miocene. This unit is composed of basalts, which show variation in texture from highly pophyric to aphyric. Within this unit, there is an intercalation of gray and glassy welded tuff. The outcrop of Alaji basalt extends from the crest of Entoto (ridge bordering to the northern parts of Addis Ababa) towards the north (Haileselassie Girmay and Getaneh Assefa, 1989).

B) Entoto Silicics: These early Miocene age silicic volcanics could represent localized terminal episodes to massive Oligocene fissure-basalt activity in Addis Ababa region (Tamiru et al., 2005). The thickness of the flow become maximum on the top of Entoto ridge and thin both towards the plateau and the plain east of Addis Ababa. According to (Tamiru Alemayehu et al., 2003), these lavas make up a thick pile of flows accumulated along east west fissures (east west fault running from Kassam River to Ambo) and uplifted northwards. This unit is uncomfortably overlain by Addis Ababa basalt on the foothills of Entoto and underlain by Alaji basalt. The Entoto silicics composed of rhyolite and trachyte with minor amount of welded tuff and obsidian (Haileselassie etal, 1989).It also out crops in the eastern part of the town from the Kokebe Tsebah School to the Benin Embassy.

C) Addis Ababa Basalt: Addis Ababa basalt is the oldest visible rock post-dating the Entoto silicic type of rock. It is mainly found in the central part of the town and underlain by the Entoto silicics and overlain by Lower welded Tuff of the Nazareth group rocks. The maximum thickness exceeding 130 meters is found at ketchene stream. It is porphyritic in texture, composed of labradorite, bytownite, olivine and augite as phenocrysts. The ground mass is made of andesine, labradorite, olivine, agnetite and pyroxene (Haileselassie etal, 1989).

Olivine porphyritic basalts outcrop in the central part of the town that includes Mercato, Teklehaymanote and Sidist Kilo. The distribution of plagioclase porphyritic basalt is almost the same as that of the olivine porphyritic basalt, but only little more northwards. It outcrops in an area, which includes Sidist Kilo, General Winget School and French Embassy. The thickness of the former varies from 1m or less in the foothills of Entoto, Lideta Airfield and Filwoha to greater than 130 meters at Ketchane stream (Morton, 1974; Varnier et al., 1985 as cited in Tamiru Alemayehu et al., 2003). The Lower Welded Tuff overlies both types of basalt nearby the Building College, the Kolfe Police School, Kokobe Tsebah School and Yeca Mariam Church. On the other hand, only in the gorge of the Ketchane stream, the olivine porphyritic basalt is overlaid by the plagioclase porphyritic basalt, while elsewhere the relationship between them is very difficult to determine (Tamiru Alemayehu et al., 2003). Addis Ababa basalt yield aged clustering around 7million years and seems to have no time or composition equivalent (Tamiru Alemayehu et al., 2003).

D) Nazareth Group: The Geologic units identified in this group are denoted as Lower Welded Tuff, Aphanitic basalt and Upper Welded Tuff. The group is underlain by Addis Ababa basalt and overlain by Bofa basalts. The rocks outcrop mainly from south of Filwoha fault and extend towards Nazareth area.

E. Lower Welded Tuff: It is the rocky outcrops as small discontinuous body in Filwoha, western parts of Addis Ababa and Sululta. Generally, it is overlain by the aphanitic basalt and underlain by the olivine and plagioclase porphyritic basalt. The age of this rock as dated by Morton et al. (1979) as cited in Tamiru Alemayehu et al., 2003), as at Addis Ababa and Sululta is 5.1 and 5.4 million years, respectively.

F. Upper Welded Tuff: This rock outcrops all over the southern part of the town including Bole, Nefas Silk and Railway station. Nevertheless, it is also present in the central and northern parts of the town. It is gray colored, vertically and horizontally jointed and composed of sandine, anorthoclase, rebecite, quartz, pumice and unidentified volcanic fragments (cited in Tamiru et al., 2005). The Geology of the study area categorized under this category according to the studies made by different scholars at national and international level.

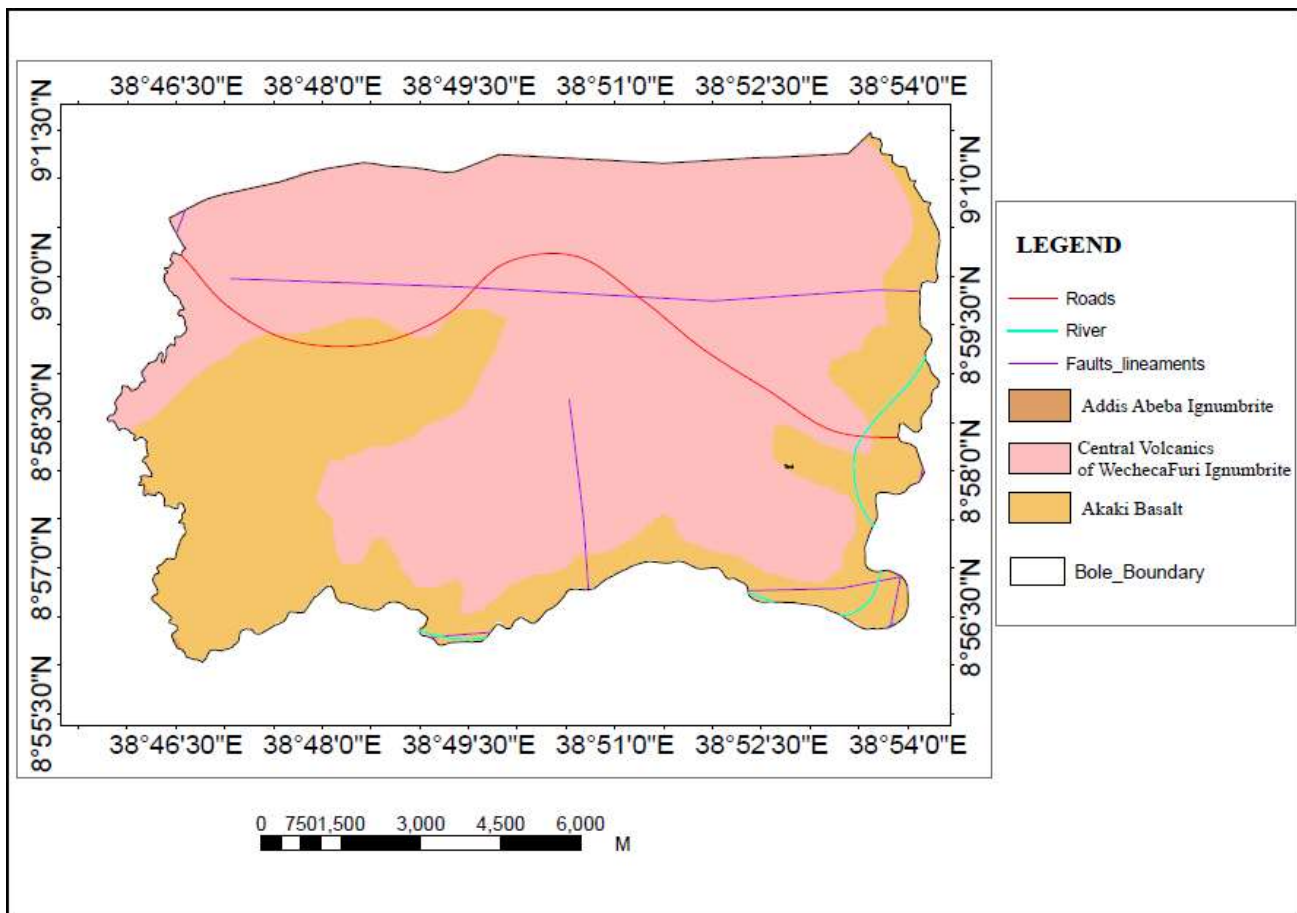


Figure 3.5 Geologic map of the study area (Source: Mulugeta H/mariyam et al., 2007)

3.1.7 Soil

Five soil forming factors namely climate, temperature and rainfall, topography, parent material, biological activities (flora and fauna) and time determine the type of soil that are formed at a particular area. As a result soil can vary from place to place. Accordingly, the soil of Addis Ababa is classified in to seven major types namely Calcic Xerosols, Chromic Luvisols, Chromic Vertisols, Eutric Nitisols, Leptosols, Ortio Solonchaks and Pellic Vertisols (Ministry of Water and Energy, 2004). The dominant soil of the region is Pellic Vertisol (277.23km^2) which is found in the southern and north east part of the city. Eutric Nitisol (111.55km^2) is the second most dominant soil found in the central and North West part of the region. Calico Xerosols (39.79km^2) is the third most dominant type of soil found in the northern part of the city.

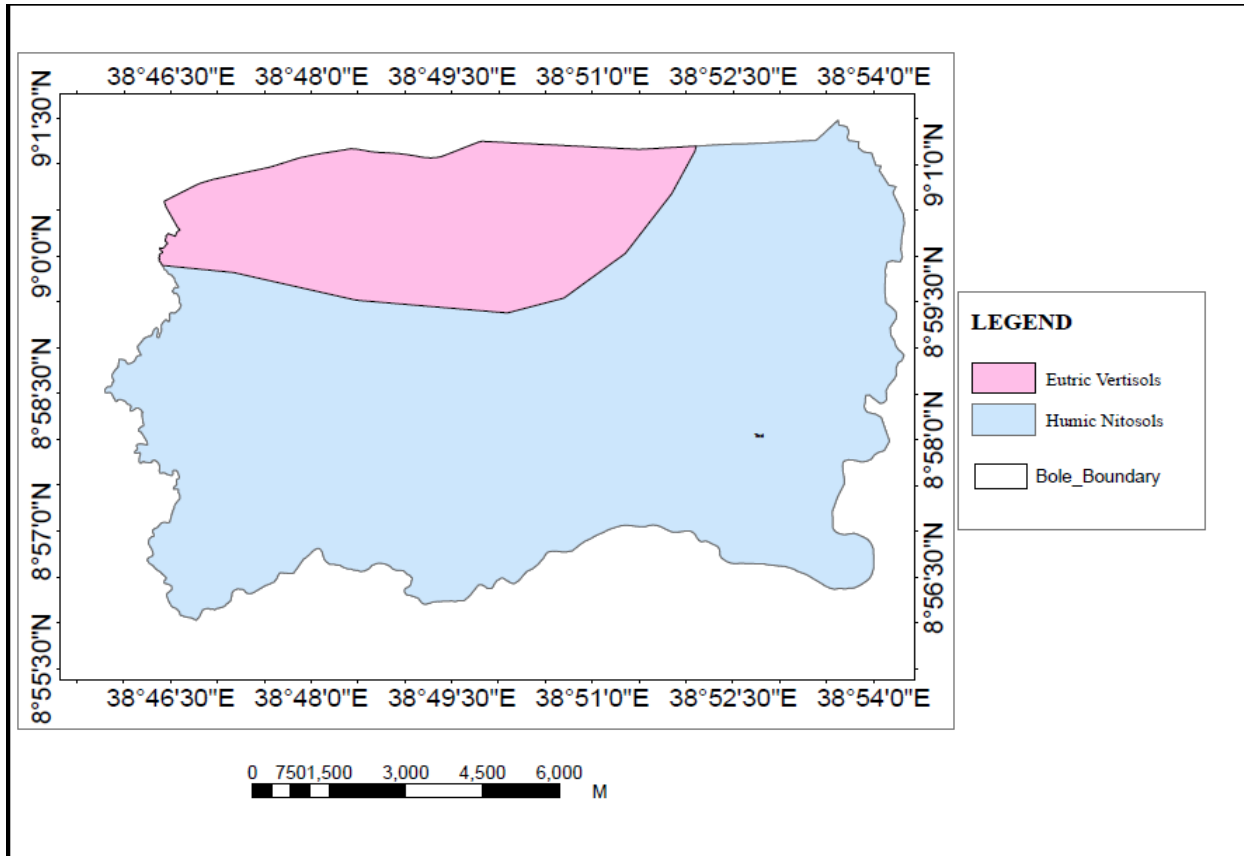


Figure 3.6 Soil map of the study area, Source Ministry of Agriculture soil data base, 1997

The permeability and infiltration of each soil depends on its textural composition. Accordingly, Vertisol (Pellic and Chromic Vertisols) is characterized by fine textured soil with >60% clay in composition. As a result, the porosity of such soil is very fine making the movement of material difficult within the soil. Hence, the permeability of Vertisol is very low except within the cracks that are formed during dry seasons. The permeability of Eutric Nitisol is moderate as its texture is generally characterized as moderately fine sized textured and with relatively less clay content than Vertisol. The permeability of Chromic Luvisol, which is found in the northwest part of the center, is also moderate like the case of Eutric Nitisol. Leptosol is characterized by shallow depth underlined by hard rock and with less developed soil. This type of soil is found in the Northern part of the center.

Topography is the major soil forming factors that determine the type and properties of soil mainly depth and texture via determining the degree of weathering and erosion. Generally, the steeper the slope, the less soil development and higher erosion rate and the shallower the depth and the courser the texture and vice versa. The area coverage of Soils in the study area is shown as in the pie chart below.

Table 3.4 soil type and distribution of the study Area.

Type of soil	Area in Hectare	Area in percentage
<p>A pie chart illustrating the distribution of soil types in the study area. The chart is divided into two segments: a larger blue segment representing Eutric Vertisols at 64%, and a smaller red segment representing Humic Nitosols at 36%. A legend above the chart identifies the colors: blue for Eutric Vertisols and red for Humic Nitosols.</p>	<p>28767.80 Eutric Vertisols</p>	<p>64%</p>
	<p>Humic Nitosols 16329.70</p>	<p>36%</p>

Source: Ministry of Agriculture Soil Data Base, 1997

3.2 Materials

The following soft wares have been used in the present study for data acquisition, design, analysis and presentation of the final research results: ArcGIS10, Auto CAD, IDRISI, ERDAS Imagine, Microsoft Word, and Microsoft Excel. In the present study Cadastral Maps of 1:500 were used. Several sorts of reports were used to back up the study with current literature of the research topic. Digital data are merged in to a GIS platform and have been used: land use land cover, DEM (Digital Elevation Model), Slope, geology, Soil Type, Soil depth, ground Water Prospects, Land use and drainage dataset map of this study.

Table 3.5 Types of software's and instrument used to execute the research

No	Types of Software's and instruments	Used for
1	ArcGIS10	For data editing, digitizing ,creating, analyzing and mapping
2	ERDAS Imagine	For image preprocessing and interpretation slope calculation, Topographic observation, Drainage identification from DEM, USGS Satellite Image
4	Auto CAD	For Study area Boundary delineation, Converting cadastral maps of (dxf) file type to (mxd) file type to convert cadastral parcels in to GIS data type
6	Micro soft office word	For word processing
7	Micro soft office Excel	For GPS data converting to Spatial Data in Arc Map
8	GPS	For coordinate data collection from the site

3.2.1 Methodological Approach

3.2.2 Data Source and Data Processing

To undertake any GIS based related analysis the most common sources of spatial data are comprised of one or more of the following sources.

1. Maps and plans of large or specific areas,
2. Aerial photographs and remote sensing high resolution satellite images,
3. Ground surveys
4. Digital data products types of data and sources are listed below in Table 3.5. Maps comprise one of the most widely available and familiar sources of spatial data. Scanning and digitizing are the two fundamental methods for integrating map sheets into a GIS environment (Geo data base).Ground survey is an alternative method for collecting spatial data. The data may be obtained directly from survey instruments, usually in the form of coordinate pairs often with attached attributes. Often survey data will be in the form of Auto CAD drawings, which may have thematic layer structure or complex block attribute structure them. An important technology that has simplified surveying is the GPS technology. Arial photography and remote sensing are now a day's increasingly popular way to gather spatial data (Treitz, 2003). Spatial data (such as area photos, satellite images, ground surveys and census data) which are already in digital form may be purchased from public and private mapping agencies. A list of selected digital data sources can be discussed in Table 3.6

Table 3.6 Summary of data and equipment's used to execute the research.

S/No	Data Type	Description	Source
1	Spatial	Geologic Map	EGS(Ethiopia Geological Survey)
		Cadastral Map (1:500)	Addis Ababa Municipality
		Land Use/Land cover Map Vector Data	Addis Ababa Municipality
		Digital Soil Map	Ministry of Agriculture(FAO)
		Ground Water Potential Map shape file	Ministry of Water Resource
		Road network Map shape file	City Administration GIS Data
		DEM (30m) High resolution	USGS
		Soil Map	Ministry of Agriculture(FAO)
2	Non spatial	Population Data	CSA
		Urban planning rules	MWUD
		Norms and standards	MWUD
3	Equipment's	GPS	The Researcher

3.3.3 Data Collection

This section of the study identifies and discusses the types and source of data that were collected for urban land suitability modeling of the study area. Before the spatial analysis is carried out, data was identified and collected. The relevant data for this study are: land use land cover, ground water prospect, digital elevation model, soil classification, Built Up area density, cadastral map, Land use land cover data was obtained from the city government land use master plan. In addition, the ground water potential data was collected from the Ministry of Water Resources and built up areas also taken from the city government land management office. Furthermore, topography is essential for land suitability modeling. It was derived from 30 meter resolution SRTM (Shuttle Radar Topographic Mapping) data. A DEM (Digital Elevation Model) is helpful for visualizing the area, for various data generation, contour line generations, basin area delineation, slope, etc.... Then, slope is derived using spatial analysis tools in ArcGIS environment. FAO Soil Classification is used in the Suitability Modeling. It is the only source of soil data in the country.

3.3.4 Geographic Information System Based Multicriteria Evaluation Methodology

GIS-based multi-criteria decision analysis involves the utilization of geographical data, the decision maker's preferences and the combination of the data and preferences according to specified decision rules in GIS environment (Malczewski, 2006). Multi-criteria approaches have the potential to reduce the costs and time involved in selecting urban land suitability by narrowing down the potential choices based on predefined criteria and weights given (Carver, 1991). Weighted Linear Combination (WLC) and Analytic Hierarchy Processes (AHP) are the two most known Multi Criteria Analysis methods that were used for this thesis.

3.3.5 Indication of Parameters Used for Urban Land Suitability Modeling

The model structure for selecting suitable urban site was built on the bases of hierarchical way by breaking down all criteria's in to sub divisions for more clarification. By deciding which factor will be grouped with which parameter this was done according to the similarity of factors with regard to the function they perform on the suitability model .(sattey1988) Table 3.7 bellow depicts the suitability analysis for bole sub city in a hierarchical approach. The first level of the hierarchy is the ultimate goal for the multi criteria Decision making process. And the second hierarchy level lists all relevant evaluation criteria used that were compared pair- wise to assess their weights and influence for modeling urban land suitability in the study area.

The final hierarchy level contains the evaluation objects all the criteria's are identified as influential factors in urban land suitability modeling and may be represent primary or secondary data. All data in the model needs manipulation and reclassification to create suitable thematic maps based up on the parameters used and registration of each layer to common coordinate system of the country that is Projection UTM Adindan Zone 37N.MCDA requires the value that contained in different layers can be transformed in to comparable units.

Table 3.7 suitability of Slope and Soil depth, soil type, Ground water prospect, road network, and geology in urban land suitability modeling of Bole sub city of Addis Ababa, Ethiopia

Criteria	Unit	Suitability rating and score			References
		Most suitable	Moderately suitable	Unsuitable	
Slope	%	0-5	5-15	>20	Hossain et al,2001
Soil depth	Cm	<45	45-90	>90	International Building standards code literature
Soil type	-	Humic Nitosols	Eutric vertisols	-	FAO soil classification of the study area and reclassified again
Ground water prospect	-	Low	Moderate	High	Ground water prospect map
Road network	M	<500	<1000	>2000	urban planning rules
Drainage	M	Low drainage area NNE of study Area	Moderate drainage area North East direction	High drainage Area South direction	Drainage map of the study area
Land use land cover	Ha				Land use map of the study area
Aspect	Deg	NW	SE	NE	Aspect map of the study area
Elevation	M	0-5	5-15	>15	Hossain et al,2001
Geology	-	-	-	Unconsolidated Geology	Ersoy and Bulut (2009)

Table 3.8 Pair-wise comparison matrix for assessing the relative importance of different factors for urban land suitability modeling in Bole sub city Numbers show the rating of the row factor relative to the column factor.

Slope	Slope	soil depth	soil type	Gwp	Road net work	LU/L C	Elevation	Weigh t
Soil depth	2	1	1/3	1/2	1	1/4	1	0.1
Soil type	1/2	1	1	1/6	1/4	1/2	1/8	0.1
Ground water prospect	3	3	1	3/2	3	3	3	0.10
Road net work	5	2	1	2/3	5	2	1/2	0.10
Drainage	8	5	4/3	1	1	4	1	0.20
Land use land cover	3	1	3/2	9		4		0.10
Geology	2	2/3	1	3	3	2		0.10
Elevation	2	1/2	1/2	3	3	3		0.20

Consistency Ratio (CR) = 0.08 < 0.1

Where LU/LC –Land use/Land cover GWP –Ground water potential

Table 3.9 Example of spread sheet calculations to show the consistency ratio of slope for bole sub city

	S	RN	L	S	RN	L	S	Average by row	k- max	CR	RI	CR
S	1	2	3	1.00	0.5	3	0.6	0.2998	3.0066	0.0033	0.5	0.0057
R. N	2	2	1	2.00	1.00	6	0.3	0.5996				
L	1/3	3	3/2	0.33	0.07	1	0.1	0.1006				
Sum				3.3333	1.670	10.00	1.00					

Where **S** -slope **RN** -Road network **L**- Land use

1. Sum the values of each column matrix and divide each matrix by the column matrix sum the result matrix is normalized matrix.

2. Average the value in row of normalized matrix: the average value is the score value or weight.

3. Compute the Eigen value (K_{max}) for the matrix with three rows and select the maximum Eigen value.

$$K=3.3333-0.2998+1.6700-0.5996+10.0000-0.1006 =3.0066$$

4. The consistency index (CI) is $(K_{max} n) (n - 1)$ $CI = (3.0066-3)/2=0.0033$

5. The consistency ratio (CR) is CI/RI where RI is the random consistency index. For $n =3$ $RI = 0.58$ sattey (1999) $CR = 0.0033/0.58 = 0.0057$ units.

$CR = 0.0057 < 0.1$ Acceptable.

3.3.6 The Weighted Index Model

Urban land suitability modeling is very complex task, tedious and costly process which needs to consider many conflicting criteria's. In this research land use land cover, soil type, groundwater prospect, built up area, soil depth and slope of the study area were used as parameters. Moreover, proximity from road, proximity from rivers or streams, groundwater potential, All the factors and constrains were internally classified in to five classes (very high, high, moderate, low and very low) with values ranging from 5 to 1, where value of 5 denotes the most suitable and value 1 denotes the least suitable for all factors and constrains considered in this thesis. Weights for each class of criteria were derived in IDRISI software using AHP methods. The method uses the expert preferences for comparing the classes and prepare matrix table. Accordingly, weight was derived for each class giving total sum of 1 (Fig. 3.7). One of the main problems in decision theory is the determination of relative importance of each parameter with each other. There are also problems which needs human judgment supplemented by mathematical tools. As all factors of the land cannot be weighted equal for the suitability assessment a weighted method needs to be employed where the relative importance parameters defines the weight. For this paper satty's Analytic Hierarchy process is widely used method to scale the weights of the defined parameters. By constructing a pair wise matrix comparison the importance matrices for the identified (3.7) parameters were generated based on satty's guide line shown the table below.

3.3.7 Derivation of Weights for Parameters used

To derivate a weight for the parameters used satty's Analytical Hierarchy process is a most widely accepted method for scaling the weights of parameters by constructing a pair wise comparison matrix of factors whose entries indicate the strength with which element dominates the other parameter.

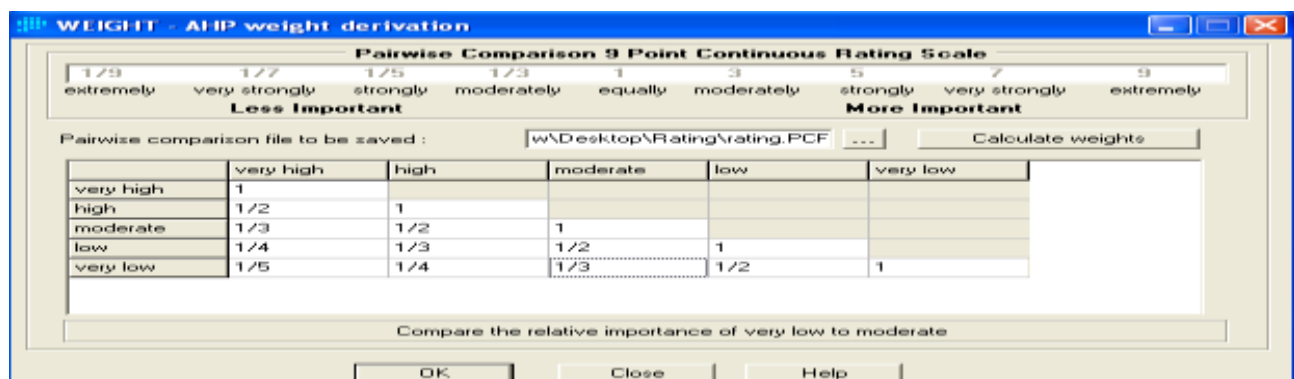


Figure 3.7 AHP weight derivation methods for criteria classes.

Table 3.10 Criteria weights calculated by AHP weight derivation module for suitability indexes.

Suitability Class	Rating /preference	Weight	Weight (%)
Very High	5	0.4185	41.8
High	4	0.2625	26.3
Moderate	3	0.1599	16.0
Low	2	0.0973	9.7
Very low	1	0.0618	6.2
Total		1.00	100.0
Consistency Ratio(CR)		0.05	2.0

CR=0.05 <0.1 Acceptable

3.3.8 Assigning Criteria Weights

One of the components of GIS Based MCE methodology is assigning criteria weights for each factor maps. The purpose of weighting in urban land suitability selection process is to express the importance or preference of each factor relative to other factor effect on urban land suitability modeling. A number of criterion-weighting procedures based on the judgments of decision makers have been proposed in the multi-criteria decision literature. The procedures include ranking, rating, pair-wise comparison, and trade-off analysis. They differ in terms of their accuracy, degree of easiness to use and understanding on the part of the decision makers, and in the theoretical foundation (Hasan et al.2009). Accordingly, one of the most promising is pairwise comparison developed in context of a decision making process is known as the AHP. In MCE using a weighted linear combination, it is necessary that the weights sum to 1.

Accordingly, in IDRISI, the weight module utilizes the pair wise comparison technique to help develop a set of factor weights that will sum to 1.0 (Table 3.7).

In AHP, weight can be derived by taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria. The comparisons concern the relative importance of the two criteria involved at a time, in determining suitability for the stated objective.

Accordingly, all possible combinations of two factors were compared based on expert judgment to prepare a pair-wise comparison matrix from which the module calculates a set of weights and consistency ratio. This ratio is very important as it shows any inconsistencies that may have arisen during the pair-wise comparison process. Figure 3.10 shows the AHP weight derivation interface to derive the weights, with its consistency ratio, for urban land suitability modeling.

3.3.9 Aggregating the Criteria Weights and Standardized Factor Maps

The distinguishing feature of GIS is its capacity for integration and spatial analysis of multisource datasets. The data are manipulated and analyzed to obtain information useful for a particular application such as urban land suitability modeling analysis (Malczewski, 2004). Urban land suitability site selection by GIS is a MCE, which involves aggregation of factors in a systematic way. Once the factor maps are prepared, the last step in suitability analysis is to evaluate the criterion so as to combine the information from the various factors. This study employs, MCE method to combine all the factor maps considered for urban land suitability modeling. Among MCE procedures Weighted Linear Combination is flexible, easy to use and manage frequently for factors aggregation (Malczewski, 2006).

With a weighted linear combination, factors were combined by applying a weight to each followed by a summation and urban land suitability map that shows suitable sites for urban development in the study area. Suitable sites were evaluated against other criteria like slope of the study area and soil type to select the best suitable sites for urban development based up on the parameters used for this thesis in ArcGIS spatial analysis environment in addition it is also possible to include social factors to avoid social insecurity.

3.3.10 Field Survey

3.3.11 Pre-Field

Before the field survey taken all relevant data has been organized in a GIS environment for analysis. Meanwhile, scale transformation has been manipulated in to a uniform standard. And projection towards UTM (Universal Transverse Mercator) so as to make the input layers compatible in a GIS platform for further GIS analysis to run urban land suitability modeling.

3.3.12 Field Work

In the field survey, Cadastral map of the study area, preliminary suitability map, and some selected sample site areas of the field observation are used. GPS data has been collected for more than 15 sample sites, elevation and UTM coordinates of each respective sample site were recorded. In addition, the preliminary suitability model has been verified with the real time scenario. Besides the land use and land cover of the sample sites is also observed.

The soil type of the area is also verified with the current data obtained from ministry of Agriculture soil data base. Slope of the study area is observed and found that most of the areas in the study area typically plain and has convenient slope for urban development activities. From the ground survey data taken by GPS and from the land use plan of the city one can observe that the study area covers most of it with Field crops and residential areas there are around 23 types of land use types in the study area they are as discussed .

Table 3.10 shows with their respective area coverage's. And the highest elevation of the study area is 2408 meter above sea level towards North East of the study area and the lowest area is 2120 meter above sea level towards South East of the study area and the Topography of the study area is Gentle slope or plain in all parts of the study area. As shown from the GPS readings and physiographic map of the study area.

3.3.13 GPS Data Collection and Interpretation

GPS Readings Taken to represent Ground Truth Land use land cover of the study Area

Table 3.11 GPS readings taken from the study area

S.No	Way point	Coordinate System UTM (Adindan)Zone37N		Elevation (M.a.s.l)	Land use land cover category
		Easting(X)	Northing(Y)		
1	Bole 001	487811.833	992034.440	2361	Field crops
2	Bole 002	480178.495	992350.174	2341	Open space
3	Bole 003	473410.127	991662.988	2331	Municipal service
4	Bole 004	488294.721	990901.512	2341	Plantation
5	Bole 005	482685.796	989285.696	2291	River
6	Bole 006	479342.728	996491.864	2301	Administration
7	Bole 007	476659.047	994266.333	2291	Religious Institution
8	Bole 008	478335.445	995355.481	2231	Manufacturing & storage
9	Bole 009	487740.837	994409.128	2231	Road Transport
10	Bole 0010	486263.633	996867.740	2281	Commercial
11	Bole 0011	485058.435	996476.387	2371	Education
12	Bole 0012	477546.872	994819.230	2371	Recreation
13	Bole 0013	487957.121	994429.822	2391	Health
14	Bole 0014	476601.126	995995.135	2381	Mixed Residential
15	Bole 0015	478556.465	997626.970	2371	Special use

Source: Existing land use map of Addis Ababa city Administration, tabulated from map by the Researcher

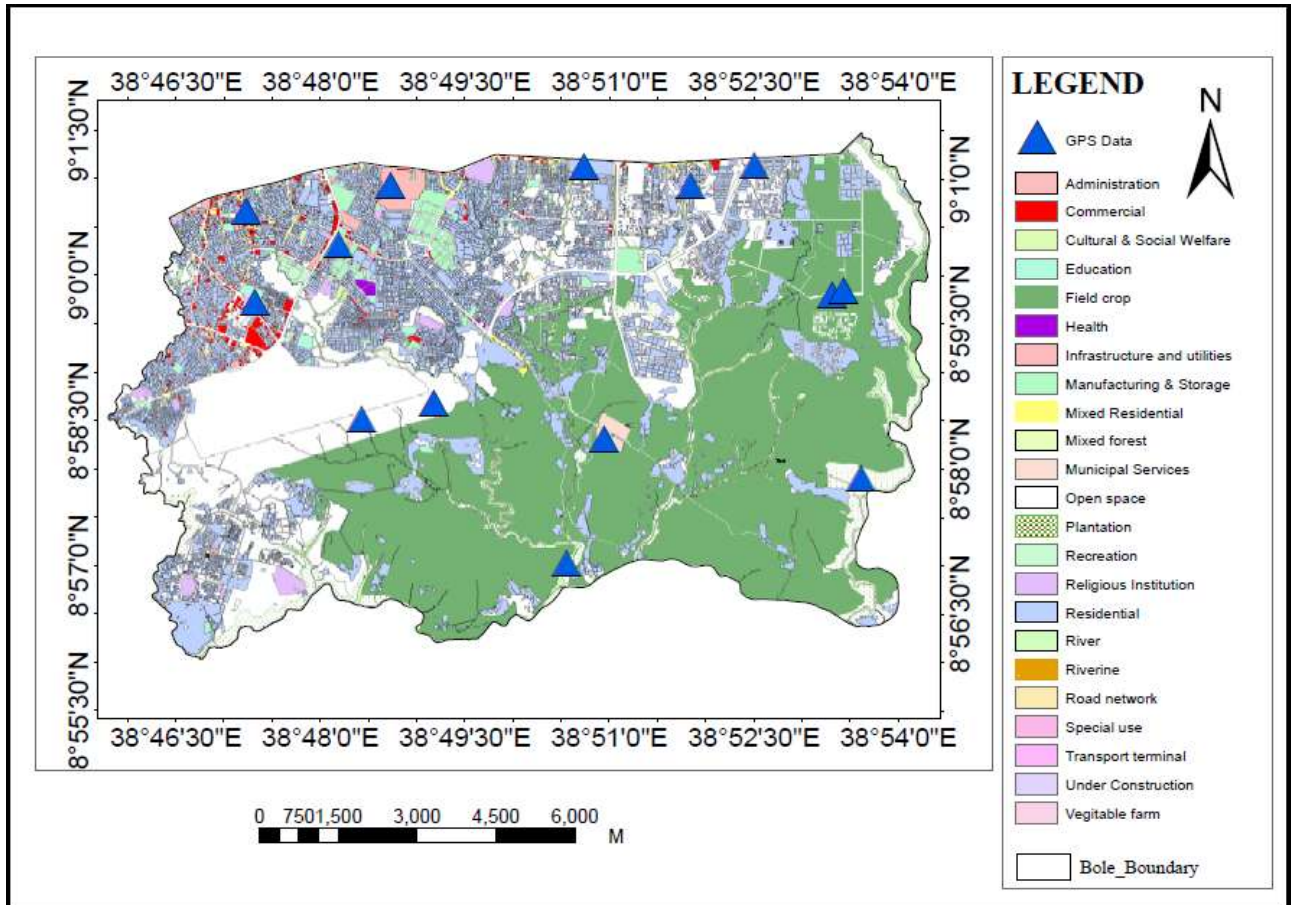


Figure 3.8 Locations of field survey sites



Figure 3.9 GARMIN Hand held GPS used to collect Ground Truth data in the Field.

3.3 Conceptual Suitability Model

Conceptual suitability model illustrates (Figure 3.10) the procedures that are undertaken while running the urban land suitability model for urban land suitability modeling of Bole sub city. First the input data (grid and shape files) of the study area are merged in to a GIS environment. The Digital Elevation Model (DEM) of the study area was clipped by the study area. And slope was derived from the DEM using surface analysis.

Next the land use land cover shape file was converted in to a raster data model (grid files) so as to make it compatible to the suitability model using overlay analysis techniques. Likewise, the soil classification shape files of the study area are again converted to grid files. Then, the Ground water data are interpolated to a grid file. The conceptual suitability model sample sites for the existing land use land cover has been selected for real time model verification.

All the model parameters were given weights based on their respective percent of influence to the suitability model criteria as compared to their model parameters. Finally, the weighted model parameters were overlaid and the suitability model is run to come up with the suitability model result.

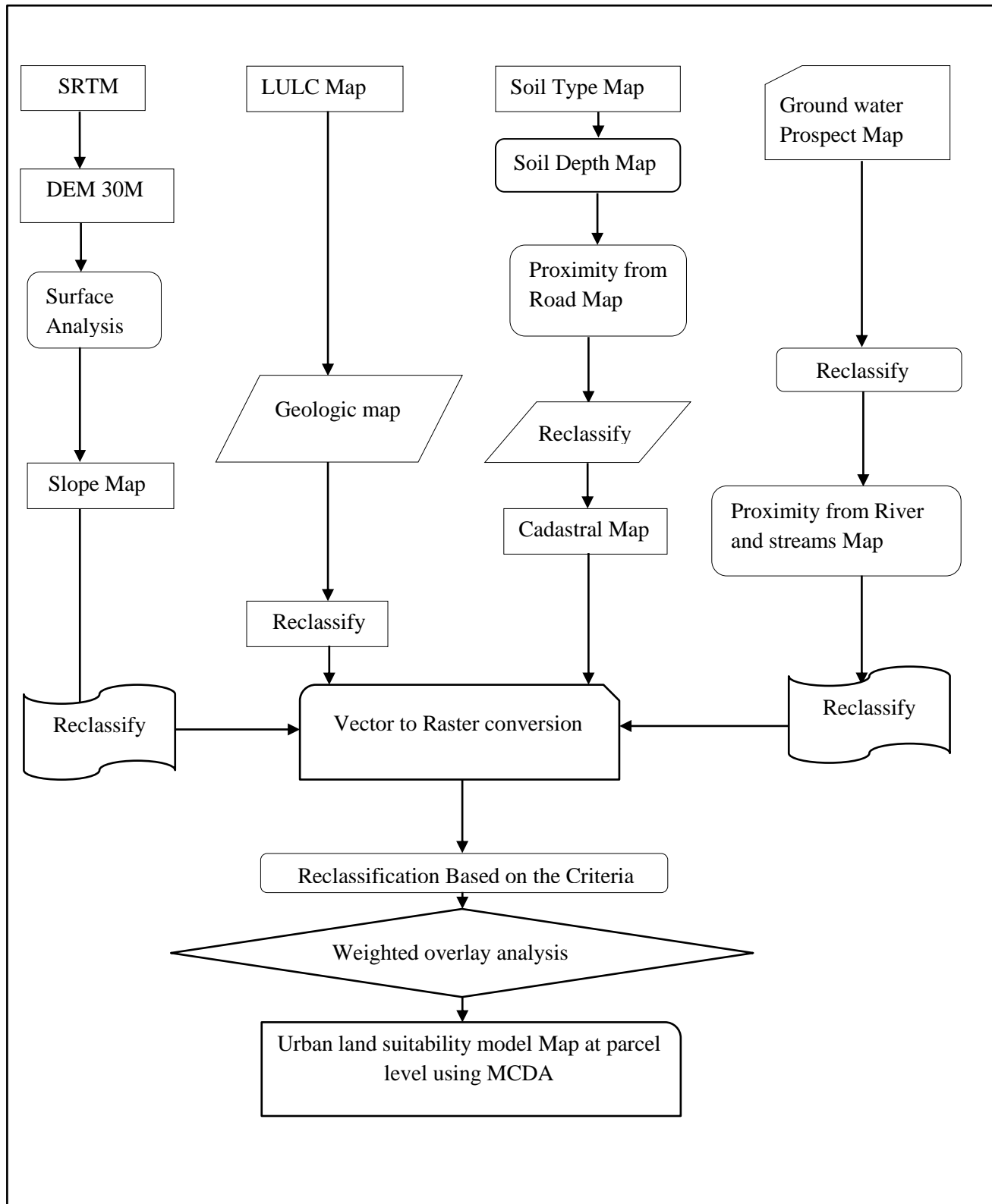


Figure 3.10 Flow chart of conceptual urban land suitability model

4. SPATIAL DATA ANALYSIS AND RESULTS

4.1 Introduction

Indication of suitable land for urban environment is a crucial issue in land administration suitability of urban land for urban development activities for this thesis is only based on the physical parameters the cumulative effect of these different parameters determine the degree of suitability and also helps for further categorizing of the land in to different orders of urban development classes. The assessment of the physical parameters of the land is possible by analyzing the parameters used for urban land suitability modeling like land use, slope, geology, flood hazard, physiography and distance from road, distance from existing development etc. which is much amendable in GIS environment.

However, assessment of physical parameters gives an indication on the limitation of the land for urban development the concept of limitation is derived from the quality of land. Example if slope is high the cost needed is more than a land which has gentle slope. In this research the seven important parameters which are most relevant for the study area acceptable by urban planners were slope, geology, rivers and streams, roads, soil type, soli depth, ground water prospect these are the most important factors used for classifying of the study area in to different suitability levels at parcel level by analyzing all the parameters in GIS environment by using weighted over lay method and MCDA techniques.

This research confirmed that the identified factors for urban land suitability modeling of the of the study area with the major weight share soli 20%, road 20%, slope15%, land use 10%, drainage10% ,Geology 15%, ground water prospect 10%.

4.2 Suitability Modeling

Suitability modeling is a methodology or a set of analytical procedures that simulate the real world conditions using GIS by their spatial relationships of geographic features to locate optimally suitable geographic areas for urban development. Hereunder, two of the GIS functionalities are applied. Under the present study, the spatial modeling functions implemented is geometric modeling and coincidence modeling. Geometric modeling Functions include calculating distances, generation buffers, and calculating areas and perimeters. And coincidence modeling Functions include overlaying datasets to find places where values coincide. Thus, it has been possible in a GIS to efficiently perform the above mentioned analysis that would be impossible or extremely time consuming if done manually.

4.3 Model Parameters

To run the suitability model, model parameters used in this thesis are: slope, ground water, soil type, soil depth and land use land cover, road network, geology, rivers and streams etc. Before model parameters are merged to the weighted overlay analysis, input model parameters were first converted in to a raster data set model. During the conversion of vector data in to a raster to make the data layers compatible for the raster analysis a 30 m cell size is taken on the basis of the DEM (Digital Elevation Model) resolution. Therefore, all the input parameters are resampled to 30 m raster cell size resolution.

In addition, to make the parameters in to a uniform scale value for the overlay analysis, each parameter is reclassified in to five suitability classes ranging from 1 to 5 on the basis of their importance to the suitability model objective, where 1 implies least suitable while 5 represents the most suitable part of the study area. After each model parameter was reclassified in to similar scale value .Finally each model parameter weighted with GIS multi criteria decision making rule ranking methods. Finally the model was run in GIS environment using spatial Analysis method.

4.3.1 Digital Elevation Model (DEM)

Digital Elevation Model (DEM) of the study area was clipped from SRTM of NASSA satellite 30 m resolution of Ethiopia by using a masking layer of the Bole sub city boundary. The DEM shows an elevation range of low altitude 2120 meter above sea level SE of the study area (Figure 4.1) and high peaks of up to 2408 around Yerer Mountains NE of the study area.

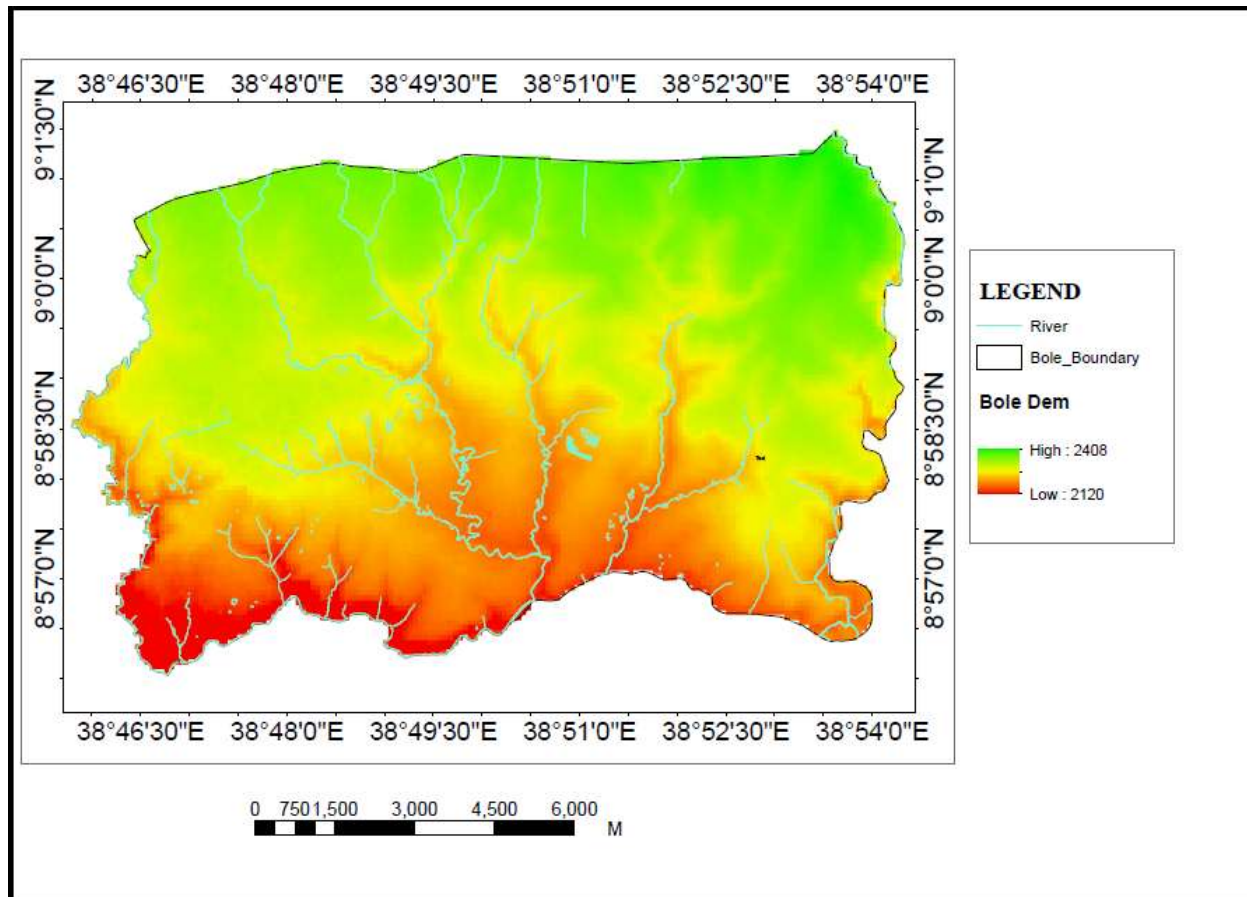


Figure 4.1 Digital elevation model map of the study area

4.3.2 Slope

Slope can be expressed as the amount of rise of a surface change in elevation divided by the distance over which the rise is computed by the run. Slope was derived from DEM for the study area in a GIS platform by using surface analysis in ArcGIS 10.1. The resulting slope shown in Figure.4.2 derived from digital elevation model of the study area comprise slope steepness ranging 0 to 20 degree. This value is again reclassified in to five slope classes so as to make the slope compatible for suitability modeling with other model parameters. Global Mapper 8 were used to derive DEM from SRTM and to generate contour while Digital elevation model was used to fill missing SRTM values in DEM. Finally, slope was generated from surface analysis in GIS environment; accordingly, slope of the study area ranges from 0-20 (Figure 4.2)

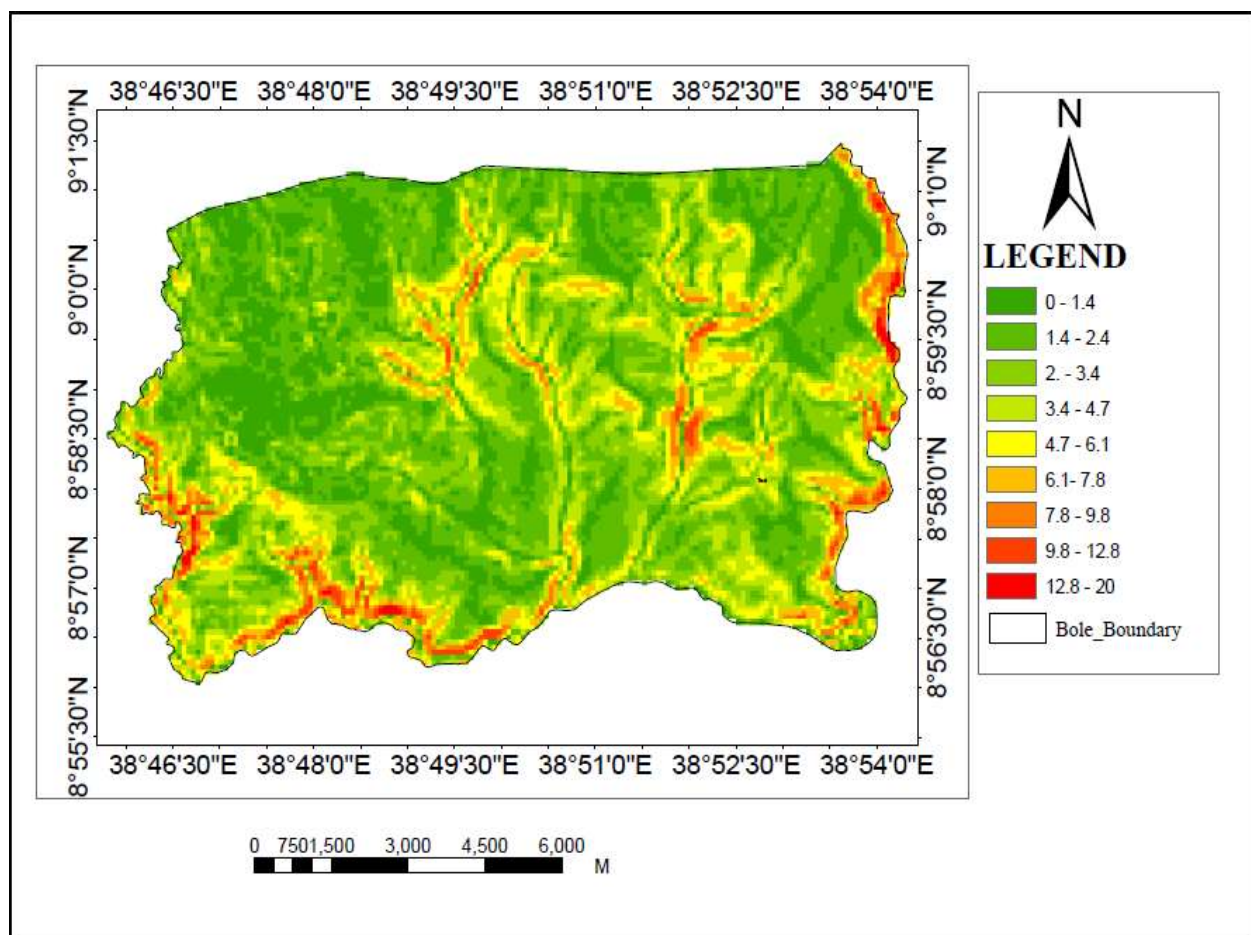


Figure 4.2 Slope map of the study area

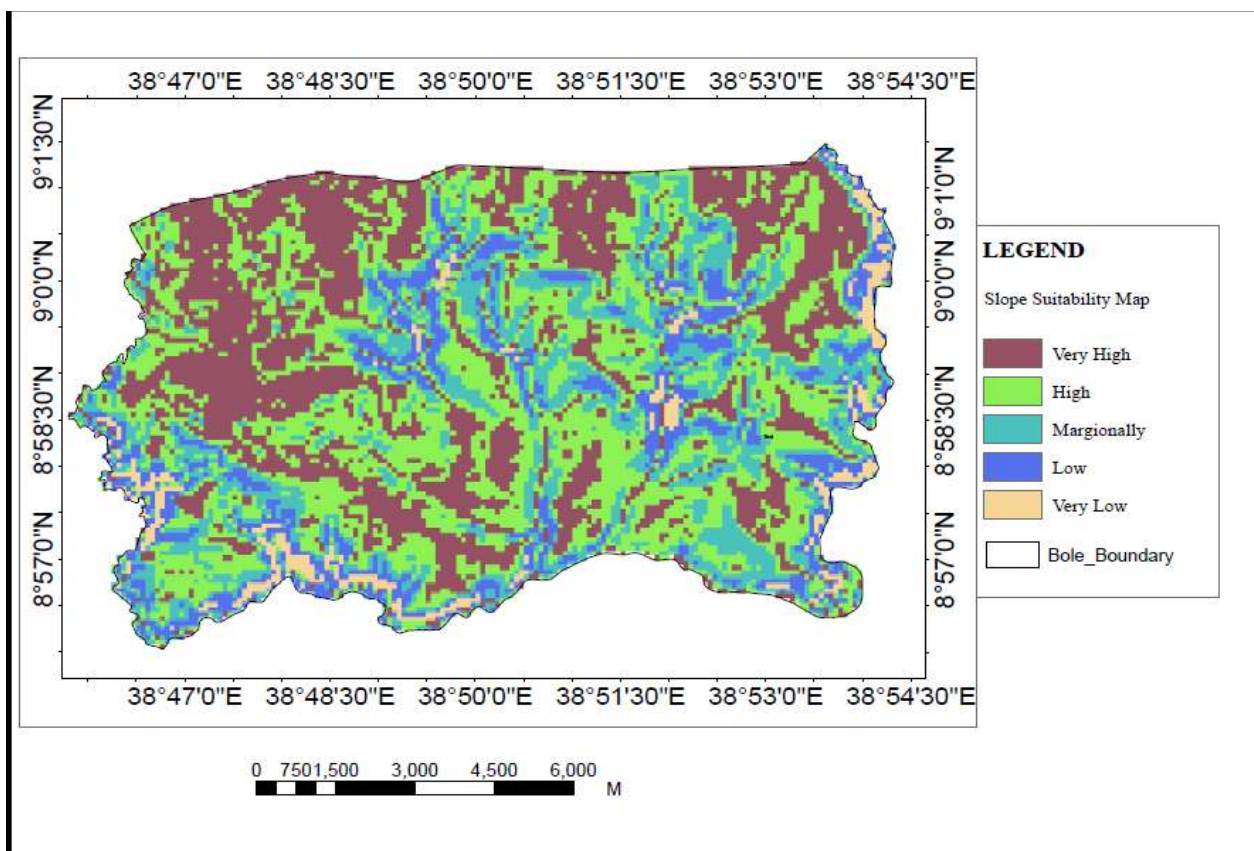


Figure 4.3 Reclassified slope suitability Index map of the study area

Reclassification involves assigning higher or lower values to more suitable locations or cell values in the study, the suitable slope value are those that represent conducive grazing and travel areas. Since the range of the new reclassified value is 1 to 5 the value of 5 takes the most suitable value whereas 1 shows the least suitable steepness area.

Table 4.1 Slope suitability classes and area coverage

S.NO	Slope class in%	Suitability	Rank	Weight	Area in (Km) ²	Area in %
1	8-20	Very low	1	0.0973	45.15	32.13
2	6-8	Low	2	0.4185	48.93	34.82
3	5-6	Moderate	3	0.2625	26.76	19.04
4	4-5	High	4	0.1599	14.82	10.54
5	0-4	Very High	5	0.0618	4.86	3.45
Total				1.00	140.52	100%

4.3.3 Soil Type

The five soil forming factors namely climate (temperature and rainfall), topography, parent material, biological activities (flora and fauna) and time determine the types of soil that are formed at a particular area. As a result soil can vary from place to place. Accordingly, soil of Addis Ababa is classified in to seven major types namely Calcic Xerosols, Chromic Luvisols, Chromic Vertisols, Eutric Nitisols, Leptosols, Orthic Solonchaks and Pellic Vertisols (Ministry of Water and Energy, 2004).

There are two types of soils in the study area they are Eutric vertisols and Humic Nitisols (Figure 4.4) soil map vector data will be converted in to raster data and then reclassified in to two for the sake of compatibility to the weighted overlay analysis in ArcGIS environment.

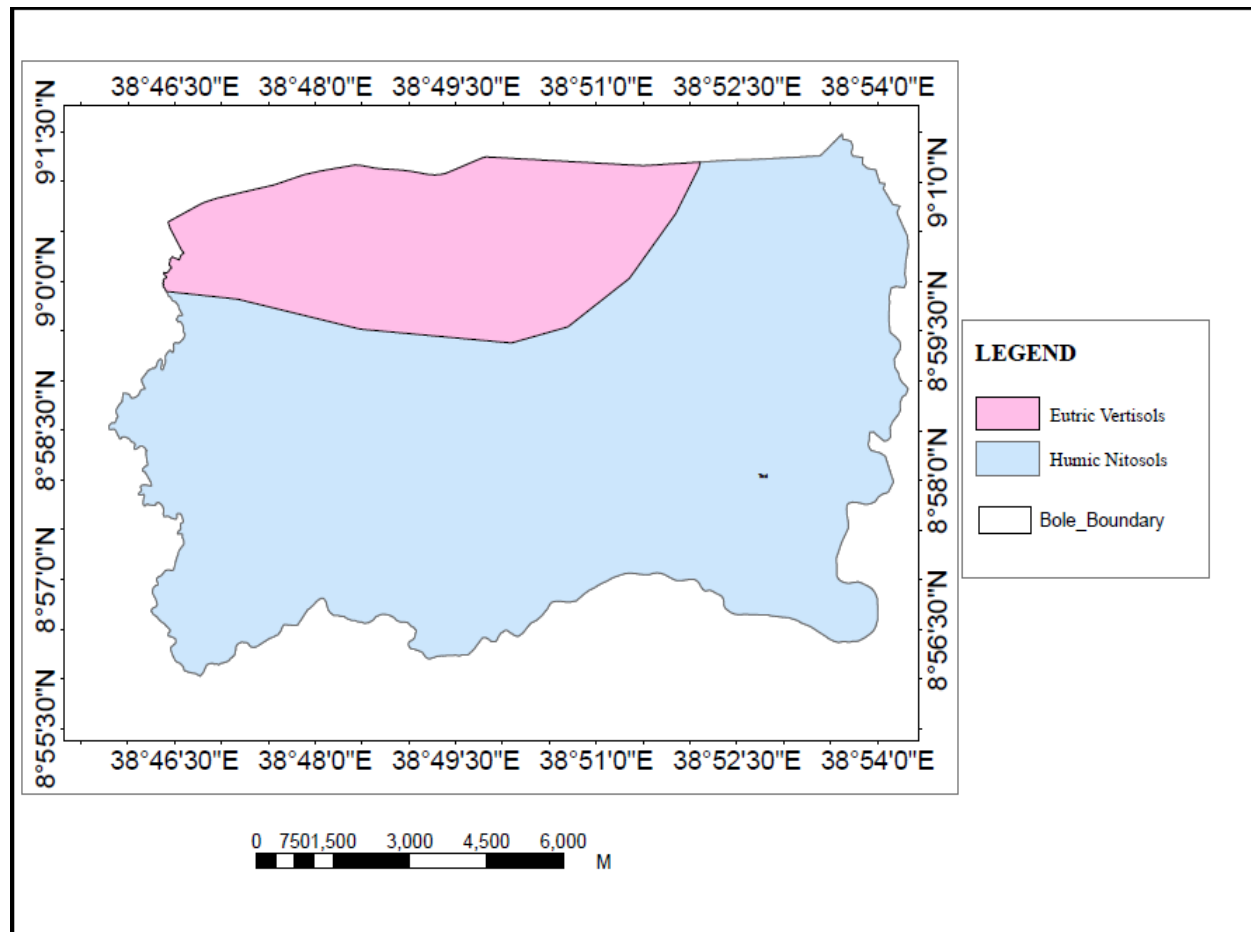


Figure 4.4 Soil type map of the study area, Source FAO soil classification

The soil type of the study area is dominated by Eutric vertisols and humic nitosols which account 28767.80 hectare which is 64% of the total area and Humic nitosols accounts 16329.70 hectare which is 36% of the total area.

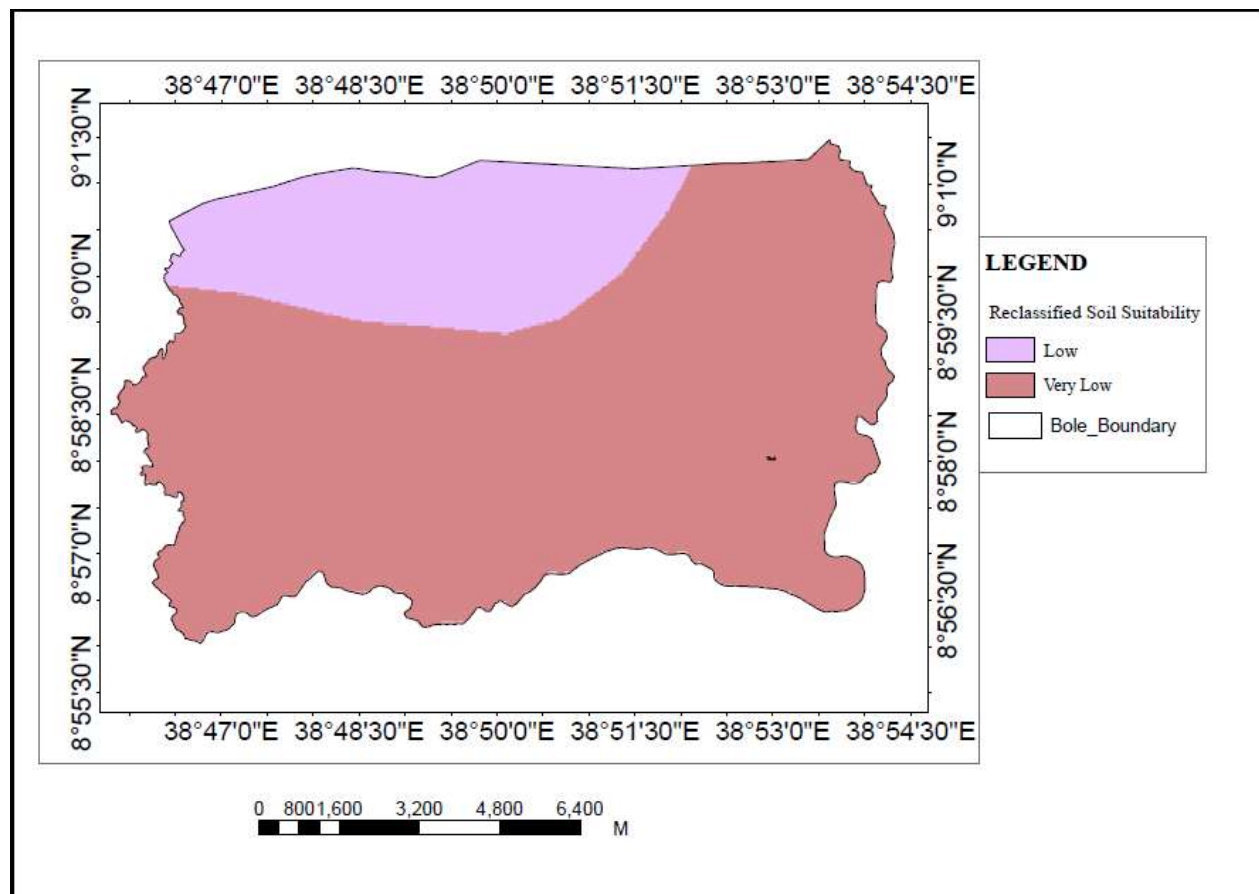


Figure 4.5 Reclassified Soil map of the study area

Table 4.2 Soil suitability classes and area coverage

S.NO	Suitability	Rank	Weight	Area in (Km) ²	Area in %
1	Very low	1	0.5	115.07	64
2	Low	2	0.5	25.45	36
Total			1.00	140.52	100%

4.3.4 Soil Depth

As per the International standards building code the minimum depth of soil for foundation should be less than 45cm for Buildings based on this soil depth classified in to three classifications.

Soil depth of the study area and area coverage are shown in the table 4.3.

Table 4.3 Areas of soil depth class in the study area.

S.No	Soil Depth	Area in(km ²)	Area in %
1	Deep >90 cm	140.52	100 %
2	Moderately Deep >45 cm <90cm	---	---
3	Shallow <45 cm	---	---
Total		140.52	100 %

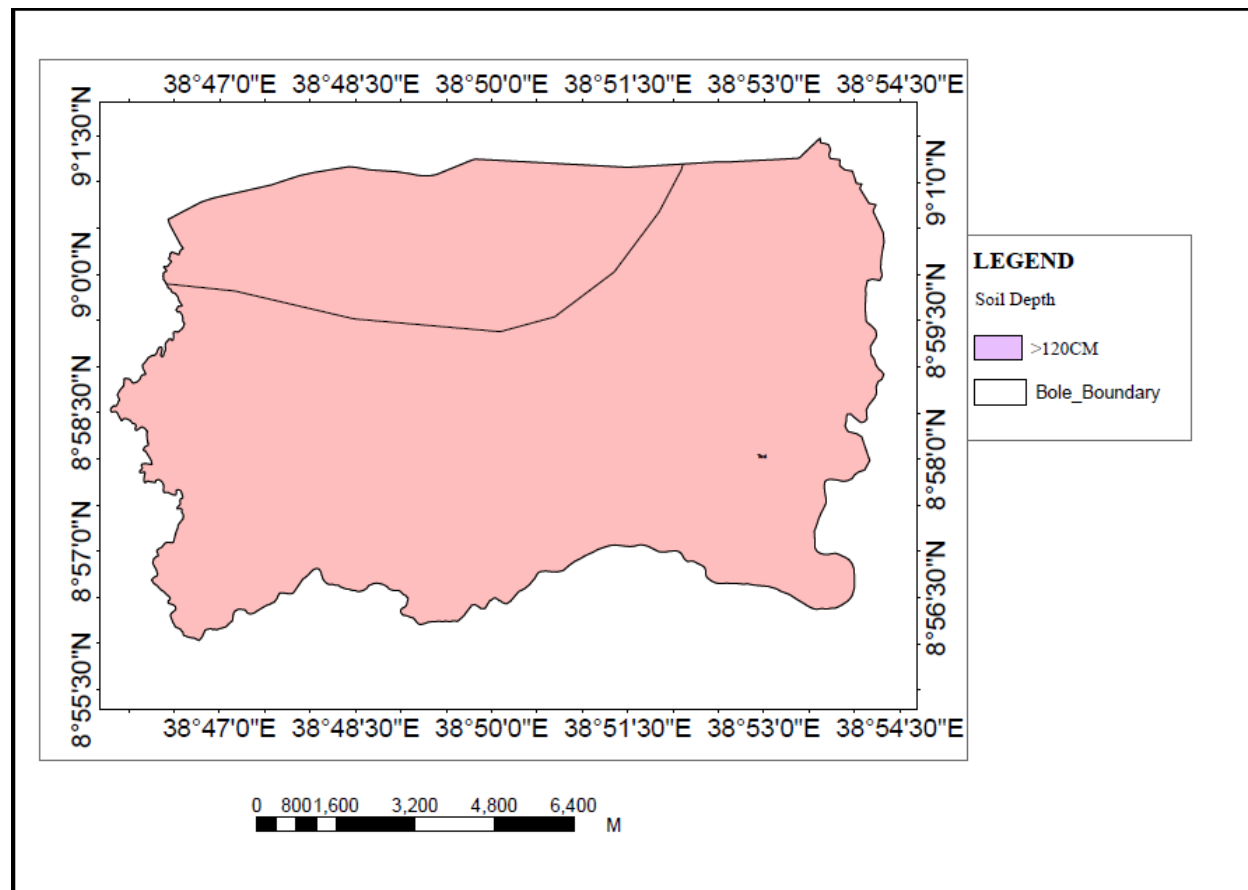


Figure 4.6 Soil depth map of the study area source, FAO soil depth classification map

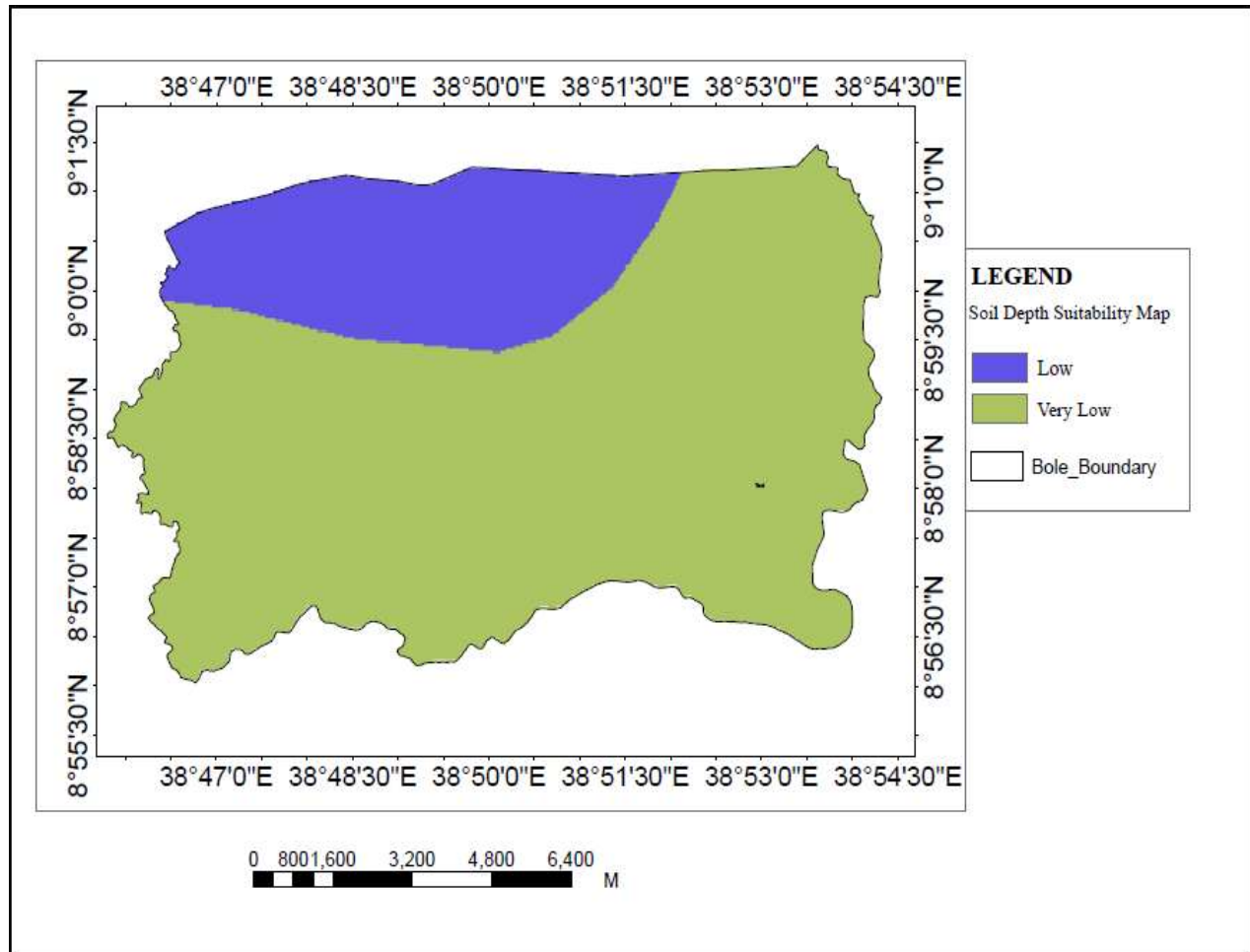


Figure 4.7 Reclassified soil depth map of the study Area

Table 4.4 Soil depth suitability classes and area coverage

S.NO	Suitability	Rank	Weight	Area in (km ²)	Area in %
1	Very low	1	0.5	115.07	64
2	Low	2	0.5	25.45	36
Total			1.00	140.52	100%

4.3.5 Proximity to Rivers and Streams

Rivers and streams of Bole sub city were generated from DEM in GIS environment using Spatial Analysis tools (Figure 4.8). The necessary preprocessing operations like patching and filling were performed in GIS and DEM respectively. The analysis was performed by assuming one stream per 500 cell size in order not to consider gullies and small depression as stream. The result of the analysis was compared with the previous river map to assess their accuracy and it was found to overlap each other in the Northern and western part of the study area and characterized by dense streams and drainage density decreases to the eastern part of the study area while size of the streams increase from north to south.

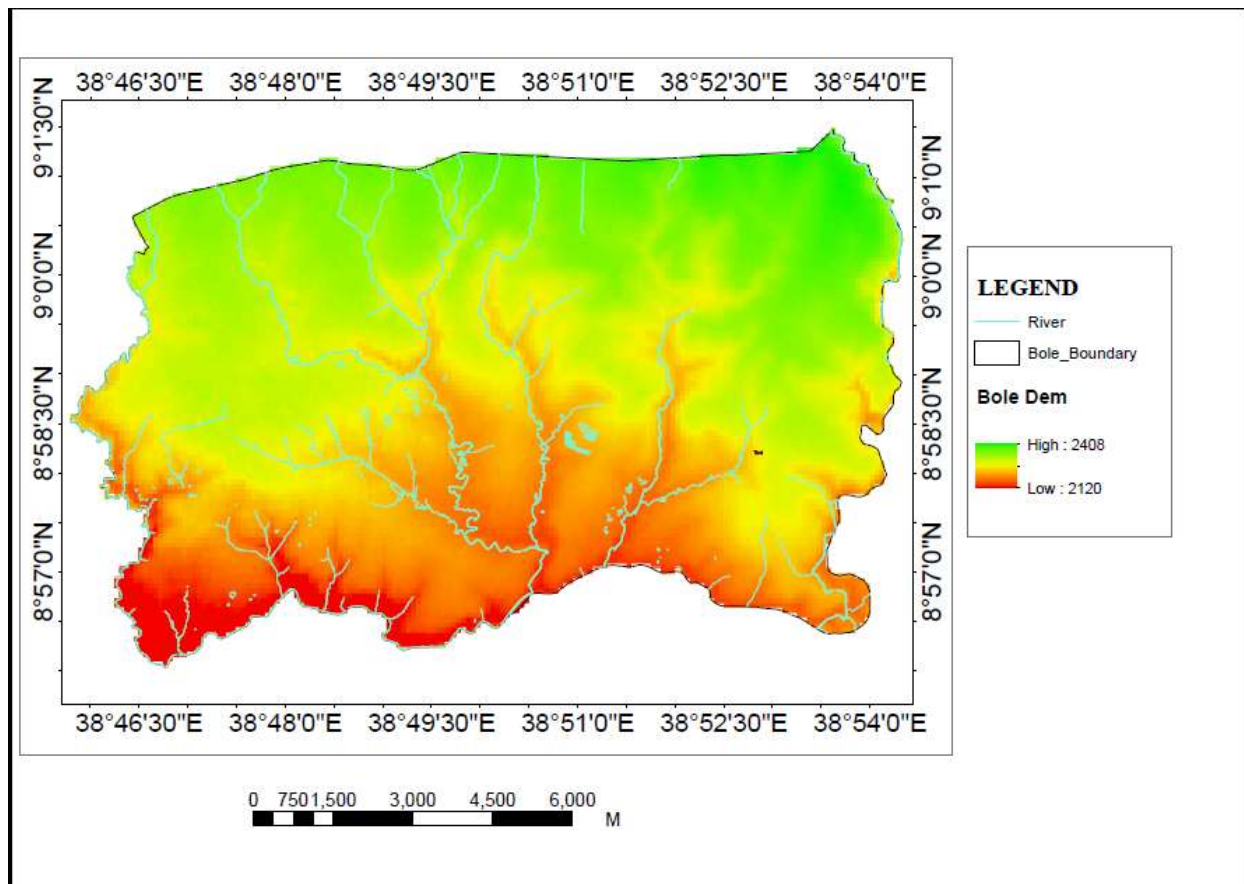


Figure 4.8 Drainage network map of the study area

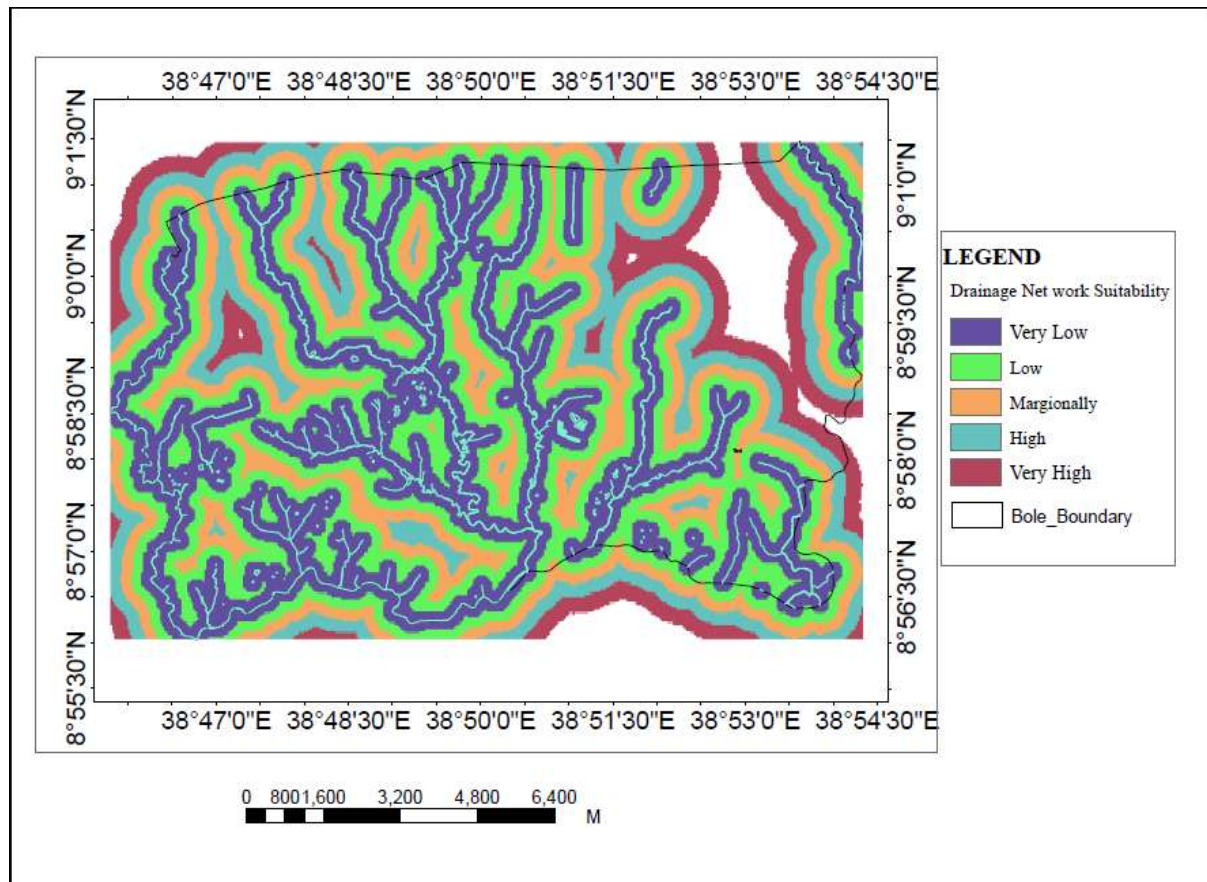


Figure 4.9 Reclassified drainage network map of the study area

Table 4.5 River and Stream proximity suitability classes and area coverage

S.NO	Distance in (M)	Suitability	Rank	Weight	Area in (km) ²	Area in %
1	0-200	Very low	1	0.0973	36.65	26.08
2	200-400	Low	2	0.4185	29.54	21.02
3	400-600	Moderate	3	0.2625	17.56	12.49
4	600-800	High	4	0.1599	11.59	8.28
5	>800	Very High	5	0.0618	44.02	31.35
Total				1.00	140.52	100 %

Source: MUDW (2006)

Accordingly, 30.10% of the study area was excluded from the suitability model processes due to the vicinity to the streams and rivers and hence suitable for urban development. An extent of 12.63% of the area was highly suitable for urban land development because of urban infrastructure. Moreover, 27.34% and 24.77% of the total areas were moderately and marginally suitable for urban development respectively.

4.3.6 Geology

Geology is one of the important factors that should be considered during urban land suitability modeling and analysis Impermeable strata and consolidated material are suitable for urban land suitability modeling as they do not allow movement of leachate.(Centre for Advanced Engineering, 2000). For this study, previous study and lithology log data were used to assess the permeability and stability of the rocks. According to Tamiru Alemayehu et al. (2003), the permeability of formation in the region not only depends on primary porosity, but also on secondary porosity resulted from weathering and fracture. The more the weathering and fracture, the more permeable and instable the rocks will be. Quaternary Basalts and Wechecha Yerer Furi Trachyte are permeable due to high degree of weathering and fractures and thus are marginally suitable for urban land suitability modeling. Moreover, Quaternary eluvial Sediments and Tertiary Sediments are highly permeable due to their primary porosity hence, unsuitable for urban land suitability modeling. However, Wechecha Yerer Furi was very low permeable due to less degree of weathering and fracture. Therefore, based on the nature of rock, degree of weathering and fracture the study area were categorized in to three permeability and urban land suitability classes and most part of the study area is suitable for urban development activities as shown in Figure 4.10

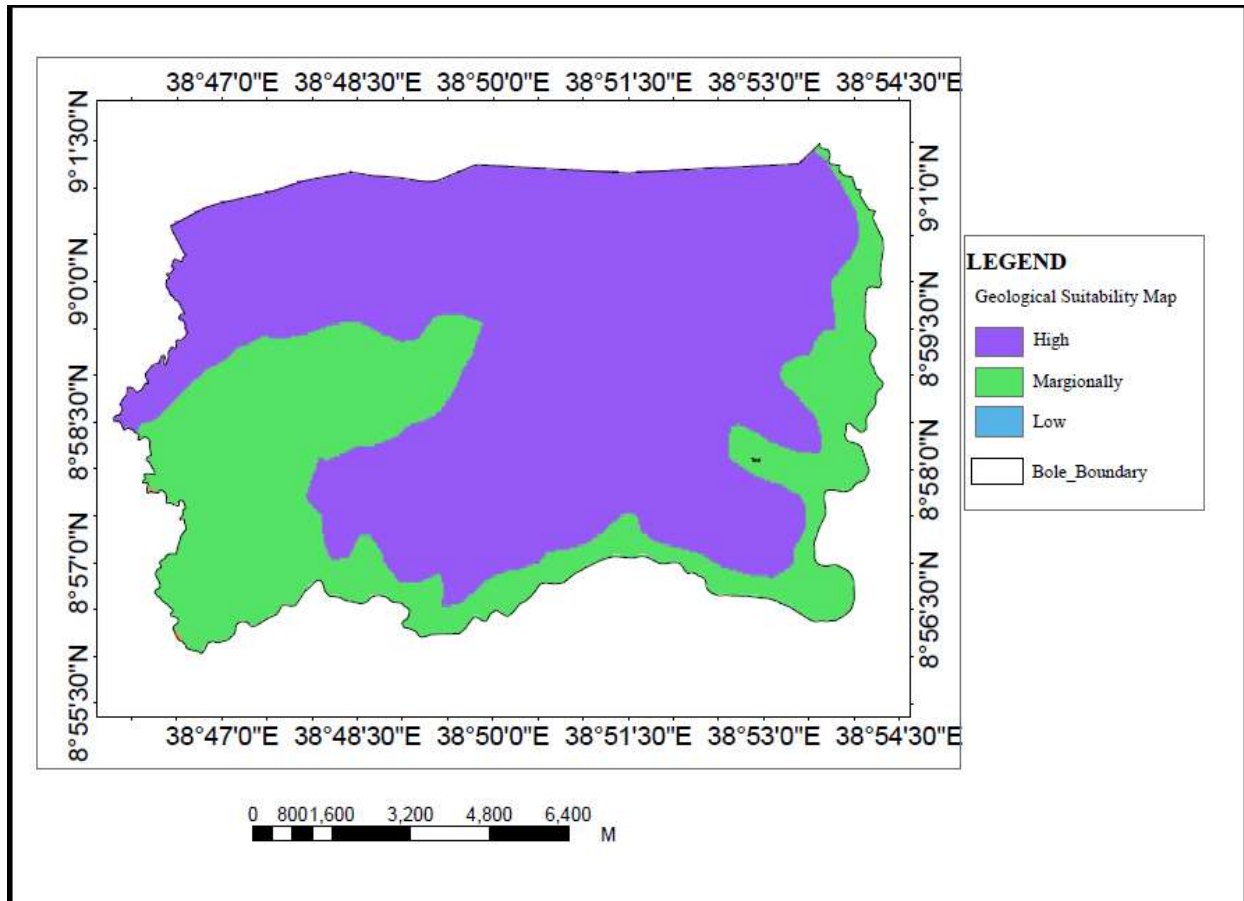


Figure 4.10 (Source: Mulugeta H/Mariam et al., 2007) Geologic Suitability Index Map of the study area

Table 4.6. Geologic Suitability and area coverage of Bole sub city

S.No	Suitability level	Area (km ²)	Area in (%)
1	High	95.31	67.82
2	Moderate	30.69	21.84
3	Low	14.51	10.32
Total		140.52	100.0

4.3.7 Proximity to Road Network

Road network is also an important Factor used to identify areas for urban development as it provides a linkage between settlement roads may be classified as major road and minor road for the sake of urban land suitability modeling analysis all important roads of the study area was taken from the city administration existing road network map and converted to raster data in order to be compatible for GIS analysis in GIS environment buffer of 500 m 1000m and 1500 m have been generated. The area lying between 500 m distance on both sides of the road have been ranked as highly suitable for development and areas lying between 1000 m and 1500 m and above are considered as low suitable for urban development.

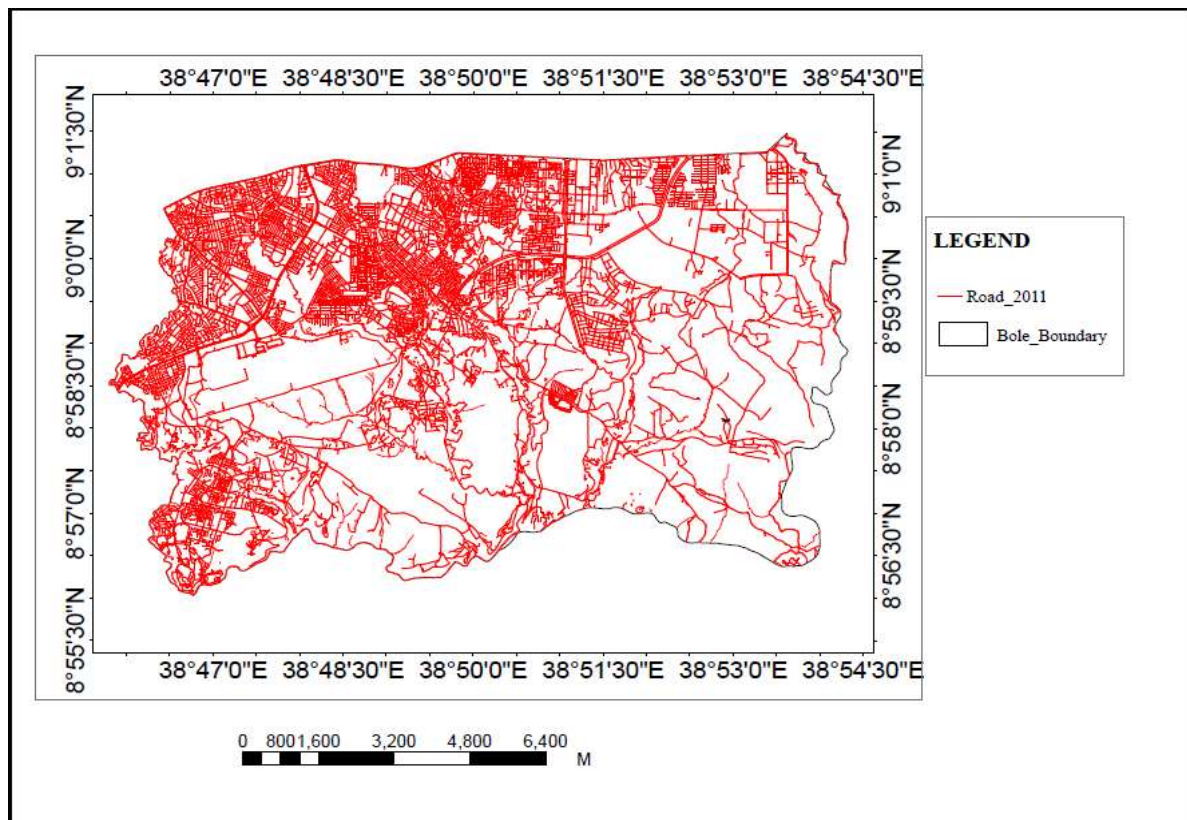


Figure 4.11 Road network map of the study area

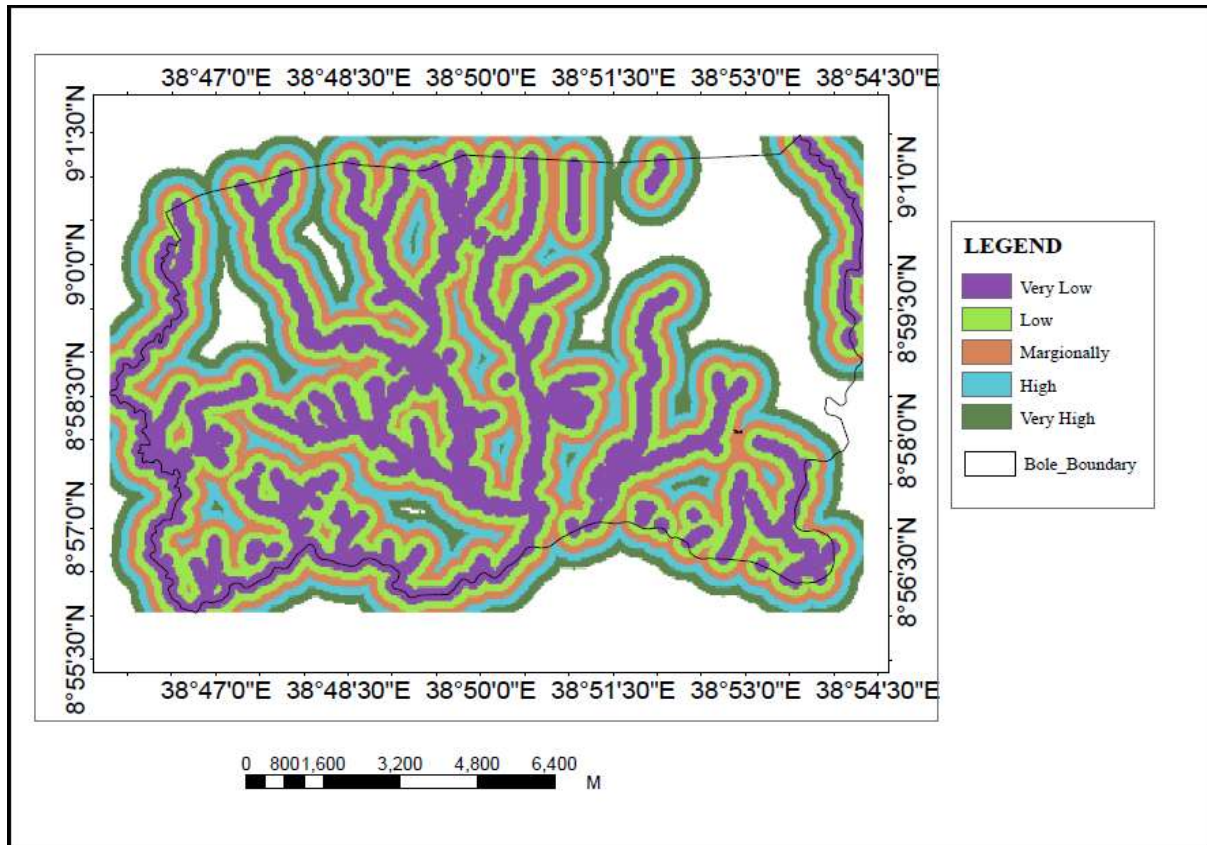


Figure 4.12 Reclassified road proximity network map of the study area

Table.4.7 Road network suitability of the study area

S.No.	Distance(M)	Suitability	Rank	Weight	Area km ²	Area in %
1	>2000	Very Low	1	0.0618	32.43	23.07
2	1500-2000	Low	2	0.4185	29.56	21.03
3	1000-1500	Moderate	3	0.2625	25.22	17.94
4	500-1000	High	4	0.1599	14.62	10.40
5	0-500	Very High	5	0.0973	38.73	27.56
Total				1.00	140.52	100.0

Source: MWUD

4.3.8 Ground Water Prospect

Ground water prospect is also important parameter for urban land suitability modeling and analysis the need for pure water and population growth is inversely related. Not only for drinking purpose but also for constructing high rise buildings it is necessary to identify soil capacity and ground water depth because plays an important role in urban land suitability modeling. It is known that higher ground water depth is more suitable for construction of buildings than lower water table depth. Low water table areas are prone to damage of buildings through seepage it also poses risk of flood which make it less suitable for urban development. Figure (4.13) shows ground water potential map of the study area.

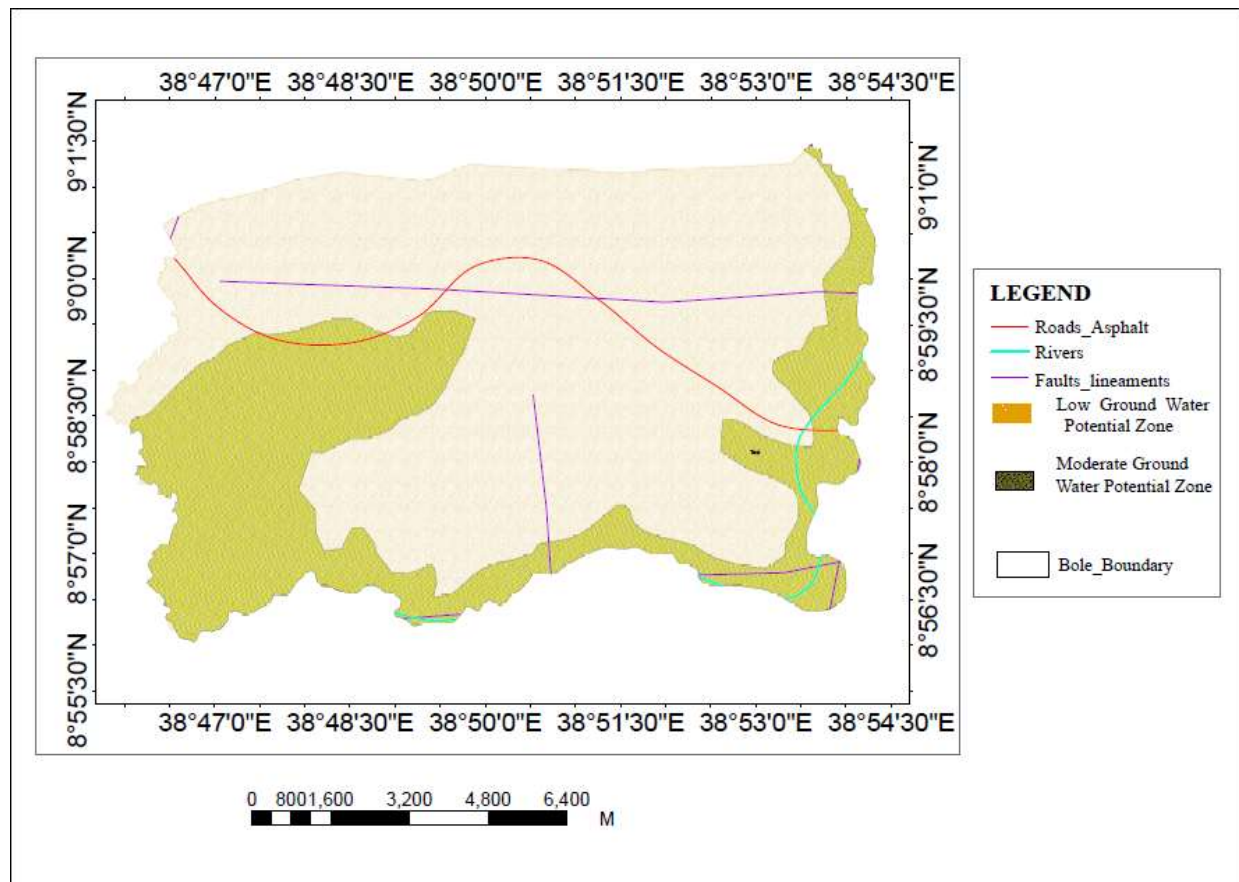
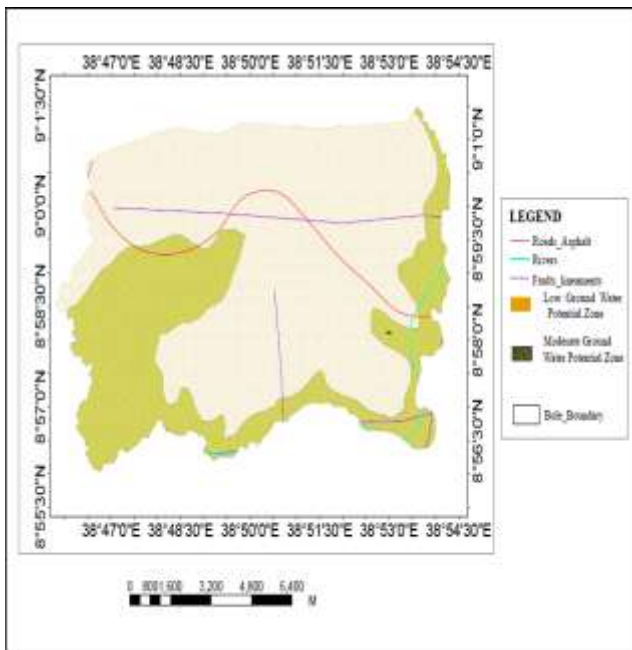
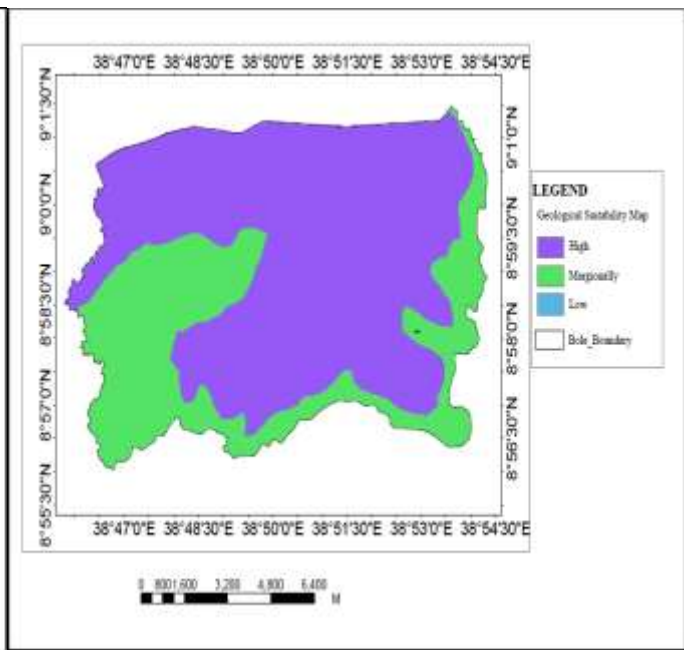


Figure 4.13 Source Ministry of water resources, 2008 Ground water prospect map of the study area

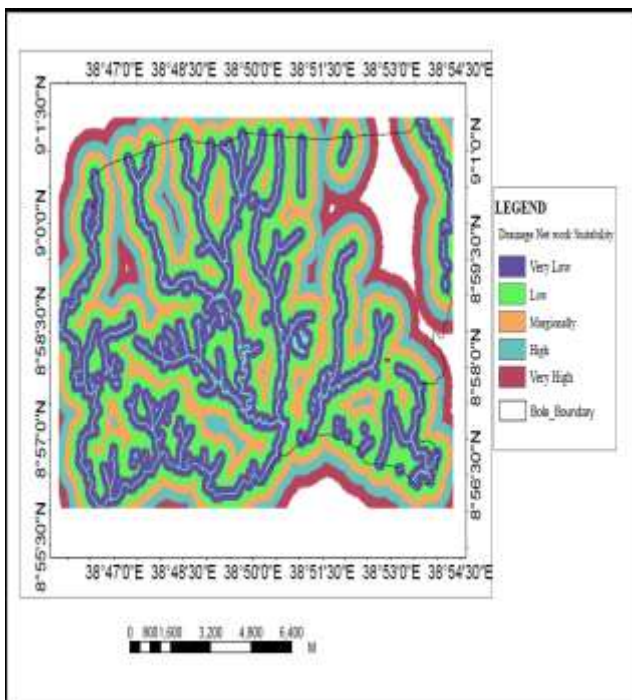
(A) Reclassified Geologic Suitability



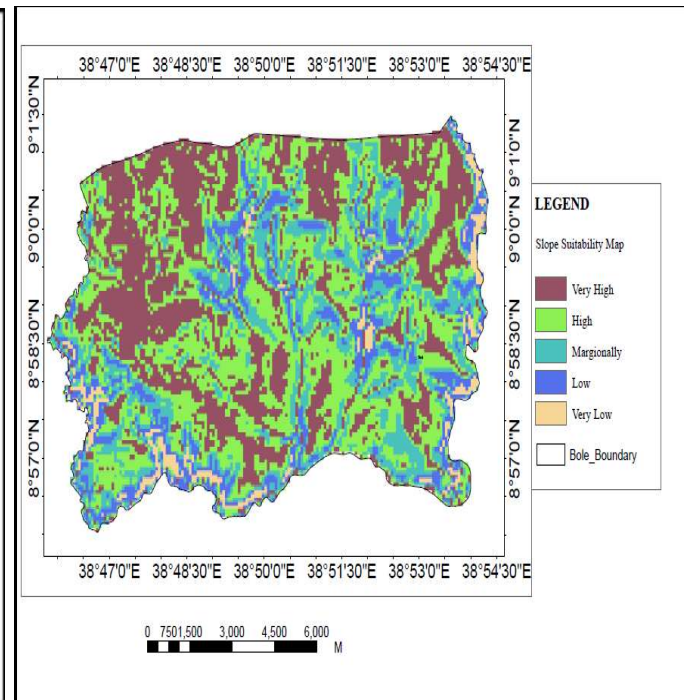
(B) Reclassified Ground water Suitability



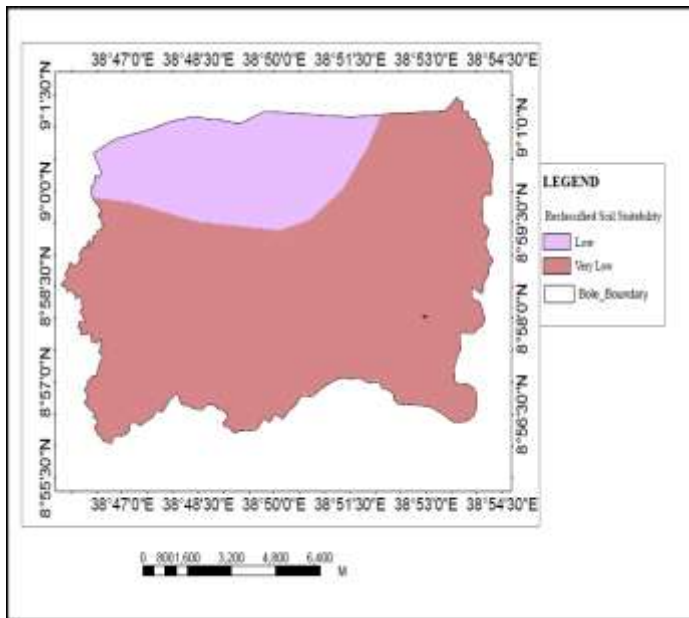
(C) Reclassified Drainage Suitability



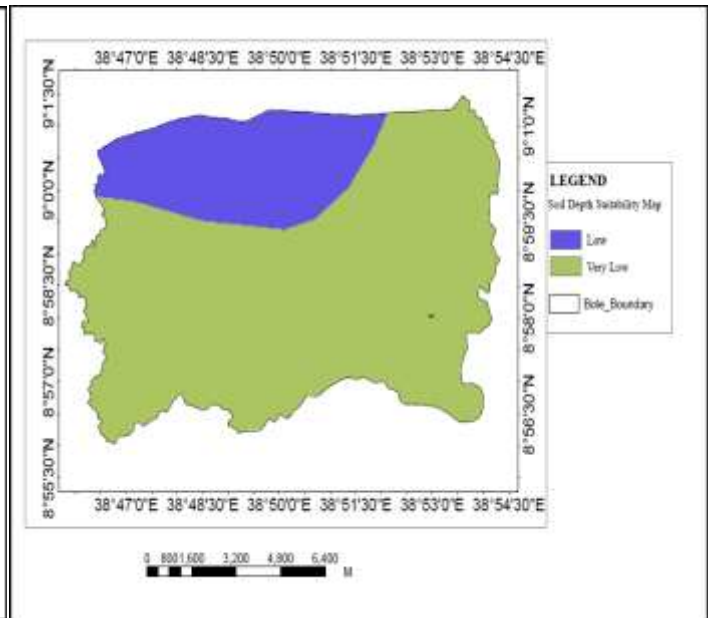
(D) Reclassified slope Suitability



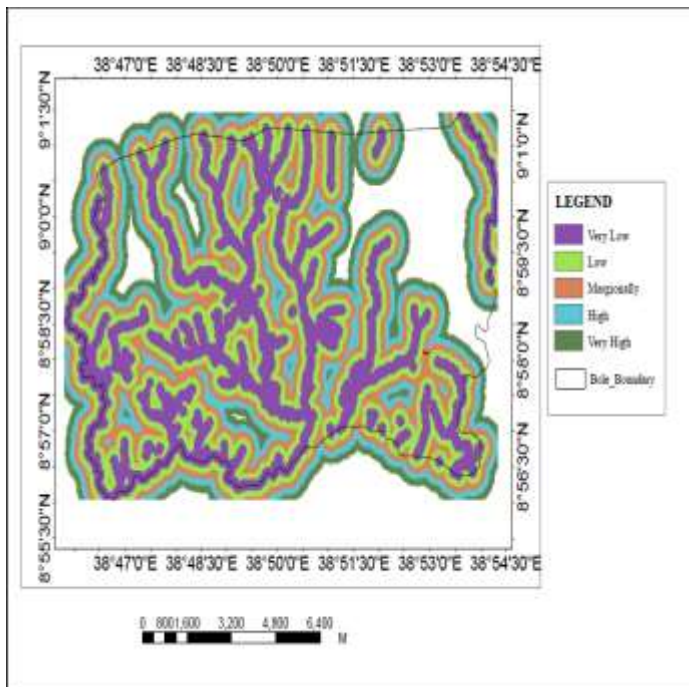
(E) Reclassified Soil Suitability



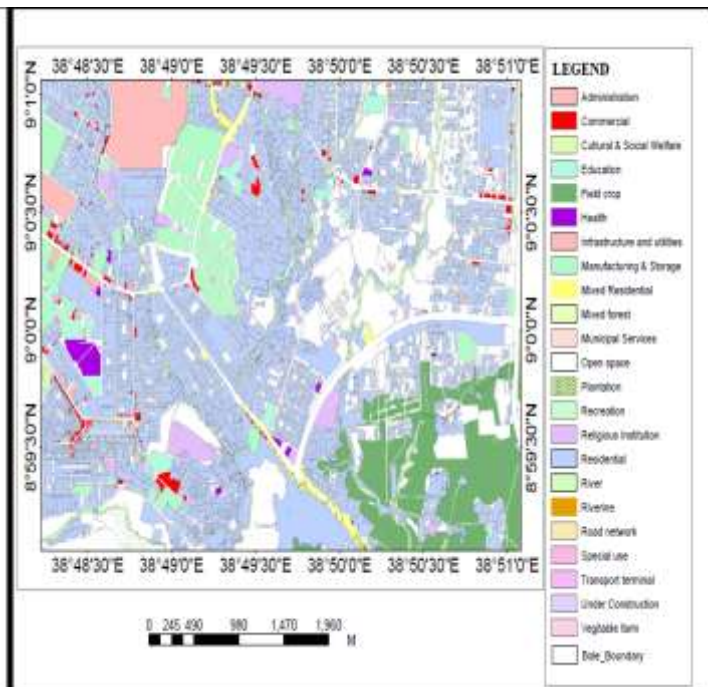
(F) Reclassified Soil Depth Suitability



(G) Reclassified Road network Suitability



(H) Land use land covers Suitability



4.14 Raster Reclassified factor maps

4.4. Urban Land Suitability Model Analysis and Results

Selection of suitable urban land for urban development is the critical issue in urban planning and land management. Urban land suitability not only based on physical parameters but it also depends on socio economic factors. The sum of these effects determines the degree of urban land suitability of an area. Assessment of physical parameters of the land is also possible by analyzing parameters like soil type, terrain, geology, flood hazard, distance from road and distance from existing development these are amendable in GIS analysis. But socio economic effects on urban land are difficult for analysis and to be specified. However the assessment of physical parameters gives an indication on the limitations of the site for urban development. The concept of limitation can be expressed in many ways like slope for example if the slope is high it requires finance, man power, material, time etc. For this research the physical parameters used for urban land suitability are land use land cover, slope, road network, geology, drainage, soil type, soil depth. These all parameters are analyzed in a GIS environment using weighted index model.

According to the model generated by the weighted overlay analysis method in ArcGIS environment out of the total area of the study area which is 140.52 km² 8.74 km² is highly unsuitable area which covers 6.22% of the total area. Less Suitable area covers an area of 29.33 km² which covers 20.87 % of the total area. Moderately Suitable area covers an area of 29.59 km² which covers 21.06 % of the total area. Highly Suitable area covers an area of 40.83 km² which covers 29.06 % of the total area.

Very High Suitable area covers an area of 32.01 km² which covers 22.87 % of the total area. Generally, about 72.09% of the total area of the study area was being suitable for urban development activities. However, about 27.91% of the total area of the study area was being unsuitable for urban development as a factor of the parameters. Like slope, soil depth, ground water prospect and others for this reason we cannot observe new urban developments in the areas which were identified as unsuitable areas for urban development.

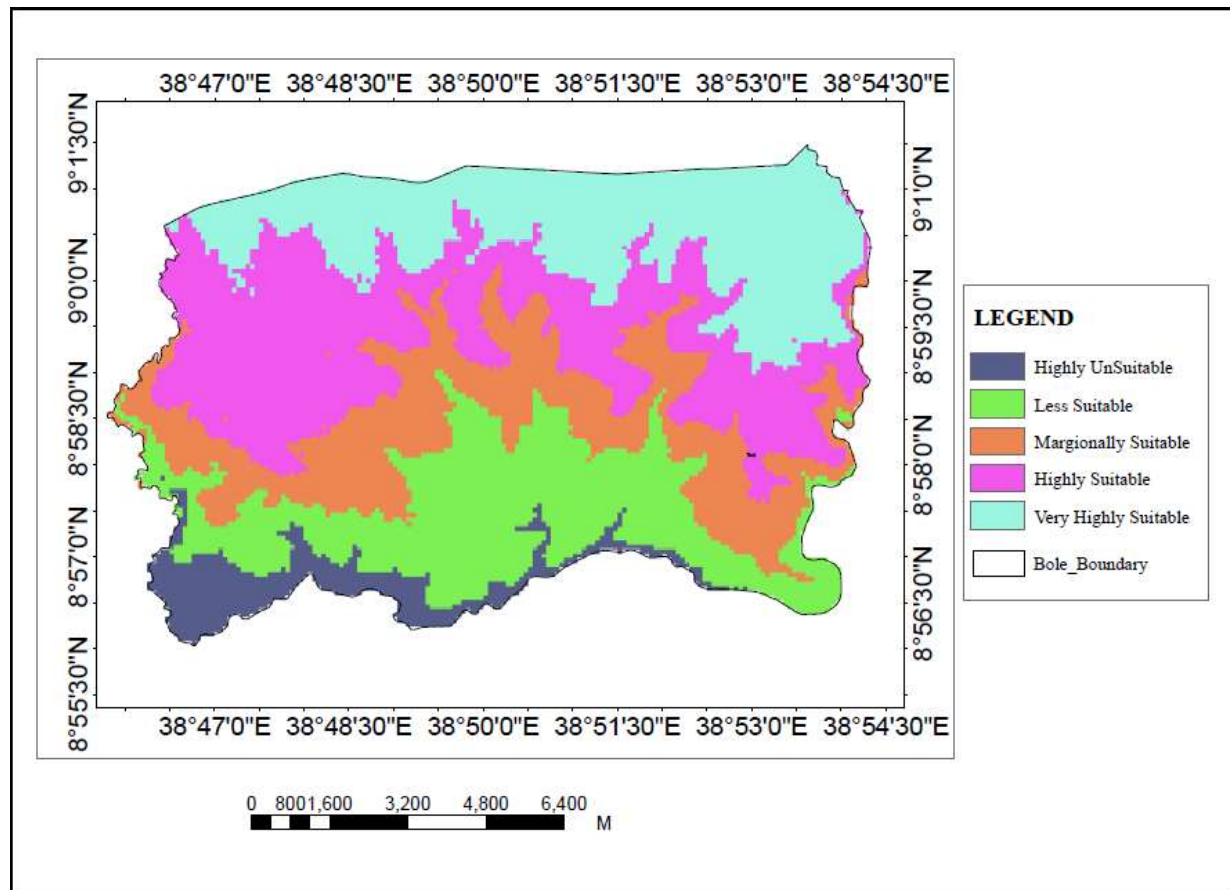


Figure.4.15 Urban land suitability model map

Table 4.8 Model suitability classes and area coverage of the study area

S.NO	Suitability level	Rank	Area in (km) ²	Area in %
1	Highly unsuitable area	1	8.74	6.22
2	Less Suitable area	2	29.33	20.87
3	Marginally suitable area	3	29.59	21.06
4	High Suitable area	4	40.83	29.06
5	Very High Suitable area	5	32.01	22.78
Total			140.52	100%

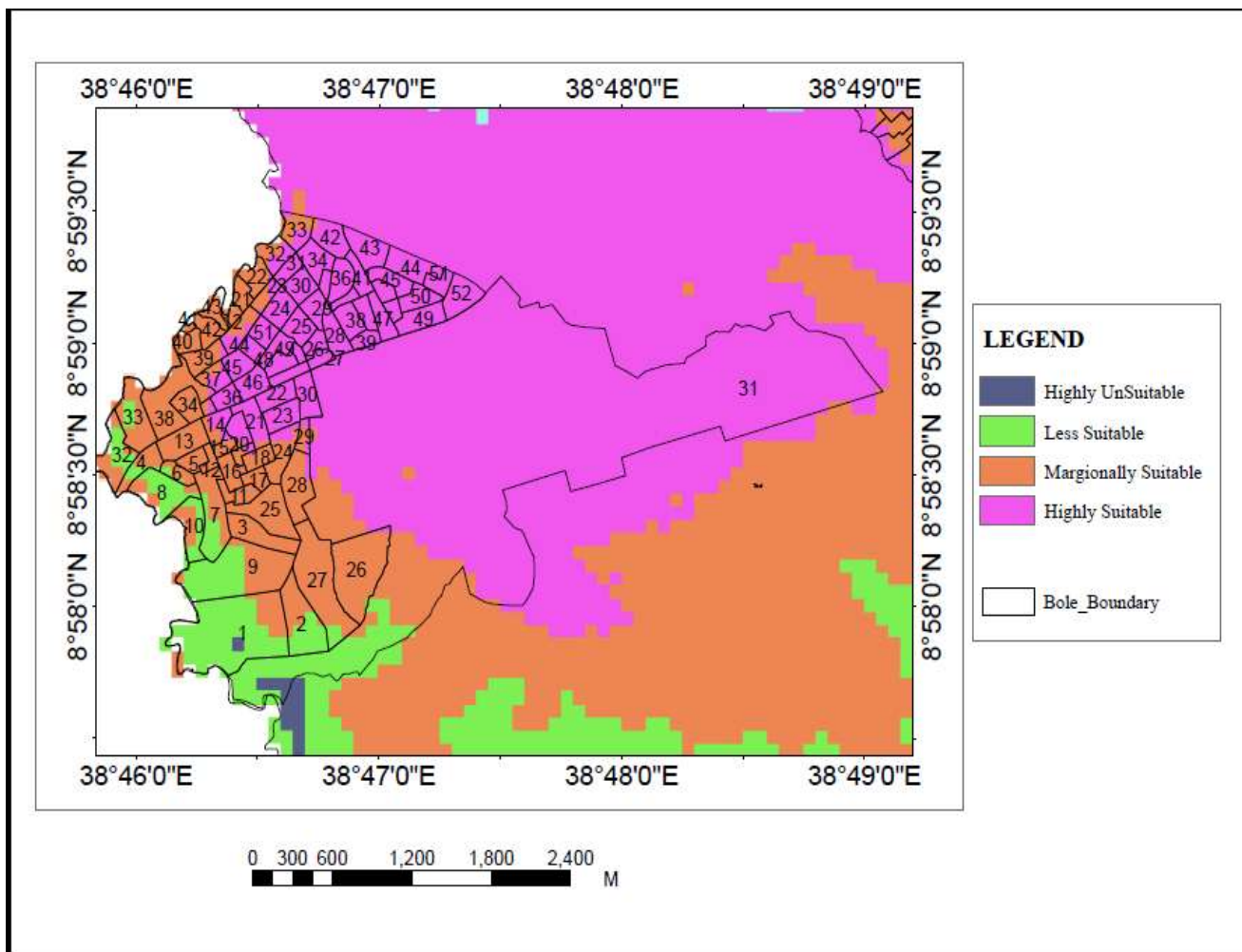


Figure 4.16 parcel wise urban land suitability modeling of the study area partial view of wereda 4, 5, 6

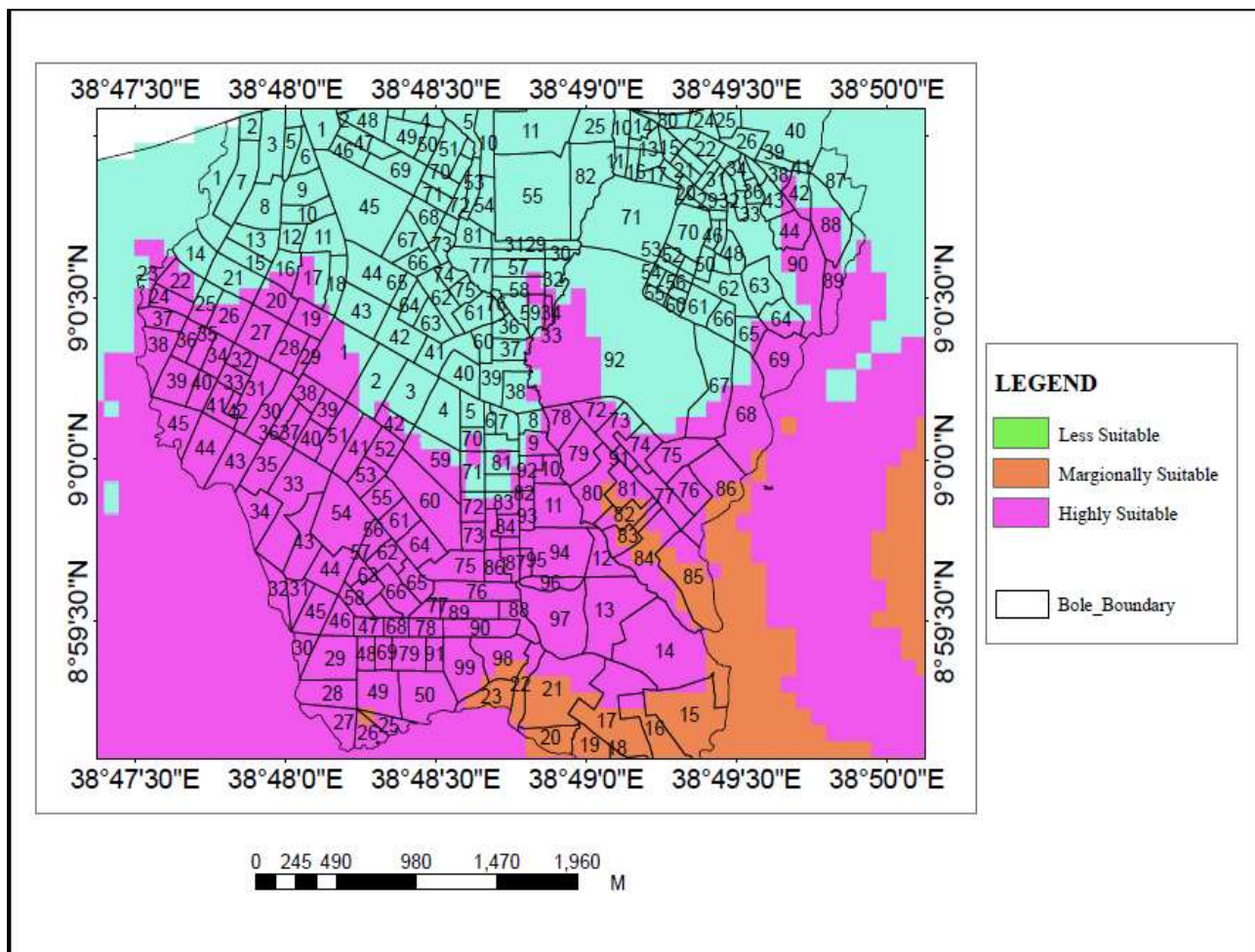


Figure 4.17 Parcel wise urban land suitability modeling of the study area partial view of wereda1&2

5. DISCUSSION

5.1 Model output Vs Urban Land Suitability Modeling

Urban land suitability model result seems to correspond with the reality of the study area. However urban land which is not suitable for urban development is also used for urban development purposes without any arrangements made. This is due to the shortage of urban land supply and high lease price which is not affordable by many residents and due to the illegal settlements made by residents.

According to the final urban land suitability model result the north eastern part of the study area is very highly suitable for urban development activities, north western part highly suitable along the central part south eastern and south western part of the area is moderately suitable.

In conclusion, this thesis indicated that

- 8.74km² (6.23 %) of the study area is highly unsuitable for urban development
- 29.33km² (20.87 %) of the study area is less suitable for urban development
- 29.59km² (21.06 %) of the study area is marginally suitable for urban development
- 40.83km² (29.06 %) of the study area is highly suitable for urban development
- 32.01km² (22.78 %) of the study area is very highly suitable for urban development

By considering the assumption behind the MCE procedure that factor maps should be not redundant the results of this research was adequate in terms of the evaluation criteria used here the final suitability model map represents a more realistic outcome.

The feedback process involving urban planners was very use full. Because, results could be in fine with their experience such an approach produced valuable information on the relative importance of the factors under evaluation and could be used for future studies. Moreover the results of this research could be important for other professionals and researchers who could use the results for diverse studies.

5.2 Final Urban Land Suitability Model Map of the Study Area

Proper use of urban land depends up on the use of urban land for a specific urban land use for this study especially it is very important to identify suitable urban land for urban development activities. Nevertheless it must have an impact to the environment. As a need to utilize land resource therefore suitability model provides suitability of the environment in parallel with the optimum utilization of the land for urban development activities. As a result the study area was classified in to five suitability classes according to the standard given by FAO and 72.09% of the study area was classified as suitable for urban development activities. But 29.33 % of the study area was classified as unsuitable for urban development activities as shown in Figure 4.18.

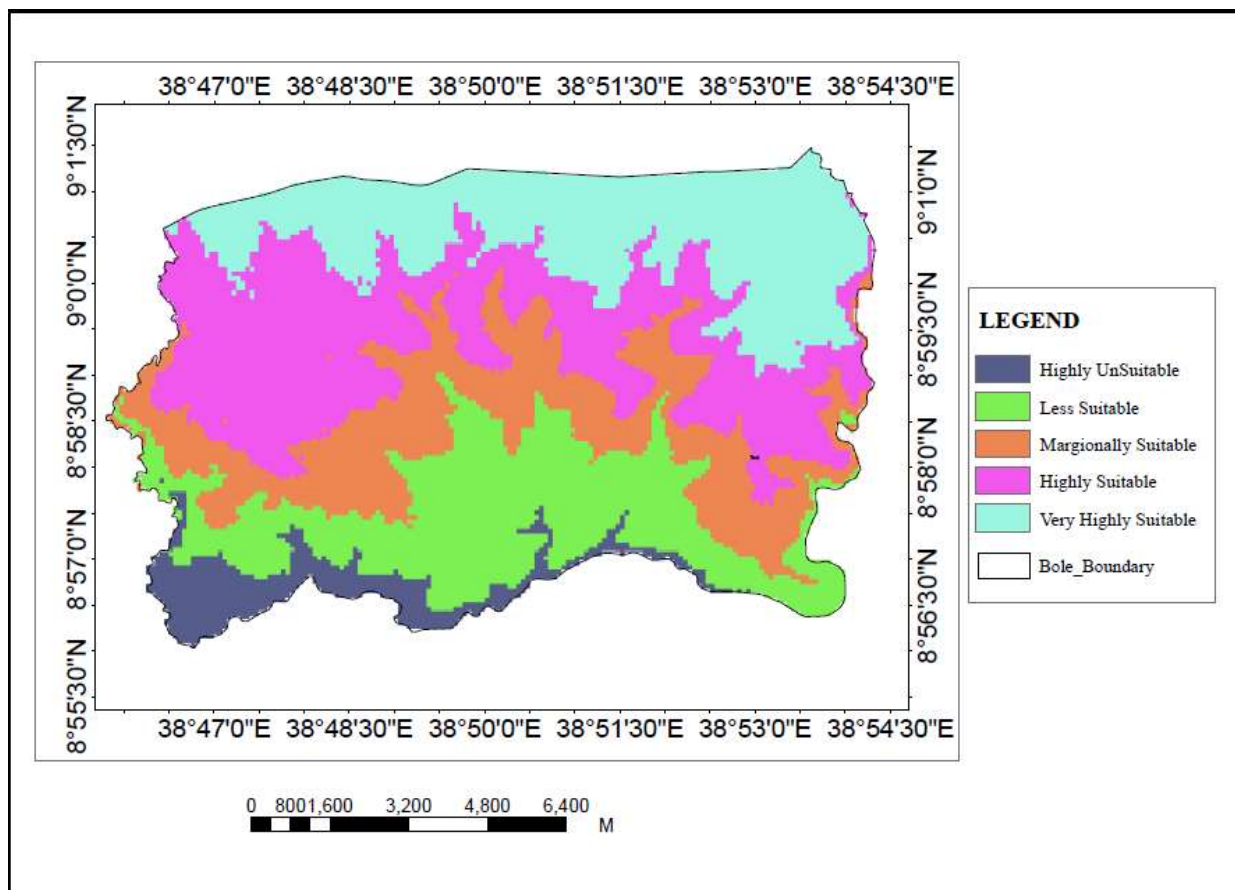


Figure 4.18 final urban land suitability model map of the study area

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This research indicates the use of remote sensing and Geographic Information System for urban land suitability modeling. The finding of this study assured that the most influential factors used for urban land suitability analysis and modeling was its slope with its infrastructure. The second important factor is drainage related to the surroundings. The third one is ground water prospect and the fourth one goes to the state of the existing urban infrastructure and another factors which identified this research are soil depth, soil type, land use land cover. This research also aims at identifying urban land suitability modeling at parcel level using multi criteria decision making methods in Bole sub city by using many parameters and approaches of RS and GIS. The results of this research indicate that the main factors for urban and suitability modeling of Bole sub city five pillars. The first and most important factor in urban land suitability modeling is its slope related to urban infrastructure development. The second factor goes to the urban infrastructure exists in the study area like road network etc. The third one is soil type because different types of soils have different capacities for urban development activities like construction of buildings for this reason soil can be identified as one and important parameter and soil depth also used an important parameter using the analysis capabilities of GIS the soil type of the study area and soil depth as well identified and used as a parameter in the weighted overlay analysis techniques of GIS by having its factor value.

The fourth one is ground water potential map of the study area this data is collected from water works construction design Share Company, according to this data areas of ground water potential zones were identified which area have high ground water potential which area have moderate ground water potential and low ground water potential and the relationship between ground water potential and urban development activities like construction of High rise buildings were analyzed. Another important factor is land use land cover, rivers and streams are also used as parameters in order to identify the best suitable area for urban development activities. Using the analysis capabilities of GIS and RS as a result **72.09** % of the study area is suitable for urban development activities and **29.33**% is unsuitable for urban development activities because of different factors like slope, urban infrastructure etc.

6.2 Recommendation

Having suitable urban land, which encourages investors and investment and realizing the costs of infrastructure make an efficient use of urban land are some of the major goals of the city administration, Furthermore, urban planning and land administration in cities now a days demanding a task of calling for the better professionals as well as new and modern approach among these demands urban land suitability modeling takes the major share. To take the advantage of the efficient and effective urban land suitability modeling the following recommendations should be paid high due attention by the city administration.

Facilitate long term and short term Trainings to the Professionals

Training to the local staffs and giving directions all over in country level especially for those professionals and leaders who have a direct relation to land management should be given priority on to prepare suitable urban land for different purposes because different urban land have different physiographic conditions at all and the professionals who involved in urban land suitability modeling and analysis should be multi professionals like urban planners, geologists, GIS and RS experts and from social scientists also in order study the socio economic impact and analysis.

Urban land suitability site selection should be done by multi professionals including social scientists in order to avoid social in security or social problems beyond to that of environmental problems.

Public participation

One of the major tasks to implement better success of urban policy as city lack of awareness and understanding from the stake holders unless the preparation of suitable urban land requires enough participation during the preparation and implementation of different rules and regulations that enable to implement better and suitable urban environment.

Allow flexible urban land use planning approach

Urban land suitability modeling plans should be flexible to provide for the new and expansion areas to help to revise urban land suitability analysis and modeling.

Provide modern and accurate Geospatial Information System for sustainable urban land management

Land management agencies and authorities should adopt modern technologies like computerized system and GIS application because these have the ability to provide necessary spatial data used for many purposes like for the preparation of urban land suitability model maps based up on the analysis capabilities of GIS and RS.

Consider geological and hydrological Parameters

Detailed Hydrological and geological studies should be taken for urban land suitability modeling of an area to show the effects hydrological and geological parameters on the overall urban development activities like construction, land use etc.

To sum up the research methodology can be used as bench mark to develop urban land suitability model. Furthermore, users may modify the urban land suitability model result of the study area by in many ways

(a)By adding parameters which did not included in this research that add value to the in the suitability analysis and modeling of the study area (b) by changing weights given for the parameters used to better reflect urban land suitability modeling of the study site in feature research, the researcher recommends using different hydrogeological, geological and socio economic parameters to improve the conceptual model. The suitability model should also refine with additional model parameters improved data accuracy to advance the precision of the model to be used as a tool for decision makers.

Areas which are identified as unsuitable areas for urban development activities should be used as green areas open spaces as well as buffer zones.

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Appendix: 1

Table 4.9 Example showing parcel wise urban land suitability modeling of bole sub city wereda.4,5,6

S. No	Parcel No	Parcel Area M ²	Level of Suitability Class
1	01	379932	Highly suitable
2	02	123304	Highly suitable
3	03	73170	Highly suitable
4	04	46560	Highly suitable
5	05	26633	Highly suitable
6	06	26692	Highly suitable
7	07	109152	Highly suitable
8	08	102300	Highly suitable
9	09	251333	Highly suitable
10	010	68952	Highly suitable
11	011	32270	Highly Suitable
12	012	15508	Highly Suitable
13	013	67381	Moderately Suitable
14	014	36728	Highly Suitable
15	015	18669	Highly Suitable
16	016	34496	Highly suitable
17	017	23658	Highly suitable
18	018	28727	Highly suitable
19	019	14040	Highly suitable
20	020	30933	Highly suitable
21	021	49998	Highly suitable

22	022	40528	Highly Suitable
23	023	44528	Highly suitable
24	024	61720	Highly Suitable
25	025	99513	Highly suitable
26	026	193062	Highly suitable
27	027	197910	Highly Suitable
28	028	88174	Highly Suitable
29	029	20727	Highly Suitable
30	030	45976	Highly Suitable
31	031	5091317	Highly Suitable
32	032	84354	Highly Suitable
33	033	94936	Highly Suitable
34	034	39177	Highly Suitable
35	035	9749	Highly Suitable
36	036	27839	Highly Suitable
37	037	34666	Highly Suitable
38	038	124668	Highly Suitable
39	039	44464	Very Highly Suitable
40	040	28764	Highly Suitable
41	041	4651	Highly Suitable
42	042	35222	Highly Suitable
43	043	27095	Highly Suitable
44	044	43998	Highly Suitable
45	045	34714	Very Highly suitable
46	046	41696	Highly Suitable
47	047	23442	Highly Suitable
48	048	27567	Highly Suitable
49	049	29553	Highly Suitable
50	050	21758	Very Highly Suitable
51	051	30866	Highly Suitable
52	052	10446	Highly Suitable

Appendix: 2

Table 4.10 Example showing parcel wise urban land suitability modeling of bole sub city wereda1&2

S. No	Parcel No	Parcel Area	Suitability Class
53	53	108830	Highly Suitable
54	54	29712	Highly Suitable
55	55	35446	Highly Suitable
56	56	8164	Highly Suitable
57	57	17694	Highly Suitable
58	58	6494	Highly Suitable
59	59	4797	Highly Suitable
60	60	8303	Highly Suitable
61	61	1715	Highly Suitable
62	62	48243	Highly Suitable
63	63	1624	Highly Suitable
64	64	108	Highly Suitable
65	65	655	Highly Suitable
66	66	26976	Highly Suitable
67	67	581	Highly Suitable
68	68	30065	Highly Suitable
69	69	19254	Highly Suitable
70	70	20306	Highly Suitable
71	71	34184	Highly Suitable
72	72	25580	Highly Suitable
73	73	23467	Highly Suitable
74	74	17493	Highly Suitable
75	75	57916	Highly Suitable
76	76	39907	Highly Suitable
77	77	14979	Highly Suitable
78	78	22396	Highly Suitable
79	79	39857	Highly Suitable
80	80	18336	Highly Suitable

81	81	27175	Highly Suitable
82	82	20915	Highly Suitable
83	83	24759	Highly Suitable
84	84	18269	Highly Suitable
85	85	8207	Highly Suitable
86	86	23388	Highly Suitable
87	87	16955	Highly Suitable
88	88	883	Highly Suitable
89	89	69552	Highly Suitable
90	90	1109	Highly Suitable
91	91	600	Highly Suitable
92	92	22671	Highly Suitable
93	93	20051	Highly Suitable
94	94	106984	Highly Suitable
95	95	11672	Highly Suitable
96	96	25345	Highly Suitable
97	97	1624	Highly Suitable
98	98	1138	Highly Suitable
99	99	1097	Highly Suitable
100	100	29456	Highly Suitable
101	101	3654	Highly Suitable
102	102	19854	Highly Suitable
103	103	4851	Highly Suitable
104	104	456612	Highly Suitable
105	105	356422	Highly Suitable
106	106	356200	Highly Suitable
107	107	756235	Highly Suitable
108	108	256352	Highly Suitable
109	109	45621	Highly Suitable
110	110	752421	Highly Suitable
111	111	4568	Highly Suitable
112	112	7485	Highly Suitable

113	113	9654	Highly Suitable
114	114	4587	Highly Suitable
115	115	26132	Highly Suitable
116	116	12360	Highly Suitable
117	117	8975	Highly Suitable
118	118	4875	Highly Suitable
119	119	10254	Highly Suitable
120	120	45687	Highly Suitable
121	121	45126	Highly Suitable
122	122	35210	Highly Suitable
123	123	6459	Highly Suitable
124	124	45841	Highly Suitable
125	125	71456	Highly Suitable
126	126	4857	Highly Suitable
127	127	15468	Highly Suitable
128	128	78945	Highly Suitable
129	129	1564	Highly Suitable
130	130	7894	Highly Suitable
131	131	45612	Highly Suitable
132	132	4789	Highly Suitable
133	133	4123	Highly Suitable
134	134	78945	Highly Suitable
135	135	45681	Highly Suitable
136	136	15468	Highly Suitable
139	137	29854	Highly Suitable

Declaration

I hereby declare that the thesis entitled

“Remote Sensing and GIS Based Urban Land Suitability Modeling at Parcel Level Using Multicriteria Decision Analysis; A Case Study of Bole Sub City, Addis Ababa, Ethiopia” has been carried out by me under the guidance of Dr. Getachew Berhan, Department of Earth Sciences, Addis Ababa University, Addis Ababa in the year 2015 as a part of Master of Science program 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.

Teklit Berhe

Signature

Date

Dr. Getachew Berhan

Signature

Date

Place: Addis Ababa

Date June (2015)

(Teklit Berhe)