Remote Sensing and Geographic Information System Based Suitability Analysis of Urban Green Space Development in Addis Ababa: A case Study of Bole Sub-city

Mathias Tesfaye Abebe

Addis Ababa University
Addis Ababa, Ethiopia
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Mathias Tesfaye Abebe

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School of Graduate Studies

This is to certify that the project prepared by Mathias Tesfaye, entitled: *Remote Sensing and Geographic Information System Based Suitability Analysis of Urban Green Space Development in Addis Ababa: A case Study of Bole Sub-city* and submitted in partial fulfillment of the requirements for the degree of Master of Arts in Geography and Environmental Studies (Specialization in GIS, Remote Sensing and Digital Cartography) complies with the regulations of the university and meets the accepted standards with respect to the originality and quality.

Signed by the Examining Committee:

External Examiner: ______________________ Signature ___________Date __________

Internal Examiner:______________________ Signature ___________ Date__________

Advisor: Dr. Tebarek Lika Signature ___________ Date__________

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Chair of Department or Graduate Program Coordinator

Declaration

I declare that this project is originally prepared by me. It is based on my own work, with acknowledgments of other sources, and has not been submitted in whole or part for any other professional qualification.

Name: Mathias Tesfaye Abebe

Signature: ______________________

Place: Department of Geography and Environmental studies
College of Social Sciences
Addis Ababa University

Abstract

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Mathias Tesfaye

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Land suitability analysis has growing importance in identifying suitable land resource for some specific uses. There is a growing demand for land for residential use, commercial, infrastructures, market and industrial purposes. Due to the dynamic urban growth trends, city administrators and planners are faced with difficulties in supplying facilities like green space. Improper urban development can bring adverse impact on urban agriculture, urban green space and environmental condition. This study aimed at identifying suitable sites for urban green space development in Addis Ababa by taking the Bole sub-city as a case study. The rate of land use/land cover change with respect to urban green space for the period between 1986 and 2015 was assessed using GIS tools and remote sensing techniques. The suitability analysis was done using GIS-based multi-criteria analysis steps. The analysis reveals that since 1986 the green spaces, represented by plantations, forestland, grassland and cultivated land have been transformed into other land uses at annual rates of 5.9%, 3.3%, 5.4% and 3.7 % respectively. This has resulted in the shrinking of plantations, forestland, grassland and cultivated land by 82.1%, 62.1%, 78.8 and 65.8 % respectively. In contrary, built-up and transport areas have been highly expanded with an annual rate of 5.7% and 1.3% and with a total area increase of 419% and 47% respectively. Moreover, based on GIS-based multi-criteria analysis, 4.2 % and 24 % of the study area was identified as highly suitable and moderately suitable for green space development respectively.

Keywords: Urban Green Space, Land Use / Land Cover, Remote Sensing, Geographic Information Systems, Multi-Criteria Analysis

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Mathias Tesfaye

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List of Acronyms and Abbreviations

AAEPA	Addis Ababa Environmental Protection Authority
AACRA	Addis Ababa City Road Authority
AHP	Analytical Hierarchy Process
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
CSA	Central Statistical Agency
DF-C	Driving Force-Land Change
DN	Digital Numbers
EMA	Ethiopian Mapping Agency
ENUGIS	Ethiopia National Urban Green Infrastructure
EPA	Environmental Protection Agency
ETM	Enhanced Thematic Mapper
ERDAS	Earth Resource Data Analysis System
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GIS-MCA	Geographic Information System Multi-criteria Analysis
GLCF	Global Land Cover Facility
Ha	Hectare
ILIC	Integrated Land Information Center
K_{hat}	Kappa Coefficient
LDP	Local Development Plan
LULC	Land Use Land Cover
MADM	Multi-attribute Decision Making
MCDM	Multi-criteria Decision Making
MCA	Multi-criteria Analysis
MoA	Ministry of Agriculture
MoUDC	Ministry of Urban Development and Construction
MoUDH	Ministry of Urban Development and Housing
MoUDHC	Ministry of Urban Development, Housing and Construction
NASA	National Aeronautics and Space Administration

NDVI	Normalized Difference Vegetation Index
NUGIS	National Urban Green Infrastructure Standards
ORAAMP	Office for the Revision of Addis Ababa Master Plan
OSM	Open Street Map
RS	Remote Sensing
TM	Thematic Mapper
UGS	Urban Green Space
UN	United Nations
UNEP	United Nations Environment Program
USGS	United States Geological Survey
UTM	Universal Transfer Mercator
WBISPP	Woody Biomass Inventory and Strategic Planning
WGS	World Geodetic System
WLC	Weighted Linear Combination

Chapter One

Introduction

1.1. Background to the study

Urbanization is a global issue which can change the physical structure of the world. Urban change is the result of the urbanization process. The urban fringes are continually being converted to urban uses in the process of urbanization (Sushil, 2010). Land Use Land Cover (LULC) pattern change, industrialization and social transformation occur during the urbanization processes.

Urbanization has negative impact on the natural environment by encroaching green spaces in many cities in Europe, North America, South America, Asia and Africa with the situation in Africa being critical (Mensah, 2014). Urban green spaces make up less than 10% of the land area of many urban areas in Nigeria, Egypt, Ghana, Rwanda, Somalia and South Africa (Mensah, 2014).

Ethiopia has one of the fastest growing urban populations in the world with the number of people living in cities expected to nearly triple in the next three decades (UN, 2015). Addis Ababa as the capital and primate city of Ethiopia has been growing and expanding in almost all directions. The growth of Addis Ababa both in terms of population and areal extent has increased land demand for residential use, commercial, market and industrial purposes. The horizontal expansion of the city inflicts serious damage to urban agriculture, urban green space and the environment (Eyob, 2008).

Due to urbanization, city administrators and urban planners are faced with difficulties in meeting growing demands for basic services such as green space, sanitation, water supply, transportation and primary health centers. Urban planners have to visualize such growth during planning, policy and decision-making. Spontaneous construction of unplanned informal houses in and beyond the administrative boundaries of towns and cities is common in developing countries. These profound changes cause a change in land use patterns which makes urban planning inevitable (Zewudu, 2011). Urban planning does not only cover matters of the built environment such as housing and transportation network, but also the integration of green spaces into the physical urban landscape (Byrne and Sipe, 2010).

Land suitability analysis is the process to determine whether the land resource is suitable for some specific uses and the suitability level by considering different factors such as LULC patterns, landscape and soil (FAO, 1981; Manlun, 2003; Kumar and Biswas, 2013). Suitability of various LULC pattern and dynamics is important to identify the most desirable site for future development. Identifying appropriate suitability factors are the ultimate objective of suitability analysis.

Suitability analysis is used for planning, landscape designing, decision making and analyze different factors. It integrates different factors of an area such as location, physiographic, environmental processes and development activities. Therefore, suitability analysis enables urban land administrators and municipal officers to make decisions and establish policies in terms of the specific land uses.

Green spaces are land uses that are covered with natural or semi-natural vegetation in the built-up and planning areas (Karen, 1995; Cemil and Gökyer, 2012). Different disciplines have suggested different terms from their own professional angles such as ecological green land system, horticultural green land system, urban green land system, urban green space, and green open space. The concept of the green space system has also been continuously developing with the development of city.

1.2. Statement of the problem

In recent years, Addis Ababa and its environs have witnessed unprecedented land degradation as a result of deforestation for fuel wood supply and human settlement. Big tracts of the city's vegetation area are converted to permanent structures at a rate of 6.65Km^2/year (Tamiru *et al.*, 2005). About 10,000 hectares of land initially reserved for green spaces have been allocated for other uses (Tadesse, 2010). Over the years, Addis Ababa has witnessed ecosystem degradation and vegetation cover losses which is estimated at 14.6% (AAEPA, 2005). In the city, 382 hectares of riparian area is being cultivated by vegetable growing farmers, which cover up to 7.13% of the city's vegetable demand (Azeb, 2007).

The problem is expected to worsen in the coming years due to the massive construction of houses, buildings and roads and the less attention given to green spaces. Besides, the city does not have up-to-date information that can give an impression about the physical changes in general and the amount of green space in particular. These necessitate the need for analyzing urban land use/land cover change and identify suitable sites for urban green space development using remote sensing and GIS technologies.

Although there are some studies on green space, the available studies mainly focused on assessment of urban green infrastructure with less attention to the suitability analysis of green space (e.g. Samson, 2014), an assessment of green area development (e.g. Gebeyehu, 2014) and the impact of urbanization in Addis Ababa city on peri-urban environment and livelihoods (e.g. Leulseged *et. al.*, 2011). Some writers highlighted the development and use of urban open spaces through time (e.g. Mikyas, 2011), and the history of urban open spaces (e.g. ORAAMP, 2009). However, these studies did not mention the issue of suitability analysis for green space in the urban setting in the context of LULC dynamics. Therefore, this study aimed at filling the existing research gap by identifying suitable sites for urban green space development in Addis Ababa by taking the Bole sub-city as a case study using suitability analysis model and GIS tools and remote sensing techniques.

1.3. Objectives of the study

1.3.1. General objective

The main objective of this study was to identify suitable sites for urban green space development in the Bole sub - city of Addis Ababa using RS and GIS technologies.

1.3.2. Specific objectives

The specific objectives of this study are to:

i. analyze urban LULC dynamics in the study area particularly green space;
ii. identify the main determinant factors for urban green space development;

iii. evaluate urban green space suitability by employing multi-criteria evaluation techniques; and
iv. identify suitable site for urban green space development.

1.4. Research questions

To realize the stated objectives, the following research questions are designed:

i. What is the extent of LULC conversion in the study area?
ii. What are the main determinant factors for urban green space development?
iii. How do multi-criteria evaluations techniques help to evaluate urban green space suitability?
iv. Which sites are suitable for urban green space development in the study area?

1.5. Significance of the study

Study of suitability analysis is important for urban and regional planners and decision makers to assess the impacts of urban horizontal expansion on green areas. This study provides invaluable data for local engineers, urban planners and policy makers on the dynamics of urban green areas, and will serve as an input for further studies.

1.6. Scope of the study

Remote sensing and GIS technologies can help to get up-to-date information about the urban LULC dynamics with frequent coverage and low cost. This study by limiting its scope to one of the ten sub cities of Addis Ababa-the Bole Sub- city, analyzes the rate of land LULC change, particularly urban green space during the period (1986 to 2015) and GIS-multi-criteria suitability analysis.

1.7. Limitation of the study

This study certainly has some limitations that could be solved through future projects in the area. One of the major limitations was the data sources that were Landsat imageries used for LULC analysis. The Landsat imageries were of 30 m resolution which are not high resolution and incurred to some LULC classification errors that were indicated in error matrixes of accuracy assessment. Getting high resolution satellite imageries such as IKONOS and QuickBird was not possible. The other shortcoming was that criteria or parameters of green space development were set by reviewing different literature and prior knowledge of the study area instead of common standards.

1.8. Organization of the research project

The **research project** consists of five chapters. Chapter one presents background to the study, statement of the problem, objectives, research questions, **s**ignificance, scope and limitations of the study. Chapter two reviews the theoretical and empirical literature. Chapter three gives description of the study area and details the methodology. Chapter four presents and discusses results of the study. The final chapter presents the conclusions and recommendations.

Chapter Two

Literature Review

2.1. Definition of urban green space

There is a large body of literature on definitions of urban green spaces (UGS). According to (Cemil and Gökyer, 2012: 107-122), “Urban green spaces are urban areas which are covered in natural or semi-natural ecosystems converted to urban spaces by human influence”. For Farrar (2009) a green space refers to recreational fields, urban agriculture, natural play space for children, community, rooftop and balcony gardens, community compost sites, community orchards, and cycling routes. According to Alamrew (2002) citing different sources an urban green space can be defined as formal and informal. Formal green areas include protected public parks, street gardens, playgrounds, sport fields, squares, private gardens, and vegetation cover in schools, hospitals, churches, mosques, embassies, cemeteries, parking lots, pedestrian lanes, etc. On the other hand, informal green areas include forest areas, river valleys, reserved expansion areas, agricultural lands, open leftover spaces, grazing lands, steeper degraded areas, shrub lands, etc. Urban green spaces are used to connect urban to nature. In this regard, green areas are the reflection in the urban spaces of natural or near natural areas surrounding the cities.

The contribution of UGSs towards improving the urban environment, quality of life and sustainability of cities in urban planning and policies is as important as the other urban infrastructures, like water, electricity, sewage systems and transportation (Fariba, 2013). In 21 St century, there is wide consensus about the importance and value of urban green spaces in cities towards planning and constructing sustainable eco-cities. Gradually growing traffic and urban heat, especially in the developing countries is not only damaging the environment, but also incur social and economic costs. Green spaces in the city should be easily accessible and adequately optimum in quality and quantity to meet social and psychological needs of citizens (Haq, 2011).

2.2. Types of urban green space

The urban green space has its own physical components, including urban forest, parks, riverine and street trees. Green space can become so many things like natural play spaces, community gardens, urban agriculture and rooftop gardens (Farrar, 2009; Rodhead, 2009). Natural play spaces are growing rapidly in popularity as they become recognized for their significant positive impacts on the health, wellbeing and growth of children. Natural play spaces use a blend of natural areas, water and local plants to interest children in learning about the wonders and secrets of the natural world. Community gardens have significant benefits to the community on social, economic and environmental aspects. Urban agriculture has a slightly different focus than community gardens and exerts an important impact on social movement around the community and food security. It is considered beneficial to both the ecological and food security movements (Samson, 2014).

Rooftop gardens can be an excellent source of organic produce for urban residents, as long as the building structure can handle the weight. There is a distinction to be made between green roofs and rooftop gardens: Green roofs are architectural and engineering projects that usually consist of a layer of grasses and low growing plants integrated into the roof of a building or built into existing roofs but rooftop gardens consist of movable growers strategically placed on existing rooftops that do not always require structural reinforcement.

2.3. Benefits of urban green space

Urban green spaces have many functions and benefits. These functions and benefits are important to improving life quality in the urban areas. Green spaces provide linkage between people (who live in the urban) and nature (Alm, 2007). The benefits of urban green areas are described below under the main headings.

Environmental Benefits

Urban green spaces provide ecosystem services for maintenance of biodiversity and regulation of urban climate. Comparing with rural areas, differences in solar input, rainfall pattern and temperature are common in urban areas. Solar radiation, air temperature, wind speed and relative humidity vary significantly due to the built environment in cities. The urban heat island effect is caused by the large areas of heat absorbing surfaces, in a combination of high energy use in cities (Mohammad and Zhirayr, 2013). Therefore, adequate forest, plantation and vegetation around urban dwellers and management of water bodies can help to mitigate the situation. Regional green space is based on the protection and optimization of natural ecological system and continuous suburban green space of large size. It is not only improving the whole ecological environment of the city region and its neighbors but also provides important support for urban environmental improvement. Furthermore, introduction of sub-urban green space into the city also acts as the base of ecological balance (Sadeghian and Vardanyan, 2013).

Economic and aesthetic benefits

Using vegetation can reduce the energy costs of cooling buildings. It has been increasingly recognized as a cost effective reason for increasing green space and tree planting in temperate climate cities. Plants improve air circulation, provide shade and they transpire. This provides a cooling effect and contributes to lower air temperatures. Haq (2011) noted as a park of 1.2 km by 1.0 km can produce an air temperature between the park and the surrounding city that is detectable up to 4 km away and also a study in Chicago has shown that increasing tree cover in the city by 10% may reduce the total energy for heating and cooling by 5 to 10%.

Areas of the city with enough greenery are aesthetically pleasing and attractive to both residents and investors. Still, indicators are very strong that green spaces and landscaping increase property values and financial re-turns for land developers, of between 5% and 15%, depending on the type of project (Bayram *et al.*, 2012).

Social and psychological benefits

Urban green spaces have a range of social and health benefits. People satisfy most of their recreational needs within the locality where they live. Urban green spaces serve as a neat resource for relaxation. People who were exposed to the natural environment, their level of stress decreased rapidly as compared to people who were exposed to urban environment, whose stress level remained high (Haq, 2011). Certainly, improvements in air quality due to vegetation have a positive impact on physical health. The connection between people and nature is significant for everyday enjoyment, work productivity and general mental health.

Biodiversity and nature conservation

Green spaces do function as protection center for reproduction of species and conservation of plants, soil and water quality. Green area can influence biodiversity by increasing habitat area, increasing inhabitants of some protected species and increasing species movement (Samson, 2014).

2.4. Status of urban green spaces in Ethiopia

The Urban Development Policy of Ethiopia has concerns with incorporating the issue of green areas, considerations of the compatibility of various land use activities, incorporation of generalized environmental objectives and identification of hazardous areas. The policy has also recognized cities as entities that strive to work towards minimizing serious urban environmental causes.

Moreover, the Environmental Policy of Ethiopia has documented the importance of planning of green spaces within urban areas. This gives a room for various stakeholders to develop and manage urban forests, street trees etc. as elements of urban green areas.

The urban planning, preparation and implementation strategy allocated 30% of the land for roads and infrastructure, 30% for green areas and shared public use and 40% for building construction in their urban land management plan (MoUDH, 2015). The green areas include open spaces and environmental sensitive areas (parks, urban agriculture, recreation, mineral resources). The development plan of Addis Ababa is being revised now, which is put into effect tree planting along the ring roads, and enforces one-plot-one tree requirements.

Mare and Fikirite (2015) noted that ecological degradation, including deforestation is widespread in Addis Ababa, for instance, the urban forest cover in Yeka Sub-city has been reduced at a considerable level.

Gebeyehu (2014) underlined that the major problems of urban land management in Addis Ababa are related to land administration, land information and real property registration. Lack of sufficient data, regular monitoring system, appropriate technologies and expertise in the field are some of the challenges. Therefore, without appropriate land management system for different land use/land cover in the urban areas, developing green areas become difficult.

2.5. An overview of land use and land cover dynamics in Ethiopian urban centers

Land use and land cover (LULC) pattern of a region is an outcome of natural and socio – economic factors and their utilization by man in time and space (Abate, 2012). Land use and land cover is an endlessly changing process taking place on the surface of the earth (Mulatu, *et al*., 2000).

LULC changes exert influence on climate and weather conditions that can range from local to global scales. They affect the composition of the atmosphere and the exchange of energy between continents and the atmosphere, which can lead to global warming. Changes in LULC can also affect biological diversity, disrupt socio-cultural practices, lead to soil erosion, alter ecosystem services, and increase natural disasters, like flooding. This calls for global attention for continuous monitoring of the changes. Up-to-date datasets on LULC change provide critical inputs to evaluate complex causes and responses in order to project future trends. They are also prerequisites for making development plans. However, the magnitude of LULC change differs with the time period being examined, geographical location, slope gradient and elevation range (Mengistie *et al*., 2013).

Various studies in Ehiopia, like analysis of urban growth and sprawl mapping using remote sensing and GIS (e.g. Zewudu, 2011), GIS and Remote sensing based land use /land cover change detection and prediction (Bireda, 2015) and LULC change analysis using object-based classification approach (e.g. Mengistie *et al*., 2013) have demonstrated the need for a study focusing on location specific LULC dynamics for sustainable management and decision-making processes. But, most literatures have general implications about LULC change impact.

Mengistie *et al*. (2013) noted two ways of capturing LULC dynamics, namely conventional ground and remote sensing based methods. The ground method is labor intensive, time consuming and difficult for capturing data from inaccessible areas with rugged topographies like the case of most Ethiopian landscape. On the other hand, remote sensing is considered the most efficient technology to handle these problems since it can explicitly reveal spatial patterns of land cover change over a large geographic area in a regular and consistent way. Remote sensing data of the earth's surface could be made readily available in digital format. Change detection has become a major application of remotely sensed data because of repetitive coverage at short time intervals, which is useful for tracking changes in LULC over longer periods of time and at more varied temporal scales than what is typically done with field experiments or ground inventory.

The processes of urbanization have become a major global driver for LULC change (Heather, 2011). LULC change is determined by the characteristics of the local biophysical environment and land suitability for a range of uses. The most important of them include: weather conditions (temperature, rainfall, snowfall, wind and moisture); local topography (slope, aspect); soil type; water resources (surface and groundwater, access to water) and current state of the quality of land (e.g. erosion, contamination, salinization).

Various demographic, economic, socio-cultural, organizational, technological, and institutional factors affect the decision of land managers to maintain or change the current use and utilization of the land (Briassoulis, 2003). Demographic traits include age and gender of the head of the household, family status, size of the household, age and gender of household members. The socio-cultural characteristics of land managers are also influential; they include education, place of living (urban vs. rural), employment status (single or multi-employment), attitudes, values, and personal traits (e.g., perception of problems, alternative uses of land, external influences on land and its productivity, etc.)

Economic considerations are critical land-use determinants. Most important among them is the transportation cost to markets, accessibility and anticipated profits from the development of a particular land parcel. The latter depend on the demand for the goods and services associated with a given land-use type. Changes in demand trigger changes in land use as they affect the associated profits.

2.6. Urbanization effects on urban green space development

Urbanization remains a major factor that has been predominantly linked to causing of green space destructions (Mensah, 2014). Urbanization takes the form of either densification of urban core or spatial expansion of urban areas outwards (urban sprawl). Densification of urban core refers to high population density and an increase in the built environment (building structures) in relation to open spaces (Mensah, 2014). The urban sprawl, on the other hand, relates to the outward expansion of urban areas often taking place in the urban fringe, peri-urban lands and former agricultural lands. Rapid urbanization has resulted in the conversion of several urban lands into built up structures and excessive destruction of the natural ecosystem, including green spaces (Honu *et al.*, 2009).

Changes in land use, particularly the replacement of green space by buildings, roads and parking lots causes urban areas to become warmer than surrounding areas because these impermeable materials absorb heat and release it more slowly (Wendel, 2011). Solar reflectance is influenced by the color of materials, with darker colors, like asphalt and tar roofs, reflecting less and absorbing more solar energy, which warms the air above them (EPA, 2008).

According to MoUDC (2014) Housing and Sustainable Urban Development report, Ethiopia is one of the least urbanized countries in Sub-Saharan Africa. Currently, 20 per cent of the total population lives in urban areas. However, the country has one of the highest rates of urbanization even by the standards of developing countries, which is estimated at 4.1 percent. In Addis Ababa, more than 3 million people live in 500,000 housing units with an average density of 6 persons per household. 30% of the households live in informal settlements and 5% are homeless. The city has already used over 75% of its potential expansion area for development within its administrative boundary. The potential expansion area of 10,000 hectares within the city's administrative boundary was expected to get exhausted by 2010.

The Addis Ababa City Development Plan for 2001-2010 designated 3,000 hectares of the city's land for developing public recreational parks, but this is not implemented on the ground. Green areas are being encroached on by small buildings and micro enterprises, such as shops. This creates serious problems for urban dwellers and environment. This negative situation contributes to undermining the quality of life, unhealthy and dangerous actions (Edwards, 2010).

According to the policy document, the main challenges facing urban areas in the country are poorly developed social and physical infrastructure; shortage and deterioration of housing; lack of recreation areas; inadequate municipal waste management; absence of well integrated urban-rural linkage; unbalanced urban growth and weakly developed national and regional urban systems.

The Urban Development Policy is trying to address the green space problem by producing National Urban Green Infrastructure Standards (NUGIS) which create the framework for municipalities to provide effective and sustainable urban green infrastructure (UGI) for their residents to protect public health and environmental quality.

2.7. Application of GIS and remote sensing in suitability analysis

GIS has been applied in many disciplines including geography, forestry, urban planning, and environmental studies. Particularly, in suitability analysis, GIS has a great role in multi criteria decision making process (Malczewski, 2006). Suitability analysis is built upon the concept of multi-criteria evaluation. Multi-criteria decision making (MCDM) or multi-attribute decision making (MADM) techniques involve the evaluation of several criteria or datasets to meet a specific objective (Eastman *et al*., 2006). In MCDM process, criteria or datasets are examined for assigning relative ranks and individual feature weights based on the land use type for which suitability being examined. Weighted summation is sufficiently straightforward to use GIS data. It will be incorporated into the land-use suitability analysis.

The suitability analysis process requires the identification of the appropriate locations for a particular land use activity by considering physical resources (elevation, slope, aspect, climate), natural resources (soils, geology, hydrology, vegetation and wildlife habitat and environmentally sensitive areas), and existing land use and development of man-made facilities such as transportation systems, existing urban areas, and utility networks (Kuldeep, 2013).

2.8. Land suitability classification

According to FAO (2007) and Sys *et al*. (1991), land suitability classification is divided into order, class, sub-class and unit. Land suitability orders indicate whether the land is assessed as suitable or not suitable for the use under consideration. There are two orders represented in maps, tables, etc. by the symbols S and N respectively. Order S suitable land on which sustained use of the kind under consideration is expected to benefits, without unacceptable risk of damage to land resources. Order N not suitable land which has qualities that appear to preclude sustained use of the kind under consideration.

Land suitability classes reflect degrees of suitability. The classes are numbered consecutively, in sequence of decreasing degrees of suitability within the order. Within the order suitable the number of classes is not specified. There might, for example, be only two, S1 and S2. The number of classes recognized should be kept to the minimum necessary to meet interpretative aims. Class S1 highly suitable land having no significant limitations to sustain 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, this expenditure will be only marginally justified.

Within the order not suitable, there are normally two Classes. Class N1 currently not suitable land having limitations which may be manageable in time, but which cannot be corrected with existing knowledge of current acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner. Class N2 permanently not suitable land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

The Subclasses are a more detailed division of classes based on land quality and characteristics (soil properties and other natural conditions). For example, Subclass S3rc is land that is marginally suitable due to rooting condition (rc) as the limiting factor. Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level. The units differ from each other in their production characteristics or in minor aspects of their management requirement often defined as differences in detail of their limitations. Their recognition permits detailed interpretation at the farm planning level. Suitability units are distinguished by Arabic numbers following a hyphen, e.g. S2e-1, S2e-2. There is no limit to the number of units recognized within a subclass.

2.9. Criteria for suitability analysis of green space

Criteria are very significant in the site selection of the identified land use and used as key drivers in the selection of the geographic location. Different researchers mentioned different criteria and sub-criteria for urban green space development such as LULC, proximity to the residential areas, proximity to the urban facilities, proximity to the historical place, distance to the existing local parks, access to transportation proximity to educational areas, population density, slope, distance to noise influence, hydrology, (eg., Heshmat *et al*., 2013; Manlun, 2003; Kuldeep, 2013; Pantalone, 2010; Yousef *et. al*., 2014; Ahmed *et. al.*, 2011; Elahe *et al.*, 2014). The criteria which are mentioned by different researchers are categorized into three units: Environmental, Socio-economic and Geomorphological (Heshmat *et al*, 2013).

2.10. Conceptual framework

Theory comes from one of the different fields that deal with the interaction of humans with their environment (e.g., economy, sociology, political, ecology, and social psychology). Theory, observation, and models are crucial components of land use research. There are three main traditions of theorizing land use such as urban and regional economics and regional science, sociology and political economy and nature-society theories (Hersperger *et al*., 2010). Urban and regional economics and regional science are important for sustainable land management and urban planning. The sociological and political economy approach is used for land use research in combination with the economic approach. Nature-society theories refer to a holistic view of the human cause of environmental change and concerned of the interaction between environment, economy, society, technology and culture.

There are three main components which determine LULC change such as driving forces, actors and land itself (Hersperger *et al*., 2010). The driving forces are forces which interact with actors to shape the land change like climate change, human activities, urbanization and population growth, etc. Government policy influences the actors through making decisions (e.g., land use policy, urban utilities planning, resettlement, etc.) Actors may be individuals or groups who own the land such as land owner and policy maker affect it directly. Land characteristics by itself can influence the land cover change (e.g., landforms) (Figure 1).

Suitable site selection process considers three parameters such as location, physiographic feature and planning aspects (Soni *et al*., 2013). Locational analysis encompasses any spatial analysis of the area like proximity to the different services; dangerousness of the location and natural feature. Physiographic features deal with features and attributes of the land surface. For example, soil type, hydrology, vegetation and topography are important parameters in the suitable site selection process. Planning aspect is another important parameter for suitability analysis (e.g., land use, population density, administration, etc.) (Figure 1).

Urban green spaces are an important part of urban ecosystems, play a vital role in environmental, economic and social aspects in urban areas (Mensah, 2014). Moreover, green spaces sequester CO2 and produce O_2; they reduce air pollution and noise; regulate microclimates; reduce the heat; maintain diversity; have recreational and social values; and produce a vitamin ‘‘G’’ for health, well-being and social safety (Uy and Nobukazu, 2008). Applying the ecological factor threshold method will help quantify how much green area is necessary to maintain an ecological balance in urban areas (Uy and Nobukazu, 2008).

In general, there are many factors that affect LULC like land owner’s activities, external driving forces, land characteristics and government policy. Conducting a study on land use requires developing urban green space by considering different parameters such as phsiographic feature, locational characters and planning aspects.

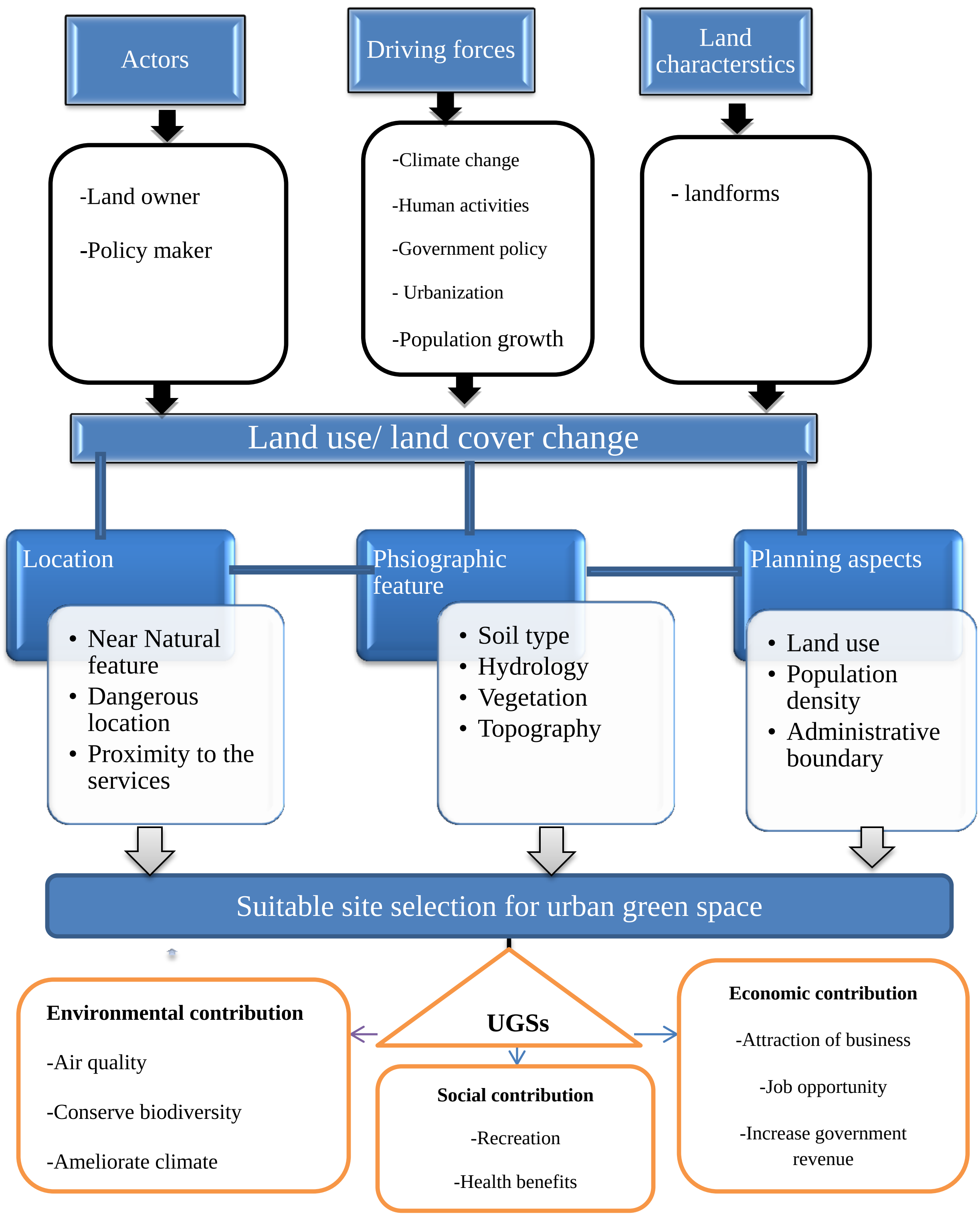


Figure 1 : Conceptual framework of LULC change and suitability analysis

Source: Hersperger *et al*., 2010; Soni *et.al*., 2013 and Mensah, 2014, modified by the author).

Chapter Three

Methods and Materials

3.1. Description of the study area

Location and topography

Addis Ababa is the capital city of Ethiopia. It is located between 8^{o} 49\` 55.929\`\` and 9$^{o}$ 5\` 53.853\`\` north latitude and between 38^{o} 38\` 16.555\`\` and 38$^{o}$ 54\` 19.547\`\` east longitudes. The city lies at the foot of mount Entoto. From its lowest point 2,114 meters above sea level in the eastern periphery, the city rises to over 3,000 meters in the Entoto mountains to the north. It lies at an average altitude of 7,546 feet (2,500 meters). Its topography ranges from rolling plain to hilly areas with relatively steeper gradient and numerous rivers, stream valleys. The City Administration of Addis Ababa extends over 540 km^{2} sub-divided into 10 sub-cities (CSA, 2007).

The Bole Sub-city is one of the largest sub-cities located in eastern Addis Ababa. It shares boundary with Yeka Sub-city in the north, Kirkos and Nifas Silk Lafto Sub-cities in the west and Akaki Kaliti sub-city in the south. The lowest point 2,114 meters in the southern periphery and the maximum elevation is 2,407 meters above sea level. The Sub-city has 14 *woredas* and covers an area of 122.8 km^{2}. (Figure 2).

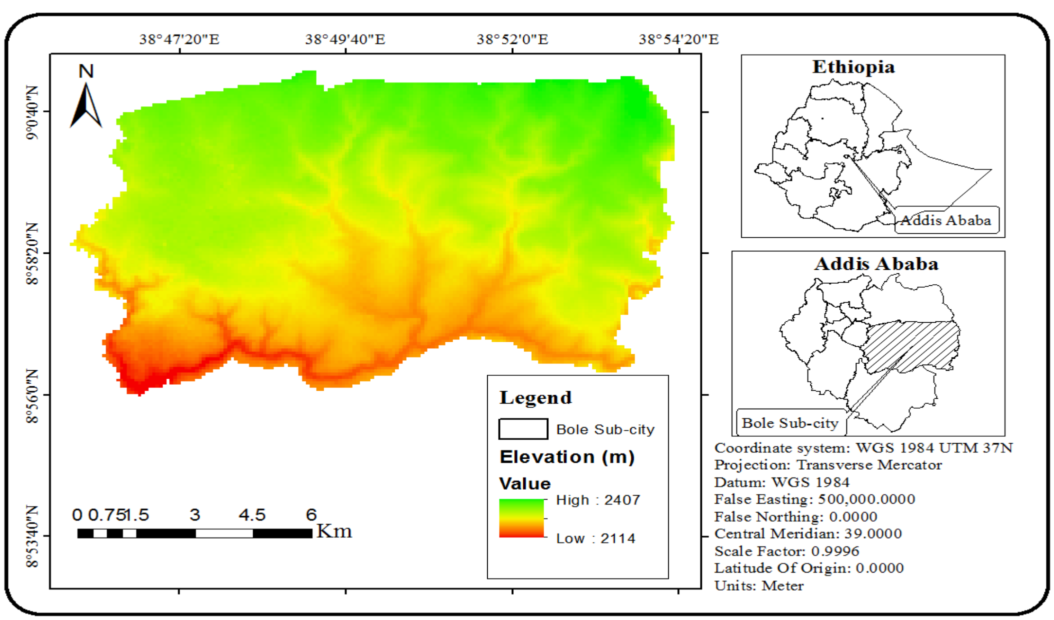
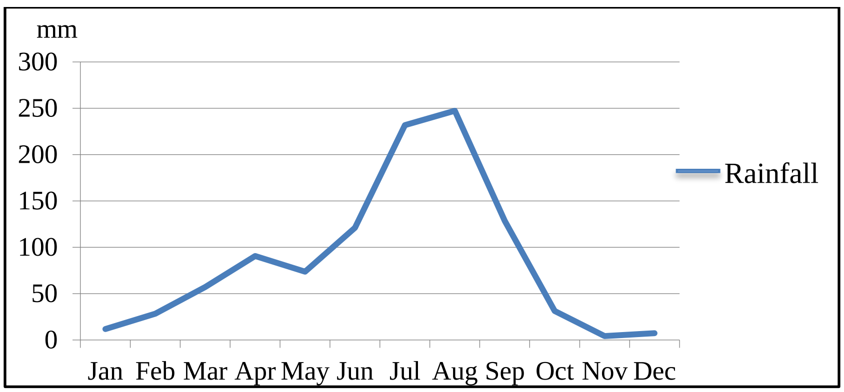


Figure 2: Location and elevation map of the Bole sub-city
Source: CSA (2007) & National Aeronautics and Space Administration (NASA) (2011)

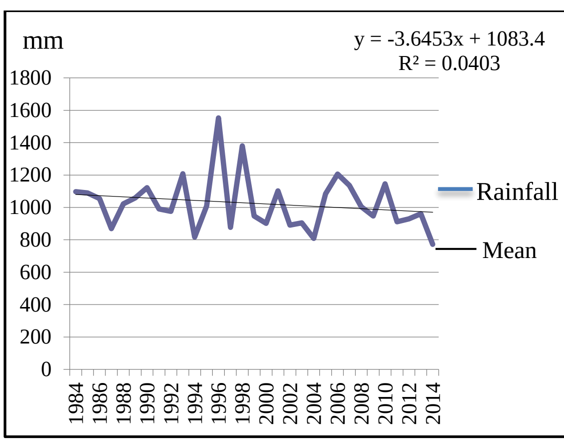
Climate

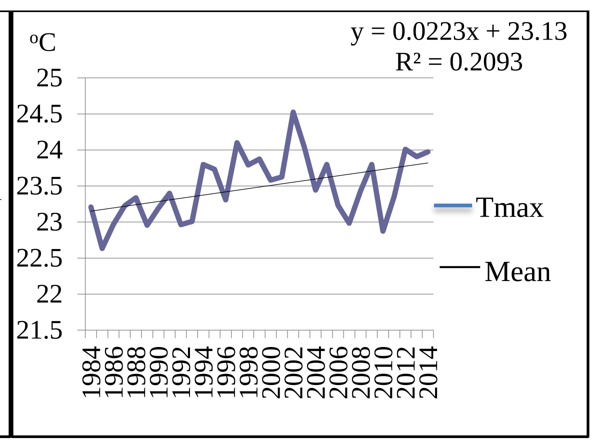
Addis Ababa has a humid subtropical highland climate. The annual mean rainfall in Addis Ababa between 1984 and 2014 was 1025.06 mm, whereas the total rainfall has shown a declining trend of 36.45 mm per decade. The highest rainfall was 1552.5 mm recorded in 1996 and the lowest was 772.2 in 2014. There was rain in all months on average even though the highest rainfall was recorded in July and August (Figure 3).

The average maximum temperature in the study area varies from 24.53°C in 2002 to 22.63°C in 1985 and the average minimum temperature varies from 11.38°C in 2014 to 7.80°C in 1986. In the period of 1984 to 2014, the mean annual maximum temperature showed a warming trend of 0.2 °C per decade and also the average temperature showed that warming trend of 0.5 °C per decade (Figure 3).

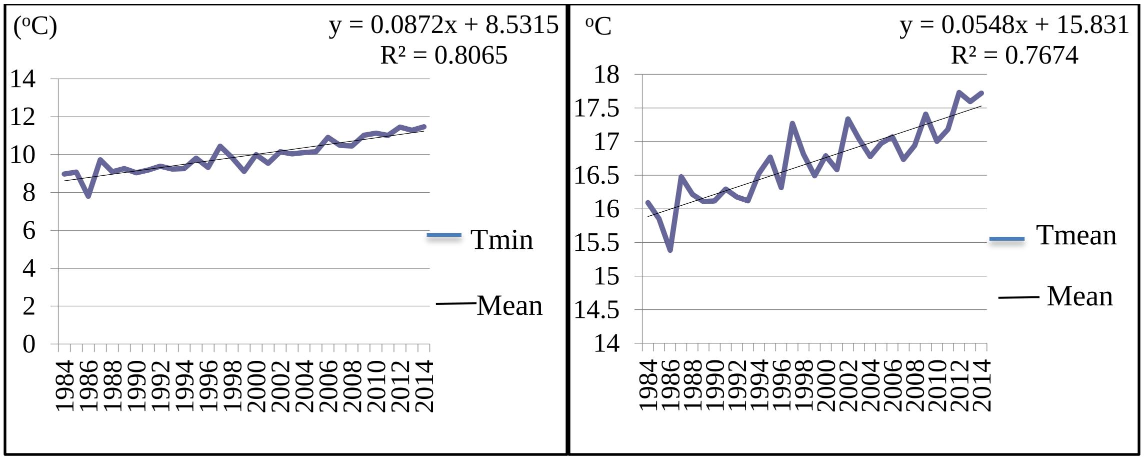


a)





b) c)



d) e)

Figure 3: Rainfall and temperature trend a) Monthly average precipitation; b) Mean annual precipitation; c) Maximum temperature; d) Minimum temperature and e) Mean temperature (1984-2014) at Bole station (Elevation 2354m, Lat/Lon 9.03 and 38.75

Source: Ethiopian Meteorological Agency (2015)

Vegetation

Urban forest in Addis Ababa can be classified into peri-urban forest and the recreation parks, roadside, riverine vegetation and plantations in private and institutional gardens (Samson, 2014). It is quite clear that urban forest varies from natural forest in many ways. It is an urban green area referring to a re-vegetation by planting trees, shrub or herbs with intended design to improve environmental quality, economic opportunity and aesthetic value. As shown in Table 1, large amount of forest is found in six sub-cities, namely, Yeka, Gullele, Kolfekeranyo, Nifas silk-lafto, Akaki-kality and Bole. Currently the city has parks with a total area of 81.72 ha. and 8148 ha. of urban forests (Hayal *et al.*, 2011 cited in Gebeyehu, 2014).

Table 1: Sub cities, localities and area dominantly covered by forests

No.	Sub-city	Localities	Area cover (ha.)
1	Yeka	Entoto, Ancorcha, Yeka Qersa,Kara	4,327
2	Gullele	Asko, Gojjamber, Raguel, Qussquam	2,803
3	Kolfekeranyo	Repi, Jemo, Filidoro, Keranyo, Sansusi	1,023
4	Nifas Silk-Lafto	Lebu, Dhertu, Gedowasha, Lafto	228
5	Akaki Kaliti	Tuludimtu, Salo Giorgis	73
6	Bole	Bole Arebasa, Bole Bulbula	42
		Total	8,496

Source: Mekonnen (2012)

Population

The population of Addis Ababa has a total population of about 3,195,000 and an annual growth rate of 3.8 % according to the 2014 population projection (CSA, 2013). The same report shows that 47.4% of the City's populations are males and the rest 52.6% are females. The Bole sub - city has an area of 120.8 km^2 with a population size of 360,387and density of 2,980 persons per km^2. The population size of the sub cities is shown in Table 2.

Table 2: Population size of (a) Sub-city (b) *Kebele*

No.	Sub-city name	Population size
1	Addis Ketema	297,793
2	Akaki Kaliti	211,380
3	Arada	246,680
4	Bole	360,387
5	Gulele	312,096
6	Kirkos	258,035
7	Kolefe Keranio	500,163
8	Lideta	235,246
9	Nifas Silk	368,883
10	Yeka	404,336
	Total	3,195,000

a)

No.	Bole sub-city *kebele*	Population	Area (ha.)	Population density (population/ha.)
1	03/05	31757	478	66.44
2	04/06/07	29,029	198	146.61
3	08/09	20,228	176	114.93
4	12/13	24,361	289	84.29
5	14/15	81,405	1346	60.48
6	16/18/21/22	13,531	4803	2.82
7	17/19/20	21,623	3051	7.09
8	01	28,203	1129	24.98
9	02	8,155	119	68.53
10	10	32,262	297	108.63
11	11	18,441	174	105.99

b)

Source: CSA (2007and 2014 projected)

3.2. Sources of data

As presented in Table 4, various spatial and non-spatial datasets were obtained from different organizations and processed using multiple GIS tools and remote sensing techniques for mapping and analysis purposes. Input datasets included Advanced Space-born Thermal Emission and Reflection Radiometer (ASTER) global DEM, Landsat TM (1986), Landsat ETM+ (2000) and Landsat ETM+ (2015).

GLCF (Global Land Cover Facilities) which is accessed from University of Maryland with collaboration of National Aeronautics and Space Administration (NASA). Currently, it provides satellite data and products, especially those Landsat imageries of MSS (multi-spectral systems- for the year 1972/73), of TM (Thematic Mapper for the year 1985-1986, 1990), and ETM + (Enhanced Thematic Mapper for the years 2000, 2005, 2011). From this source the 1986 (TM) and 2000 (ETM+) imagery were downloaded freely. The other source was http://libra.developmentseed.org which was used to freely download the 2015 (ETM+) imagery. Landsat 7 ETM+ data are acquired at three different resolutions. The thermal band (band 6) is collected at 60 meters, bands 1-5, 7 are collected at 30 meters, and the panchromatic band (band 8) is collected at 15 meters. These data were used to produce LULC map and analyze the dynamics of urban green space of the study area. Sources of data are described in Table 3.

Table 3: Data sources

Dataset	Source	Resolution	Purpose	Type	Year
Landsat TM	GLCF	30 x 30(m)	Classification	Raster	21/01/1986
Landsat ETM+	GLCF	30 x 30(m)	Classification	Raster	05/12/2000
Landsat ETM+	http://libra.developmentseed.org	30 x 30(m)	Classification	Raster	14/01/2015
Land use plan	Integrated land Information center		Reference		2012
ASTER Global Digital Elevation Models version 2	The US National Aeronautics and Space Administration (https://earthdata.nasa.gov/)	30m	To drive slope	Raster	2011
GPS field survey	Survey	-	Reference & suitability analysis	Vector	2015/16
Soil data	Ministry of Agriculture		For suitability analysis	vector	2013
Population	CSA	-	For suitability analysis	Excel	2007& 2014(projected)
Road network	Addis Ababa City Road Authority and OSM		For suitability analysis	Vector	2012 &2014
Stream	OSM		For suitability analysis	Vector	2014
Bole boundary	CSA		For delineated	vector	2007
Topographic maps: sheet no. 0838 B2 & 0838B1 0938 D4	EMA	1:50000	Reference	vector	1973 & 1982
Aerial photos	EMA	1:50000	Reference	Raster	27/11/1982
City map of Addis Ababa	EMA	1:15000 & 1: 25000	Reference	Raster	1986 & 2000

3.3. Sampling techniques

There are ten sub-cities in Addis Ababa. The study employed purposive sampling techniques to select *Bole* sub-city because, *Bole* sub-city is one of the largest sub-cities in terms of area hosting many business centers and shopping malls, organizations, recreational sites and the Bole International Airport, but urban forest area coverage is relatively smaller than other sub-cities (*Yeka, Gullele, Kolfe Keranyo, Nifas Silk-Lafto* and *Akaki Kality*) (Mokenen, 2012).

Sample reference data

There are many spatial sampling techniques available for the selection of sample reference data such as random, systematic, clustered, stratified, or a combination of them. In this study, the stratified random sampling technique was used because all LULC types can be sufficiently represented, no matter how a LULC size small or limited in its spatial distribution (Gao, 2009).

There is no common standardized consent for reference sample size determination. The minimum sample size for each LULC category necessary for 85% interpretation accuracy be set to 20 and for 90 % accuracy to 30 (van Genderen and Lock, 1977 cited in Gao, 2009). On the other hand, Lillesand *et al.* (2008) argued that a minimum of 50 samples for each map class should be collected for maps of less than 4,046.9 km^2 and fewer than 12 classes. Therefore, by considering the size of Bole sub-city (122.9km^2) and seven LULC classes (built-up, transport area, plantation, forestland, grassland, cultivated land and bareland) a minimum of 50 samples per LULC category were used. During field survey, sample reference data positions were recorded using GPS.

3.4. Data pre-processing

Before LULC classification, remotely sensed data pre-processing techniques were employed using ERDAS IMAGINE 2013 software. Image enhancement is concerned with the modification of images to optimize their appearance of the visual system. Various false color composite raster band combinations in Red-Green-Blue order, contrast enhancement, noise removal, haze reduction, histogram equalization, convolution, environmental correction, brightness adjustment and principal component analysis image enhancement techniques were employed. The data pre-processing tool functions are described as follows.

Noise Removal: Image noise is any unwanted disturbance in image that is due to limitations in the sensing, signal digitization, or data recording process. Noise can either degrade or totally mask the true radiometric information content of a digital image. Hence, noise removal usually precedes any subsequent enhancement or classification of the image data. It restores an image to as close an approximation of the original scene as possible.

Haze reduction: It reduces the atmospheric effects. Atmospheric effects can cause imagery to have a limited dynamic range, appearing as haziness or reduced contrast.

Histogram equalization: It maximizes the contrast of the data by applying a non-linear contrast stretch that redistributes pixel values so as approximately the same number of pixels with each value within a range.

Convolution (Spatial filtering): It performs image enhancement operations such as averaging, high-pass, or low-pass filtering on a raster image.

Environmental Correction: It compensates for unwanted spectral variations in scene pixels. These variations are caused by differences in atmospheric and other environmental conditions.

Brightness adjustment: It corrects the brightness variations in an image. The adjust brightness algorithm works by correcting each range line average.

Principal Components: It used to compress a data. It allows redundant data to be compacted into fewer bands, that is, the dimensionality of the data is reduced.

3.5. Image classification

As presented in Figure 4, satellite imageries were classified and analyzed using the basic photogrammetric elements (color, tone, texture, size, shape, structure, association, and shadow); the prior knowledge of the area and field observation.

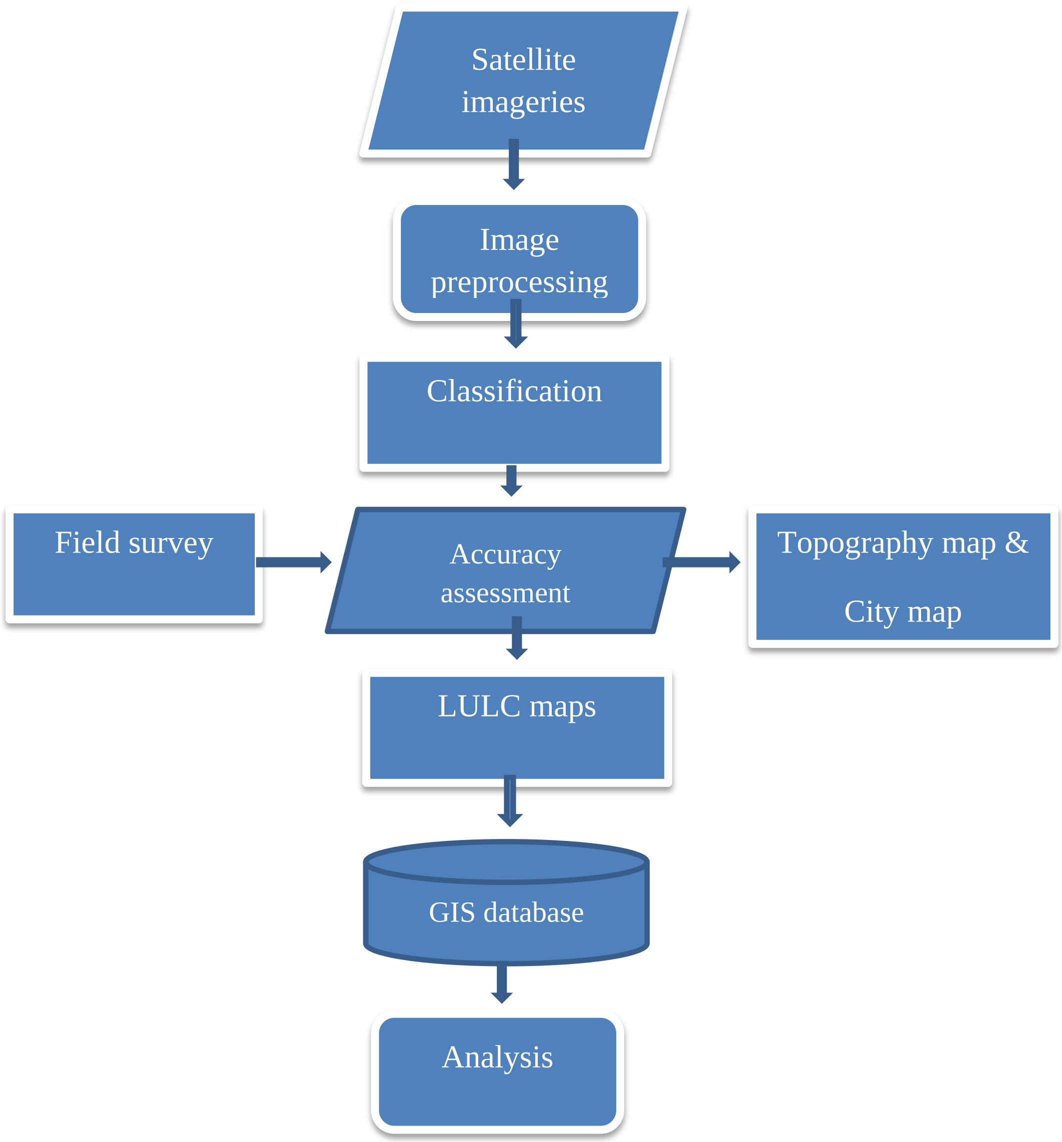


Figure 4: Image classification process

LULC map for 1986, 2000, and 2015 were produced by supervised classification using the maximum likelihood classifier of ERDAS IMAGINE 2013 software. In supervised classification, three activities were done such as collecting spectral signature, evaluating signature and classified images using maximum likelihood classification. LULC classification was employed from the prior knowledge of the study area and based on the U.S. Geological Survey Land Use/Cover System developed by Anderson et al. (1976). The images were interpreted or classified into seven LULC classes, namely built-up, transport area, plantation, forestland, grassland, cultivated land and bareland (Table 4).

Table 4: Description of LULC classification scheme

LULC types	Description
Plantation	Areas dominated by *Eucalyptus* tree species.
Forestland	Areas dominated by natural high forests, which are coniferous or deciduous.
Grasslands	All areas covered with natural grass and small shrubs dominated by grass.
Cultivated land	Areas of land prepared for growing agricultural crops. This category includes areas currently under crop and land under preparation.
Bare lands	Parts of the land surface which is mainly covered by bare soil.
Built-up	Areas allotted for residential, commercial and government and private institution.
Transport area	Areas occupied by airport, road network and transport stations.

Image classification has categorized all pixels in an image into LULC classes. Normally, multi-spectral data are used to perform the classification and the spectral pattern present within the data for each pixel is used as the numerical basis for categorization. Hence, different feature types manifest different combinations of digital numbers based on their inherent spectral reflectance properties. Spectral pattern recognition refers to the family of classification procedures that utilizes this pixel-by-pixel spectral information as the basis for computerized LULC classification.

3.6. Accuracy assessment

Accuracy assessment was employed for determining whether the output map meets or does not meet level of acceptance. Error matrices are a common method of expressing classification accuracy, and were created to compare category by category basis, the reference data (ground truth) and the corresponding results of classification (Lillesand *et al*., 2008). The study assessed the accuracy of the classification results for each classified image.

After creating the error matrix for each classification, user accuracy, producer accuracy, overall accuracy and Kappa coefficient were computed. According to Lillesand *et al.* (2008) user's accuracies are computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category (the row total). Producer's accuracies result from dividing the number of correctly classified pixels in each category (on the major diagonal) by the number of training set pixels used for that category (the column total). The Kappa coefficient of agreement was used for multi-variate statistical measure that can be used to test LULC classification accuracy. Computing K_{hat} is the ability to use this value as a basis for determining the statistical significance of any given matrix or the differences among matrices.

$$\hat{K} = \frac{n\sum_{i=1}^{r} xii - \sum_{i=1}^{r}(xi+ \, . \, x+i)}{N^2 - \sum_{i=1}^{r}(xi+ \, . \, x+i)} \qquad (1)$$

Where r = number of rows in the error matrix; Xii = number of observations in row i and column i (on the major diagonal); Xi+ = total of observations in row i (shown as marginal total to right of the matrix); X·+i = total of observations in column i (shown as marginal total at bottom of the matrix) and N = total number of observations included in matrix.

3.7. Methods of data analysis

After the data is collected from various sources, the data were analyzed by using different softwares like Arc GIS 10.3 and ERDAS Imagine 2013. The cross tabulation in the spatial analyst module of the ArcGIS was employed to drive the change matrix. The change from 1986 to 2000, from 2000 to 2015 and for the whole entire period from 1986 to 2015 were tabulated in matrices (Table 5 a, b & c).

As presented in Tables 5 a, b and c, the computed change matrix consists of columns that display categories at time 1 and rows that display categories at time 2. It shows the amount of changes in the hectare and the percentage of which LULC class changed to other classes. The notation Pij is the proportion of the land that experiences transition from category i to category j. According to Pontius (2004), the diagonal elements indicate the persistence of the category j. Entries off the diagonal indicate a transition from category i to a different category j. The proportion of the LULC in category i in time 1

Pi+ is the sum of Pij over all j and the proportion of the LULC in category j in time 2 P+j is the sum of Pij over all i. The gain values computed by subtracting the persistence value from the total area of final year and the loss value also computed by subtracting the persistence value of the total area of the initial year. The net change was calculated as the difference between gain and loss. The values were presented in terms of hectares and percentages. The percentage LULC changes were calculated using the following equation.

$$\text{Percentage LULC change} = \frac{\text{Area final year - Area initial year}}{\text{Area initial year}} \times 100 \qquad (2)$$

Where area is the extent of each LULC type. Positive values suggest an increase whereas negative values imply a decrease in extent.

The LULC change rate was computed using the formula suggested by Puyravaud (2003):

$$r = \left(\frac{1}{\Delta t}\right) ln\left(\frac{A2}{A1}\right) * 100 \qquad (3)$$

Where r is the annual rate of change in %, Δt is the time interval in years during the LULC change being assessed, *ln* is the base of the natural logarithm function, and A1 and A2 are initial and final LULC areas respectively.

Post classification comparison change detection was made to determine the change in LULC between two classified maps and Normalized Difference Vegetation Index (NDVI) was used in this study.

The NDVI model equation is expressed as:

$$NDVI = \frac{\text{NIR}-\text{RED}}{\text{NIR}+\text{RED}} \qquad (4)$$

Where NIR and RED are reflectance in the near infrared and the red bands, respectively. The NDVI value is ranging from -1 to +1 whereas vegetation surfaces have NDVI values ranging from 0.1 to 1.0.

Table 5: Land use/Land cover change matrix

a)

	LULC	LULC types 1986															
		PL		TA		FL		GL		BL		CL		BA		Total	
		Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%
LULC type 2000	**PL**	78.7	10.4	111.2	8.2	102.3	9.5	429.0	22.0	18.7	4.3	1003.0	19.7	37.4	1.7	1780.3	14.8
	TA	96.0	12.7	352.1	26.1	86.5	8.0	692.5	35.49	58.0	13.2	492.9	9.7	159.4	7.1	1438.4	11.9
	FL	65.1	8.6	196.2	14.5	283.9	26.3	128.4	6.6	60.1	13.7	439.3	8.6	173.8	7.7	1346.7	11.2
	GL	34.7	4.6	166.3	12.3	235.2	21.8	234.7	12.0	63.7	14.5	636.3	12.5	48.7	2.2	1819.7	15.1
	BL	1.3	0.2	12.1	0.9	18.1	1.7	13.1	0.6	23.2	5.3	23.1	0.5	6.6	0.3	97.6	0.8
	CL	410.5	54.3	344.6	25.6	212.3	19.6	240.4	12.3	72.3	16.5	2151.7	42.3	952.8	42.2	3627.1	30.1
	BA	69.4	9.2	165.8	12.3	142.4	13.2	212.9	10.9	142.1	32.4	338.3	6.7	880.0	39.0	1950.9	16.2
	Total	754.6	100.0	1346.6	100.0	1077.0	100.0	1951.0	100.0	436.9	100.0	5076.6	100.0	1395.5	100.0	12038	100

b)

	LULC	LULC types 2000															
		PL		TA		FL		GL		BL		CL		BA		Total	
		Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%
LULC types 2015	**PL**	6.1	0.3	7.6	0.5	24.3	1.8	10.1	0.6	0.5	0.5	81.5	2.2	5.3	0.3	135.3	1.1
	TA	291.7	16.4	456.1	31.8	194.8	14.5	312.0	17.2	17.2	17.7	534.1	14.7	173.3	8.9	1979.0	16.4
	FL	31.8	1.8	38.8	2.7	147.0	10.9	75.5	4.2	7.7	7.9	63.9	1.8	43.6	2.2	408.4	3.4
	GL	107.7	6.1	37.4	2.6	24.4	1.8	113.1	6.2	2.6	2.7	119.6	3.3	9.3	0.5	414.2	3.4
	BL	25.6	1.4	13.0	0.9	9.8	0.7	32.6	1.8	1.9	2.0	30.8	0.8	8.4	0.4	122.2	1.0
	CL	255.7	14.4	134.0	9.3	187.7	13.9	191.2	10.5	5.8	6.0	919.0	25.4	47.8	2.5	1736.8	14.4
	BA	1060.1	59.6	749.3	52.2	758.7	56.3	1082.9	59.6	61.7	63.3	1872.9	51.7	1656.5	85.2	7242.2	60.2
	Total	1780.3	100.0	1438.4	100.0	1346.7	100.0	1819.7	100.0	97.6	100.0	3627.1	100.0	1950.9	100.0	12038	100.0

c)

		LULC types 1986															
	LULC	**PL**		**TA**		**FL**		**GL**		**BL**		**CL**		**BA**		**Total**	
		Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%
LULC type 2015	**PL**	13.8	1.8	10.7	0.8	6.5	0.6	7.4	0.4	1.3	0.3	91.5	1.8	4.1	0.3	135.3	1.1
	TA	133.1	17.6	396.4	29.4	143.4	13.3	284.2	14.6	68.6	15.7	817.8	16.1	135.6	9.7	1979.0	16.4
	FL	6.8	0.9	32.2	2.4	106.7	9.9	56.5	2.9	43.5	9.9	107.3	2.1	55.5	4.0	408.4	3.4
	GL	15.0	2.0	42.4	3.1	53.7	5.0	142.1	7.3	9.9	2.3	141.3	2.8	9.8	0.7	414.2	3.4
	BL	1.9	0.2	11.4	0.8	10.4	1.0	33.7	1.7	7.4	1.7	48.0	0.9	9.4	0.7	122.2	1.0
	CL	172.8	22.9	190.2	14.1	63.2	5.9	174.4	8.9	13.0	3.0	1082.0	21.3	41.2	3.0	1736.8	14.4
	BA	411.1	54.5	663.4	49.3	693.1	64.4	1252.8	64.2	293.2	67.1	2788.6	54.9	1140.0	81.7	7242.2	60.2
	Total	754.6	100.0	1346.6	100.0	1077.0	100.0	1951.0	100.0	436.9	100.0	5076.6	100.0	1395.5	100.0	12038	100

Note: PL=Plantation, TA=Transport Area, FL=Forest land, BL= Bareland, CL= Cultivated land, and BA= Built-up

Site selection process for urban green space involves various social, technological, environmental and economic aspects. GIS-MCDA is a process that transforms and combines geographical data and value judgments (the decision-maker's preferences) to obtain information for decision making (Malczewski, 2006). GIS-MCDA provide a flexible tool that is able to handle and bring together a wide range of variables assessed in different ways and thus offer useful assistance to the decision maker in pointing at suitable locations (Taha & Daim, 2013).

In order to select the best sites for urban green space (park, community garden, playground and recreational fields) in the Bole sub - city, six GIS-based MCA steps were followed (Figure 5).

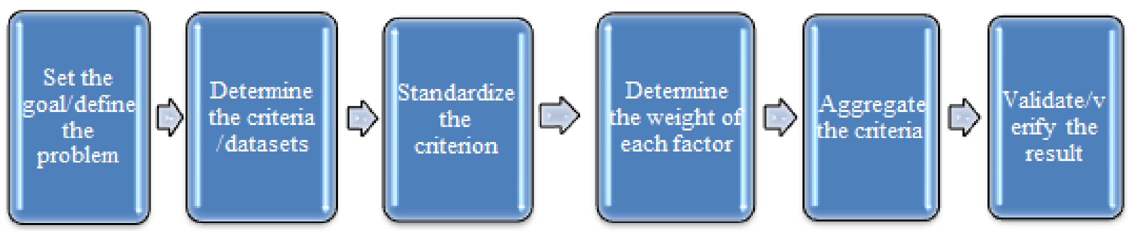


Figure 5: Methods of Multi-Criteria Evaluation (MCE) Steps (modified after Eastman *et al*., 1995)

The first step was to set the goal or define the problem. In this study the aim of GIS-based MCA is to produce a map showing suitable sites for green space in the Bole sub-city. The second step was determining factors/ criteria that are important for green space development. The factors used for site selection process for a green space were selected based on different literatures and prior knowledge of that particular area. Based on literatures and previous related studies conducted by different researchers (e.g. Heshmat *et al*., 2013; Manlun, 2003; Kuldeep, 2013; Pantalone, 2010; Yousef *et. al*., 2014; Ahmed *et. al.*, 2011; Elahe *et al.*, 2014), LULC, population density, soil type, slope, proximity to existing road, distance to existing parks, distance to noise influence, distance to historical place and distance to stream were selected as factors that are important for the green space development in the Bole sub - city. These datasets were collected from various sources and processed using ArcGIS software for MCA.

The third step was standardizing each factor/ criterion scores. It is important to set the suitability values of the factors to a common scale to make comparisons possible. Therefore, all input datasets were changed into a raster at 30 meter resolution and to a common measurement scale using conversion. Based on the FAO land suitability classification, the datasets were reclassified from highly suitable (S1) to permanently unsuitable (N2); where S1 represents the highly suitable, S2 moderate, S3 less suitable, N1 not suitable and N2 represent permanently unsuitable conditions for green space.

The fourth step was defining weights for each criterion based on its importance for the green space development. Several methods are available to determine the weight like Analytical Hierarchy Process (AHP), ranking and rating.

In this study the Analytical Hierarchy Process (AHP) method was adopted to assign weight for each factor because, AHP uses a hierarchical structure; it enables decision makers to define high level strategic objectives and specific metrics for a better assessment of strategic alignment and it can be applied in any organization with any level of maturity because the inputs are normalized using either numerical data or subjective judgments when metrics are not available and the process gives itself to sensitivity analysis (Saaty, 1980).

AHP and the Geographic Information System (GIS) are an integrated technique used to assess suitable land use for UGS in Bole-sub-city. A pairwise comparison matrix was constructed, where each criterion was compared with the other criteria, relative to its importance, on a scale from 1 to 9 as shown in table 6.

Table 6: AHP Scale of Relative Importance

Intensity of relative importance	Definition	Explanation
1	Equal Importance	Two activities combine equally to the objective.
3	Moderate importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another.
7	Demonstrated importance	An Activity is strongly favoured and its dominance is demonstrated in practice.
9	Extreme Importance	The evidence favouring one activity over another is of the highest possible order of affirmation. 2
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed.
Reciprocals of above non-zero numbers.	If an activity has one of the above numbers (e.g. 3) compared with a second activity, then the second activity has the reciprocal value (i.e.1/3) when compared to the first.	

Source: Saaty (1985)

Priority vector is also called normalized principal Eigen vector. To normalize the values, divided the cell value by its column total and calculated the priority vector or weight by determining the mean value of the rows (Saaty, 1980). 0.31, 0.20, 0.11, 0.04, 0.03 ,0.09, 0.04,0.07 and 0.11 was obtained as a weight value for the LULC, population density, distance from the road, distance from the stream, distance from the historical place, noise influence, distance from the existing park, slope, and soil type respectively with 0.01 of consistency ratio (Table 7).

Table 7: Pairwise comparison matrix

Criteria	LULC	Population density	Road	River	Historical place	Noise influence	Park	Slope	Soil type	Weight
LULC	1.00	2.00	3.00	7.00	9.00	3.00	7.0	5.00	3.0	0.31
Population density	0.50	1.00	2.00	5.00	7.00	2.00	5.0	3.00	2.0	0.20
Road	0.33	0.50	1.00	3.00	5.00	1.00	3.0	2.00	1.0	0.11
River	0.14	0.20	0.33	1.00	2.00	0.33	1.0	0.50	0.3	0.04
Historical place	0.11	0.14	0.33	0.50	1.00	0.20	0.5	0.33	0.2	0.03
Noise influence	0.33	0.50	1.00	3.00	0.50	1.00	3.0	0.50	1.0	0.09
Park	0.14	0.20	0.33	1.00	2.00	0.33	1.0	0.50	0.3	0.04
Slope	0.20	0.33	0.50	2.00	3.00	0.50	2.0	1.00	0.5	0.07
Soil type	0.33	0.50	1.00	3.00	5.00	1.00	3.0	2.00	1.0	0.11

A consistency ratio of less than 0.1 shows a consistent comparison between the criteria and it was considered as acceptable (Saaty, 1980).

CR = Consistency Index (CI)/Random Consistency Index (RI) (Table 8) (1)

CI = (λmax – n)/n – 1 (2)

Where λ max is the Principal Eigen Value; n is the number of factors

λmax = Σ of the products between each element of the priority vector and column totals.

Table 8: Random Consistency Index (RI) (Saaty, 1980).

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

Step five was to aggregate the criteria using weighted linear combination and apply it in the ArcGIS raster calculator. Validate or verify the result was the final step. It helps to assess the reliability of the output and usually assessed by ground truth verification and sensitivity analysis. Sensitivity analysis was performed by changing the weight of criteria and field survey were conducted for ground truth verification.

In weighted linear combination (WLC) procedure, factors or parameters (Vi) multiplied by the weight of the suitability parameters (Wi) to get composite weights and then summed. WLC is a straightforward linear method calculating composite weights. This function multiplies and sums up the layers to produce suitability maps for green space. Therefore, the weighted linear technique (Mendoza, 1997) was applied to generate a suitable site map for green space.

$$E = \sum_{i=1}^{n}(wi * vi) \quad (3)$$

Where Wi = relative importance or weight of factors/parameters i, Vi = parameters i and n = total number of parameters related to the study.

Chapter Four

Results and Discussion

4.1. Accuracy assessment of the classification

Classified LULC maps from remote sensed imageries may contain some errors. Therefore, accuracy assessment was employed to find out those errors so as ensure reliability of the produced LULC maps. The classified maps were assessed and compared with a referenced data and ground truth using an error matrix.

The overall accuracies for the three reference years: 1986, 2000 and 2015 are 87%, 86% and 89% with the Kappa statistics of 0.81, 0.80 and 0.83 respectively (Table 9). The Kappa statistics value greater than 0.80 (i.e., 80%) represents a strong agreement and a value between 0.60 and 0.80 represents a substantial agreement (Landis and Koch, 1977). Hence, the maps met the accuracy requirements for change detection analysis (Anderson *et al*., 1976), and there is a positive correlation between the remotely sensed classified samples and the reference data.

Results of user's accuracy in this study showed that in 1986 the maximum class accuracy was for built-up area (96%) and the minimum was for forestland (80%). In 2000, user's accuracy ranges from lowest accuracy (80%, forestland) to relatively correctly classified (95%, built-up) whereas in the period 2015, it ranges from 85% (grassland and forestland) to 97% (built-up). Results of producer's accuracy showed that built-up area relatively correctly classified: 95%, 98% and 97% in 1986, 2000 and 2015 respectively. The lowest accuracy was 81%, 80% and 84% in 1986, 2000 and 2015 respectively (Table 9).

Table 9: Error matrix of classification for (a) 1986, (b) 2000 and (c) 2015

	Reference samples								
Classified samples	PL	TA	FL	GL	BL	CL	BA	Row total	UA (100%)
PL	46	0	2	2	1	6	0	57	81
TA	3	49	0	0	0	0	3	55	89
FL	5	0	48	2	1	4	0	60	80
GL	3	4	1	56	4	1	0	69	81
BL	0	3	0	0	45	0	0	48	94
CA	0	0	5	1	0	64	0	70	91
BA	0	2	0	0	0	0	54	56	96
Total column	57	58	56	61	51	75	57	415	
PA(100%)	81	84	86	92	88	85	95		
Overall accuracy = 87%									
K^= 81%									

a)

Note: PL=Plantation, TA=Transport Area, FL=Forest land, BL= Bareland, CL= Cultivated land, BA= Built-up Area, UA=User Accuracy and PA=Producer Accuracy

	Reference samples								
Classified samples	PL	TA	FA	GL	BL	CL	BA	Row total	UA (100%)
PL	50	0	4	2	1	4	0	61	82
TA	3	47	1	1	4	0	0	56	84
FL	4	0	45	3	1	3	0	56	80
GL	3	0	4	54	1	1	1	64	84
BL	0	3	0	0	42	1	0	46	91
CL	2	0	2	4	1	62	0	71	87
BA	0	3	0	0	0	0	58	61	95
Total column	62	53	56	64	50	71	59	415	
PA (100%)	81	89	80	84	84	87	98		
Overall accuracy = 86%									
K^= 80%									

b)

Classified samples	Reference samples PL	TA	FL	GL	BL	CL	BA	Row total	UA (100%)
PL	48	0	2	2	0	1	0	53	91
TA	4	58	1	0	1	0	1	65	89
FL	2	1	52	2	2	2	0	61	85
GL	1	0	3	52	1	3	1	61	85
BL	0	2	0	1	46	1	0	50	92
CL	1	0	4	3	1	54	0	63	86
BA	0	0	0	0	2	0	65	67	97
Total column	56	61	62	60	53	61	67	420	
PA (100%)	86	95	84	87	87	89	97		
Overall accuracy = 89%									
Kˆ = 83%									

c)

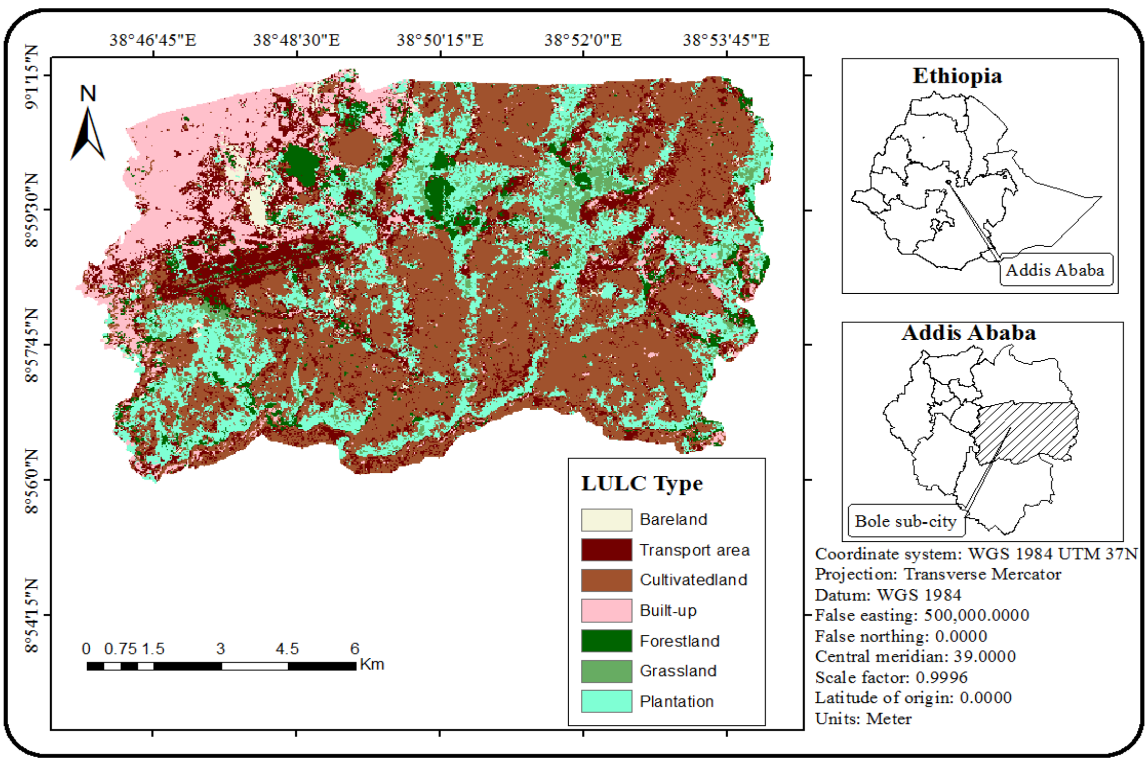
4.2. LULC classification and dynamics

In this study, three LULC classification maps were produced (Figure 7 a, b and c) and spatio-temporal LULC dynamic process was analyzed (Table 10). Based on the LULC classification, the major part of the area was covered by cultivated land in 1986 later shifted to built-up area. In 1986, cultivated land, grassland, forestland and plantation covered 42.2%, 16.2%, 8.9% and 6.3% of the total area respectively. The remaining parts of the area were covered with built-up (11.6%), transport area (11.2%) and bareland (3.6%) respectively.

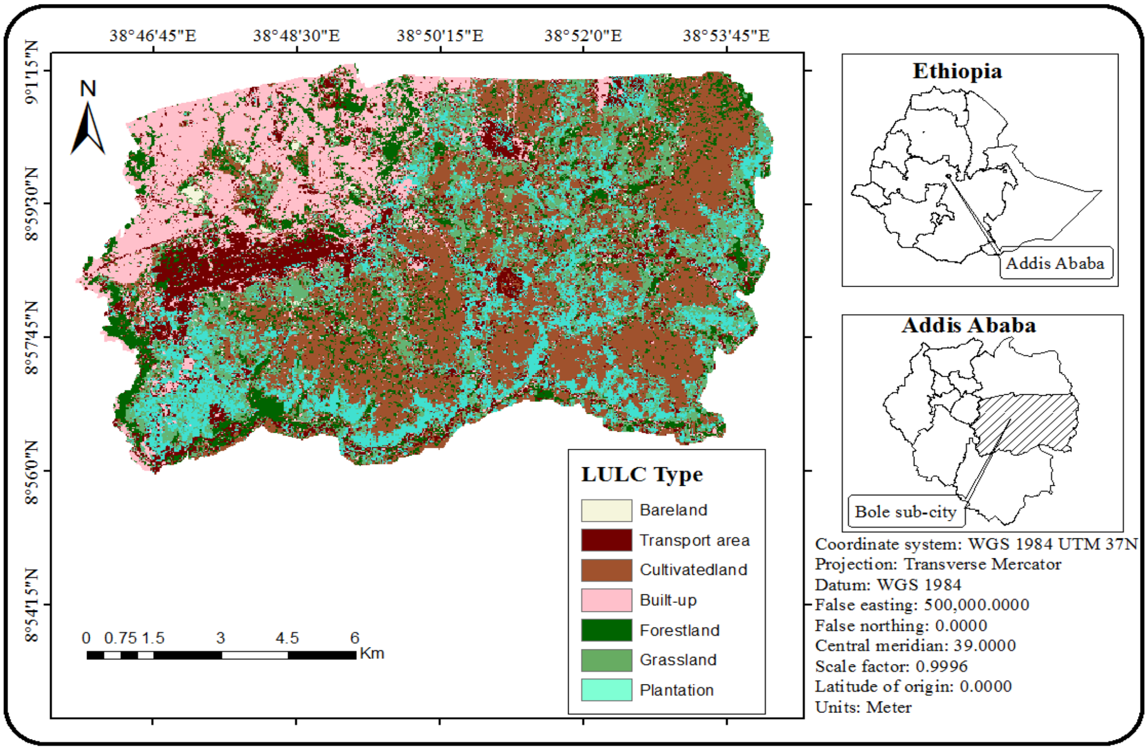
In 2000, cultivated land, grassland, forestland and plantation covered 30.1%, 15.1%, 11.2% and 14.8% of the total area respectively. The rest of the areas were covered with built-up (16.2%), transport area (11.9%) and bareland (0.8%) respectively. In 2015 built-up area had the largest areal coverage (60.2%) and the remaining (39.8%) was the share of other LULC classes (Table 10, Figure 6 and Figure 7). To some extent in the classification, the plantation LULC type was generalized to other classes, but, as evident in the field observation, plantation is highly diminished due to urbanization. The vegetation cover has been declining since the year 1986 in the order of 73.6% for 1986, 71.2% for 2000 and 22.4% for 2015.

The vegetated land cover types were highly transformed categories throughout the study period (Table 10). From 1986-2015, plantations, forestland, grassland and cultivated land shrunk at annual rates of 5.9%, 3.3%, 5.4% and 3.7 % with a corresponding change of 82.1%, 62.1%, 78.8 and 65.8 % respectively. In contrary, built-up and transport areas highly expanded at an annual rate of 5.7% and 1.3% respectively with 419% and 47% change in the total area respectively (Table 10).

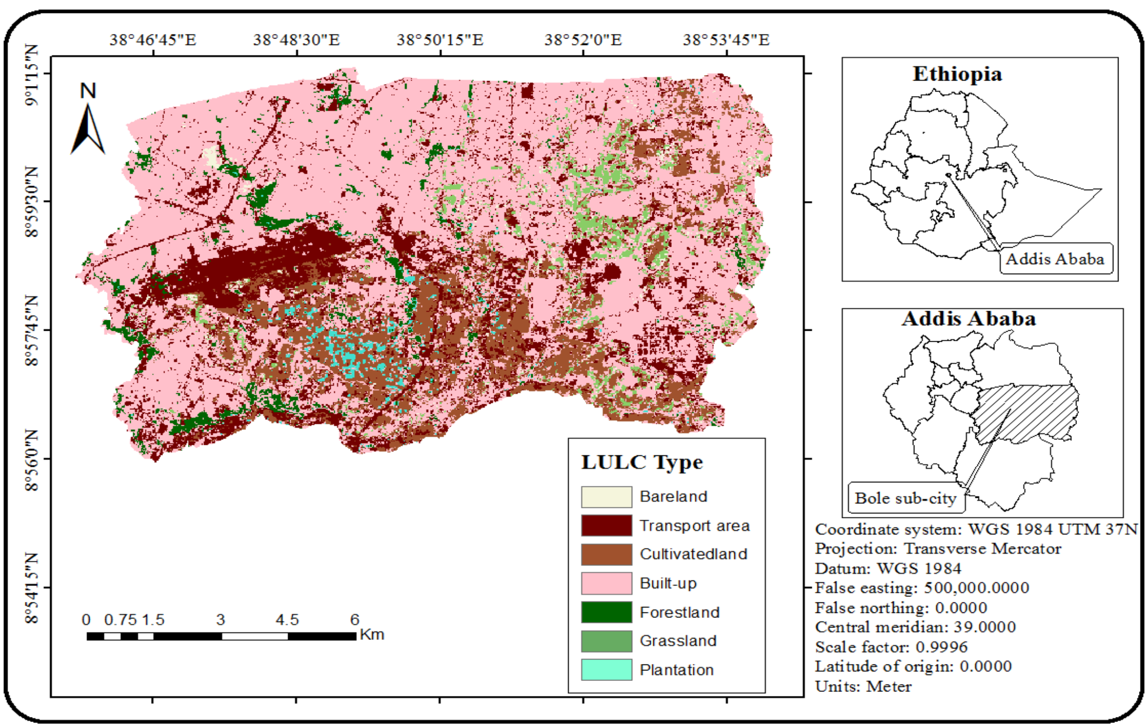
The NDVI analysis was employed in order to show the vegetation cover transition. In 1986, the NDVI value was in the range of -0.33 to 0.83 which shows that there was a high vegetation cover whereas in 2000 and 2015, the value declined in the range of -0.10-0.54 and -0.37-0.27 respectively (Table 11). Therefore, vegetation covers have been transformed to other LULC units such as built-up area, transport area and bareland. In general, 6165 ha of green spaces have been changed into other LULC types since 1986.



a)

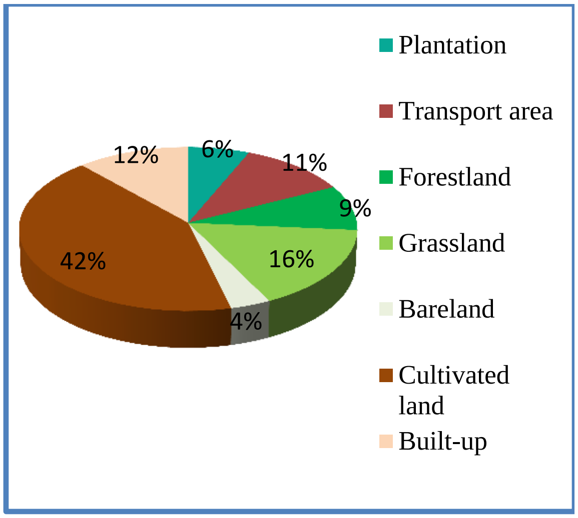


b)

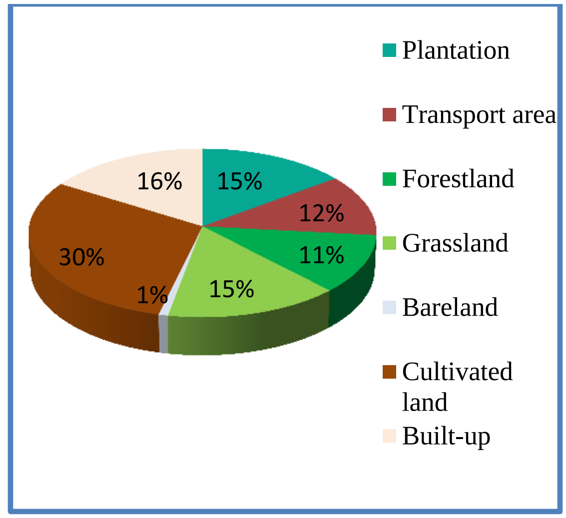


c)

Figure 6: LULC classification of (a) 1986, (b) 2000 and (c) 2015



a)



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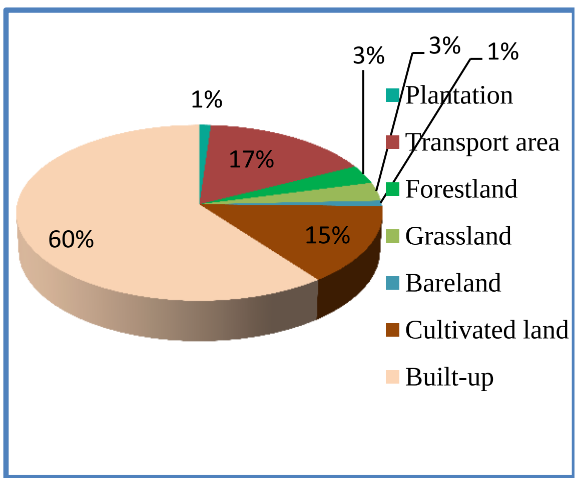


c)

Figure 7: Graphical representation of LULC transformation of (a) 1986, (b) 2000 & (c) 2015

Table 10: LULC transformation between 1986, 2000 and 2016

LULC	1986		2000		2015		Change 1986-2000			Change 2000-2015			Change 1986 -2015		
	Ha	%	Ha	%	Ha	%	Ha	(%)	Rate (%)	Ha	%	Rate (%)	Ha	%	Rate (%)
PL	754.6	6.3	1780.3	14.8	135.3	1.1	1025.7	135.9	6.13	-1645.0	-92.4	-16.84	-619.3	-82.1	-5.9
TA	1346.6	11.2	1438.4	11.9	1979.0	16.4	91.8	6.8	0.48	540.6	37.6	2.15	632.4	47.0	1.3
FL	1077	8.9	1346.7	11.2	408.4	3.4	269.7	25.0	1.59	-938.3	-69.7	-8.03	-668.6	-62.1	-3.3
GL	1951	16.2	1819.7	15.1	414.2	3.4	-131.3	-6.7	-0.52	-1405.4	-77.2	-8.45	-1536.8	-78.8	-5.4
BL	436.9	3.6	97.6	0.8	122.2	1.0	-339.4	-77.7	-10.82	24.6	25.2	1.49	-314.7	-72.0	-4.4
CL	5076.6	42.2	3627.1	30.1	1736.8	14.4	-1449.5	-28.6	-2.45	-1890.3	-52.1	-4.90	-3339.8	-65.8	-3.7
BA	1395.5	11.6	1950.9	16.2	7242.1	60.2	555.4	39.8	2.30	5291.2	271.2	8.74	5846.6	419.0	5.7
Total	12038	100	12038	100	12038	100									

Note: PL=Plantation, TA=Transport Area, FL=Forest land, BL= Bareland, CL= Cultivated land, and BA= Built-up

Table 11: NDVI value

Images year	NDVI value range
1986	-0.33-0.83
2000	-0.10-0.54
2015	-0.37-0.27

Gains, losses and persistence

As can be observed from Table 12, in the period 1986 to 2000, green spaces such as plantation, forestland, grassland and cultivated land had gained 1701.6, 1062.8, 1585.0 and 1475.4 hectares of land respectively, and lost 675.9, 793.1, 1716.3 and 2924.9 hectares of land in the same order. However, 78.7, 283.9, 234.7 and 2151.7 hectares of plantation, forestland, grassland and cultivated land remained without area change respectively. The cultivated land and grassland highly changed to other LULC class. Plantation had shown a remarkable increase with a net change of 12.8%. Estimates of vegetation cover for 2000 as obtained from the WBISPP (Woody Biomass Inventory and Strategic Planning) (2004) report were around 7900 ha, which is a high figure as it includes other vegetated area like forestland.

Table 12: Land use/Land cover change during 1986-2000

LULC Type	Persistence		Gains		Losses		Net Change	
	Ha	%	Ha	%	Ha	%	Ha	%
PL	78.7	10.4	1701.6	21.2	-675.9	-8.4	1025.7	12.8
TA	352.1	26.1	1086.3	13.5	-994.5	-12.4	91.8	1.1
FL	283.9	26.3	1062.8	13.2	-793.1	-9.9	269.7	3.4
GL	234.7	12.0	1585.0	19.7	-1716.3	-21.4	-131.3	-1.6
BL	23.2	5.3	74.4	0.9	-413.7	-5.1	-339.3	-4.2
CL	2151.7	42.3	1475.4	18.4	-2924.9	-36.4	-1449.5	-18.0
BA	880.0	39.0	1070.9	13.3	-515.5	-6.4	555.4	6.9
Total	4004.3	33.26	8033.9	100	-8033.9	-100.0	0.0	0.0

In the period 2000-2015, green spaces such as plantation, forestland, grassland and cultivated land have shrunken with net change value of 18.8%, 10.7%, 16.2% and 21.6% of the total area respectively. However, plantation (0.3%), forestland (10.9%), grassland (6.2%) and cultivated land (25.4%) area persisted without area change. During the same period, the built-up and transport area highly gained (63.9% and 17.4%, respectively); whereas 3.4% and 11.2% were converted into another LULC class respectively (Table 13).

Table 13: Land use/Land cover change during 2000-2015

LULC Type	Persistence		Gains		Losses		Net Change	
	Ha	%	Ha	%	Ha	%	Ha	%
PL	6.1	0.3	129.2	1.5	-1774.2	-20.3	-1645.0	-18.8
TA	456.1	31.8	1522.9	17.4	-982.3	-11.2	540.6	6.2
FL	147.0	10.9	261.4	3.0	-1199.7	-13.7	-938.3	-10.7
GL	113.1	6.2	301.1	3.4	-1706.6	-19.5	-1405.5	-16.1
BL	1.9	2.0	120.3	1.4	-95.7	-1.1	24.6	0.3
CL	919.0	25.4	817.8	9.4	-2708.1	-31.0	-1890.3	-21.6
BA	1656.5	85.2	5585.7	63.9	-294.4	-3.4	5291.3	60.6
Total	3299.7	27.4	8738.4	100	-8738.4	-100.0	0.0	0.0

In the period 1986 to 2015, cultivated land was highly changed as compared to other vegetated land with additional gains of 654.8 hectares (7.2%) and with losses of 3994.6 hectares (43.7%) to another LULC type. However, 1082 hectares (21.3%) remained without area change. On the other hand, other green spaces, namely, plantation, forestland and grassland lost large areas (740.8, 970.3 and 1808.9 hectares respectively) and gained (121.5, 301.7 and 272.1 hectares respectively). The remaining LULC type-built-up and transport area had gained 6102.2 and 1582.6 hectares and lost 255.5 and 950.2 hectares respectively (Table 14).

Table 14: Land use/Land cover change during 1986-2015

LULC Type	Persistence		Gains		Losses		Net Change	
	Ha	%	Ha	%	Ha	%	Ha	%
PL	13.8	1.8	121.5	1.3	-740.8	-8.1	-619.3	-6.8
TA	396.4	29.4	1582.6	17.3	-950.2	-10.4	632.4	6.9
FL	106.7	9.9	301.7	3.3	-970.3	-10.6	-668.6	-7.3
GL	142.1	7.3	272.1	3.0	-1808.9	-19.8	-1536.8	-16.8
BL	7.4	1.7	114.8	1.3	-429.5	-4.7	-314.7	-3.4
CL	1082.0	21.3	654.8	7.2	-3994.6	-43.7	-3339.8	-36.5
BA	1140.0	81.7	6102.2	66.7	-255.5	-2.8	5846.7	63.9
Total	2888.4	23.99	9149.7	100	-9149.7	-100.0	0.0	0.0

Eyob (2008) reported that, a rapid and unplanned expansion and commercial development, along with population pressure, has negative impact on the green space. At present the green spaces of Addis Ababa are almost transformed to urban habitats accommodating an excessive population due to a high rate of rural–urban migration. Similarly, Samson (2014) and Gebeyehu (2014) noted that in Addis Ababa city, there are many challenges that affect the urban green space such as lack of public awareness, low level of community participation, poor implementation of government policies, lack of budget, lack of skilled manpower, shortage of land in urban areas, illegal settlement, problem of regular follow-up and lack of cooperation among different stakeholders. This reduction of green spaces has indicated that the city administration has a problem of proper planning and implementation to keep the city green with the exception of intervening in some areas such as the establishment of a few parks and roadside plantations under a city beautification program.

4.3. Suitability analysis for urban green space development

4.3.1. Suitability of land use/land cover

The LULC of the study area was analyzed using 30 m resolution of Landsat image, land use plan of the city and ground truth verification. The literature (e.g. Ahmed *et al*., 2011; Manlun, 2003; Heshmat *et al*., 2013) tells us that it is advisable to select land occupied by bare and grasslands for green space development. In the study area, major LULC classes were built-up (60.2%), cultivated land (14.4%), plantation (1.1%), forestland (3.4%), grassland (3.4%), transport area (16.4 %) and bareland (1.0%) (Table 15 and Figure 8).

Table 15: Reclassified LULC

LULC type	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
Bareland and Grassland	S1	5	536.4	4.5
Plantation	S2	4	135.3	1.1
Forest land	S3	3	408.4	3.4
Cultivated land	N1	2	1736.8	14.4
Built-up and Transport area	N2	1	9221.2	76.6

Note: S1= highly suitable, S2= moderate, S3= less suitable, N1= not suitable and N2= permanently unsuitable conditions for green space.

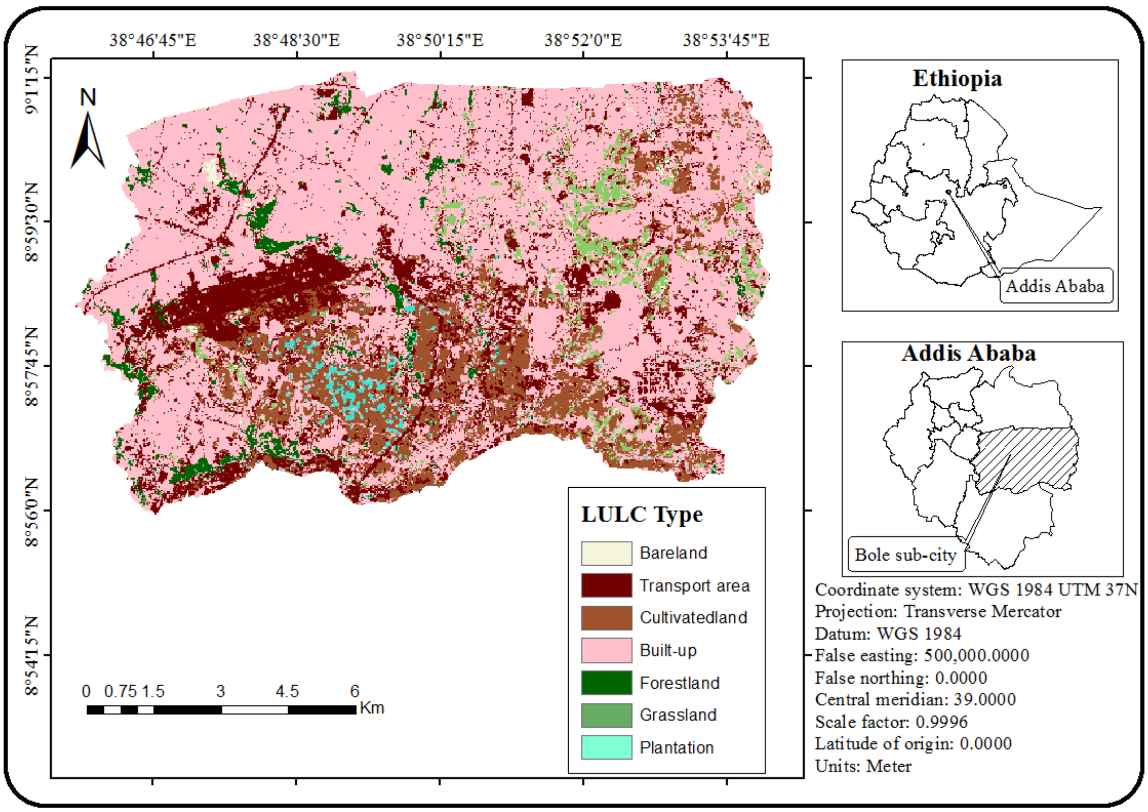


Figure 8: LULC classification of 2015

4.3.2. Suitability of distance from roads

Elah *et al.* (2014) and Ahmed *et al.* (2011) suggested that the green space site is preferable when it is located at a suitable distance from roads in order to access transportation. Accordingly, the green space site is totally unsuitable if distance from roads is greater than 2 km. The distance starting from 0.5 km up to 1 km is considered as moderately suitable. If less than 0.5 km, the site is highly suitable. Based on these criteria, 75.6% of the study area is found to be highly suitable; 15.3 % moderately suitable, and 1.1 % totally unsuitable for green space development (Table 16 and Figure 9).

Table 16: Reclassified distance from road and area coverage of suitability levels

Distance from road (km)	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
< 0.5	S1	5	9186.5	75.6
0.5 - 1.0	S2	4	1856.5	15.3
1.0 – 1.5	S3	3	634.5	5.2
1.5 - 2.0	N1	2	336.1	2.8
> 2.0	N2	1	136.0	1.1

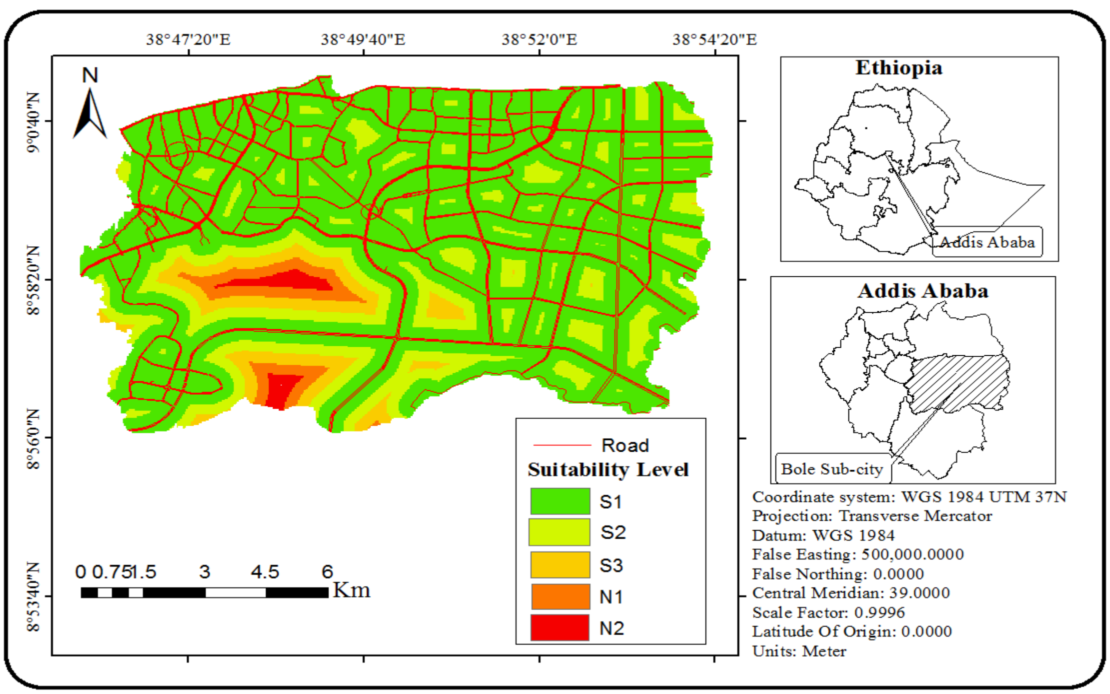


Figure 9: Reclassified distance from road map

4.3.3. Suitability of distance from the stream

The closer lands to the stream banks get more preferences and used to maintain the environmental health of the area (Kuldeep, 2013). Manlun (2003) and Heshmat *et al*. (2013) also noted that lands closest to water resources like rivers, lakes and reservoirs are highly suitable for green space development. Therefore, based on this argument, if distance from the stream is less than 0.5 km (42.4% of the area), the area is considered as highly suitable and in between 0.5 km and 1 km moderately suitable (28.4% of the area). Whereas 0.8% of the area is relatively considered as totally unsuitable which is greater than 2 km from the stream (Table 17 and Figure 10).

Table 17: Reclassified distance from stream and area coverage of suitability levels

Distance from stream (km)	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
< 0.5	S1	5	5231.6	42.4
0.5 - 1.0	S2	4	3500.3	28.4
1.0 – 1.5	S3	3	2369.6	19.2
1.5 - 2.0	N1	2	1139.4	9.2
> 2.0	N2	1	99.9	0.8

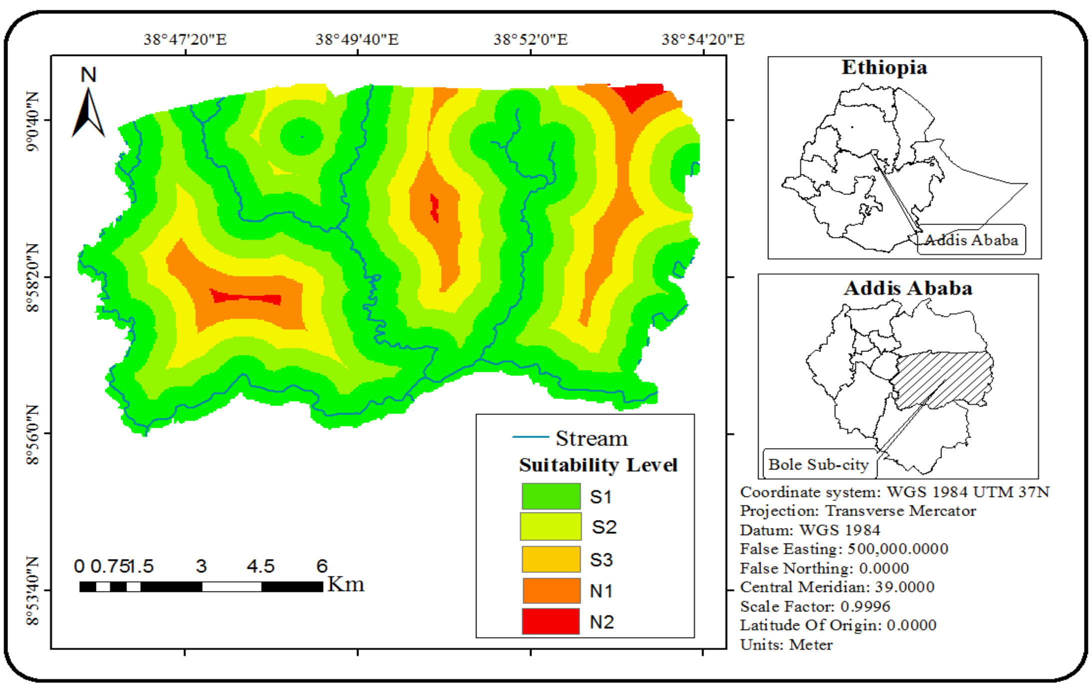


Figure 10: Reclassified distance from stream map

4.3.4. Suitability of distance from historical place

Developing of green space closer to historical place can maintain and preserve the historical place in the case of maintaining ecological balance (Manlun, 2003). Therefore, the land which is closer to historical place is more suitable than the further land. Areas distanced from the historical place by less than 1.5 km, in between 1.5 and 3 km, and greater than 6 km are considered highly suitable, moderately suitable and totally unsuitable respectively. Accordingly 18.9% of the study area were identified as highly suitable and 3.1% totally unsuitable (Table 18 and Figure 11).

Table 18: Reclassified distance from historical place and area coverage of suitability levels

Distance from historical place (km)	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
<1.5	S1	5	2281.0	18.9
1.5 – 3.0	S2	4	3631.9	30.0
3.0- 4.5	S3	3	3858.7	31.9
4.5-6.0	N1	2	1948.4	16.1
>6.0	N2	1	368.2	3.1

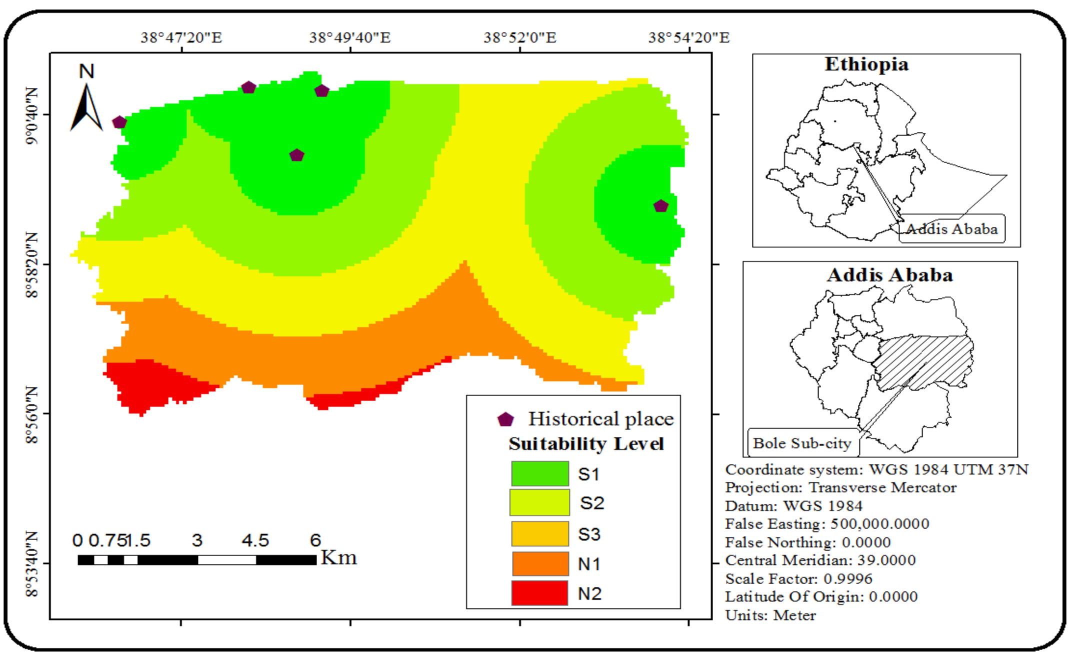


Figure 11: Reclassified distance from historical place map

4.3.5. Suitability of distance from noise influence

Noisy areas are not suitable for green space like the factory area because of high sound pollution and smokes (Manlun, 2003). Therefore, the farther lands from the factory get more preferences for developing green space. The study considered the reclassified distances as totally unsuitable if less than 1 km, not suitable between 1km and 2 km, less suitable from 2 km to 3 km, moderately suitable from 3 to 4 km and highly suitable greater than 4 km for developing green space. In the study area, highly suitable area covers the highest share (29.4% of the total area) as compared to other level of suitability (moderately suitable, 17.0 %, and totally not suitable, 19.7%) for developing green space (Table 19 and Figure 12).

Table 19: Reclassified distance from factory and area coverage of suitability levels

Distance from factory (km)	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
> 4	S1	5	3550.0	29.4
3 - 4	S2	4	2052.0	17.0
2 - 3	S3	3	1966.0	16.3
1 -2	N1	2	2141.0	17.7
< 1	N2	1	2381.0	19.7

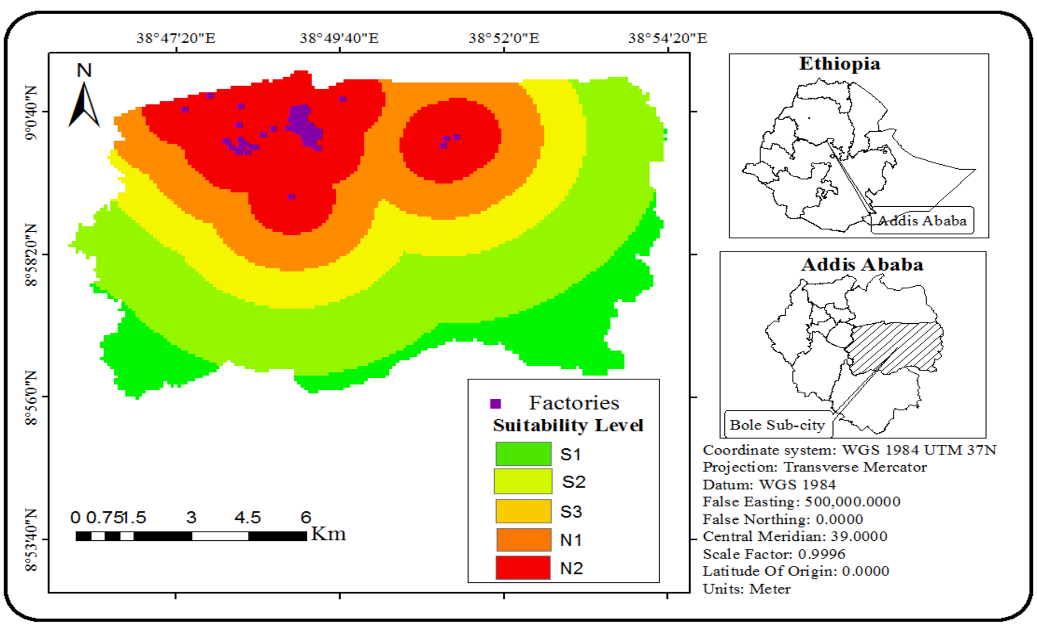


Figure 12: Reclassified distance from factory map

4.3.6. Suitability of distance from the park

In the study area, there are three main parks such *as shalla* , *peacok* and *adowa park*. The area which is the farthest from the existing park highly lacks green space or vegetation (Pantalone, 2010). Therefore, if distance from the park is greater than 6 km, it will be considered as highly suitable; 4.5 - 6 km, moderately suitable; and less than 1.5 km, permanently not suitable for developing green space (Table 20 and Figure 13).

Table 20: Reclassified distance from park and area coverage of suitability levels

Distance from park (km)	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
> 6	S1	5	2066.9	17.1
4.5 – 6	S2	4	1964.5	16.3
3.0 – 4.5	S3	3	2917.5	24.2
1.5 – 3.0	N1	2	2791.4	23.1
< 1.5	N2	1	2338.6	19.4

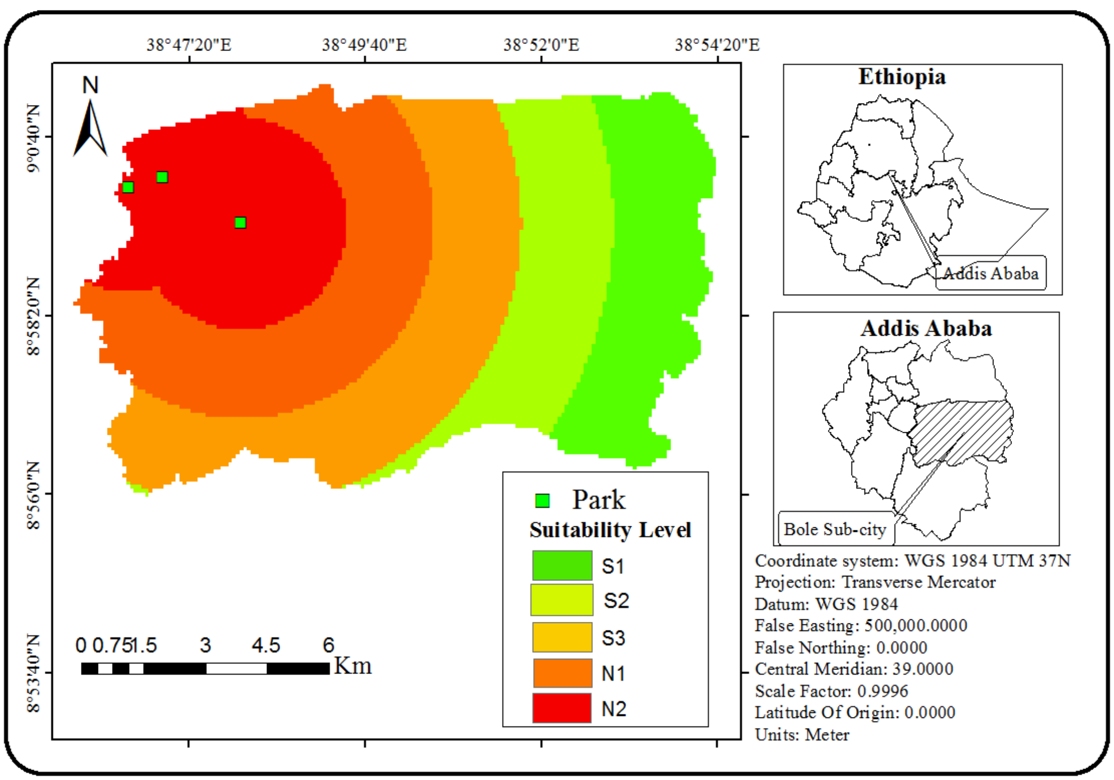


Figure 13: Reclassified distance from park map

4.3.7. Suitability of slope

Different researchers consider areas with low slopes are highly suitable for developing park (e.g. Heshmat *et al.*, 2013; Yousef *et al.*, 2014). Yousef *et al.* (2014) states the aim of building a green space is to create a common space for use by all sectors of society such as children, the elderly and the disabled; so taking the necessary measures in this respect is essential. Based on FAO (2006), the slope value 0 to 0.2 % is considered as flat and up to 5 gently slope. 5 to 10 % and 10 to 15 % is called sloping and strongly sloping respectively. Whereas 15 to 30 % and above 30 % is moderately steep and steep respectively. Therefore, this study considered the flat and gently slope as more highly suitable than the land with steep slope. The majority of the study area falls under the slope class of less than 5%, which covers 71.2% of the total study area. The slope value greater than 30%, which has the least coverage (0.1%), totally unsuitable compared to the other (Table 21 and Figure 14).

Table 21: Reclassified slope and area coverage of suitability levels

Slope (%)	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
<5	S1	5	8567.3	71.2
5-10	S2	4	2849.8	23.7
10-15	S3	3	535.8	4.5
15-30	N1	2	77.9	0.7
>30	N2	1	5.9	0.1

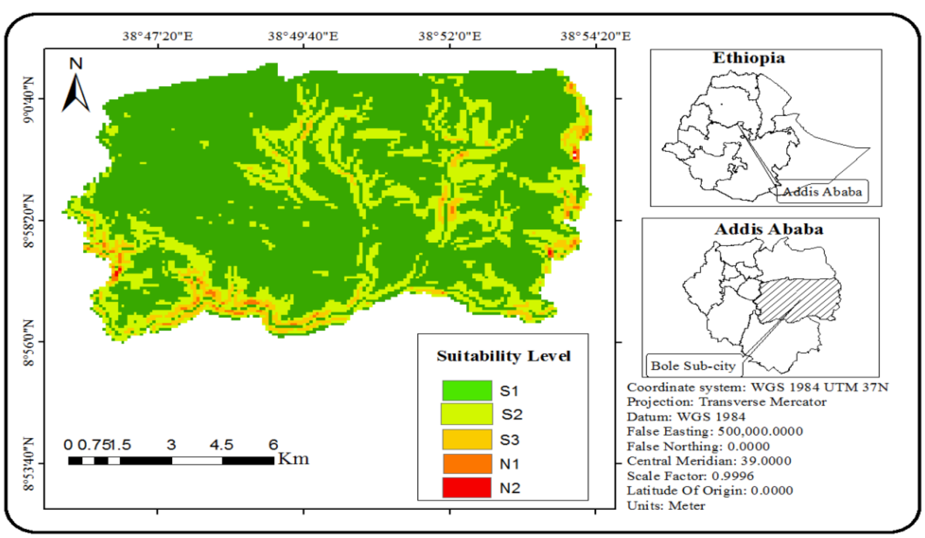


Figure 14: Reclassified slope

4.3.8. Suitability of soil type

Soils of Addis Ababa are classified into seven categories, namely chromic vertisols, pellic vertisols, etruic nitosols, orthic solonchaks, calcic xerosols, chromic luvisols and leptosols (MoA, 2007). Specifically, in the study area only four soil types are available such as chromic vertisols, pellic vertisols, etruic nitosols and orthic solonchaks. Based on the UNEP (2005) soil suitability standards, vertisols are considered as suitable soil because of its 30% or more clay content and it covers a large area (82.2%). Based on color, vertisols have two groups: chroma and pellic vertisols. Chroma vertisols have high amount of clay relative to pellic vertisols (Kamara and Haque, 1988). Etruic nitosols are relatively less suitable but fertile soils covering 15.2% of the area. Orthic solonchaks soils known for their high content of salts are common in arid and semi-arid areas (FAO, 2007). In this study, this soil is considered as unsuitable compared to the other types and covers 2.7% of the area (Table 22 and Figure 15).

Table 22: Reclassified soil and area coverage of suitability levels

Soil type	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
Chromic vertisols	S1	4	1566.7	13.0
Pellic vertisols	S2	3	8353.1	69.2
Etruic nitosols	S3	2	1830.8	15.2
Orthic solonchaks	N1	1	328.4	2.7

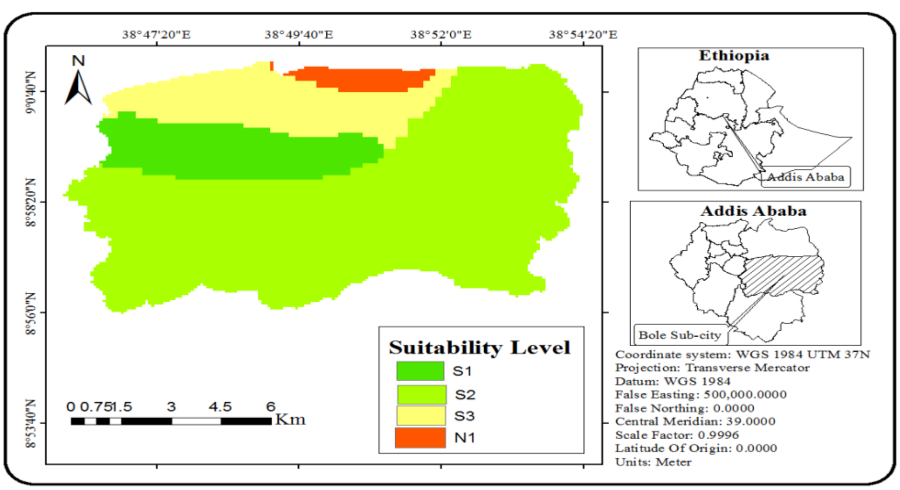


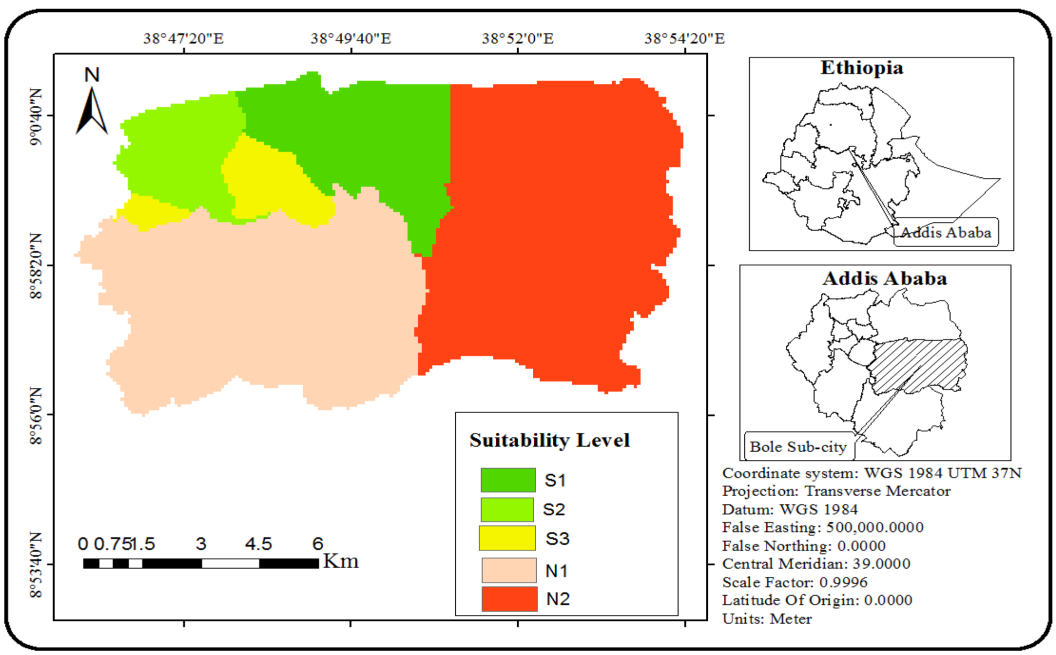
Figure 15: Reclassified soil map
Source: Ministry of Agriculture (MoA) (2013)

4.3.9. Population density

Population density is one of the major criteria for suitable site selection of green space. Some researchers (e.g. Ahmed *et al.*, 2011; Elahe *et al.*, 2014; Heshmat *et al.*, 2013; Pantalone, 2010) recommend that populated areas are highly suitable for developing green space. The north-west and northern part of the study area is highly populated and suitable areas for developing green space. The eastern part is sparsely populated and hence unsuitable for green area. With respect to population density, highly suitable and moderately suitable areas cover 1135.5 ha and 1942.1 ha of the total area respectively (Table 23 and Figure 16).

Table 23: Reclassified population density and area coverage of suitability levels

Population density (pop/ha)	Level of suitability	Value	Area (Ha.)	Percent of total area (%)
>80	S1	5	1135.5	9.4
50-80	S2	4	1942.1	16.1
20-50	S3	3	1129.8	9.4
5-20	N1	2	3050.9	25.3
<5	N2	1	4804.3	39.8



Source: CSA (2007)

Figure 16: Reclassified population density map

4.4. Overlaying and suitable sites

AHP pairwise comparison matrix was created and criteria weights were calculated for each factor by comparing factors using a scale with values from 9 to 1/9. The reclassified input datasets were assigned a weight value to express the importance of each criterion to the other criteria for suitable site selection for green space. In order to select suitable sites for green space development all the reclassified input datasets were overlaid using the weighted overlay tool or a raster calculator in ArcGIS (Table 24 & Figure 17).

Table 24: Suitability level per criteria for green space site selection

Criteria	**Measurement unit**	**Suitability level**					**Weight (%)**
		5 S1	4 S2	3 S3	2 N1	1 N2	
LULC	Class	BL &GL	Pl	FL	CL	BA & TA	31
Pop. den.	Pop./ ha.	>80	50-80	20-50	5-20	<5	20
Distance to road	km	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	> 2.0	11
Distance to stream	km	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	> 2.0	4
Distance to HP	km	< 1.5	1.5-3.0	3.0-4.5	4.5-6.0	>6.0	3
Distance to factory	km	>4	3-4	2-3	1-2	<1	9
Distance to park	km	>6.0	4.5-6.0	3.0-4.5	1.5-3.0	<1.5	4
Slope	%	<5	5-10	10-15	15-30	>30	7
Soil type	Class	Chromic vertisols	Pellic vertisols	Etruic nitosols	Orthic solonchaks		11

Note: BL= Bareland, GL= Grassland, Pl= Plantation, FL= forestland, BA=Built-up Area, HP= Historical palce, Pop.den. =population density and TA= Transport Area

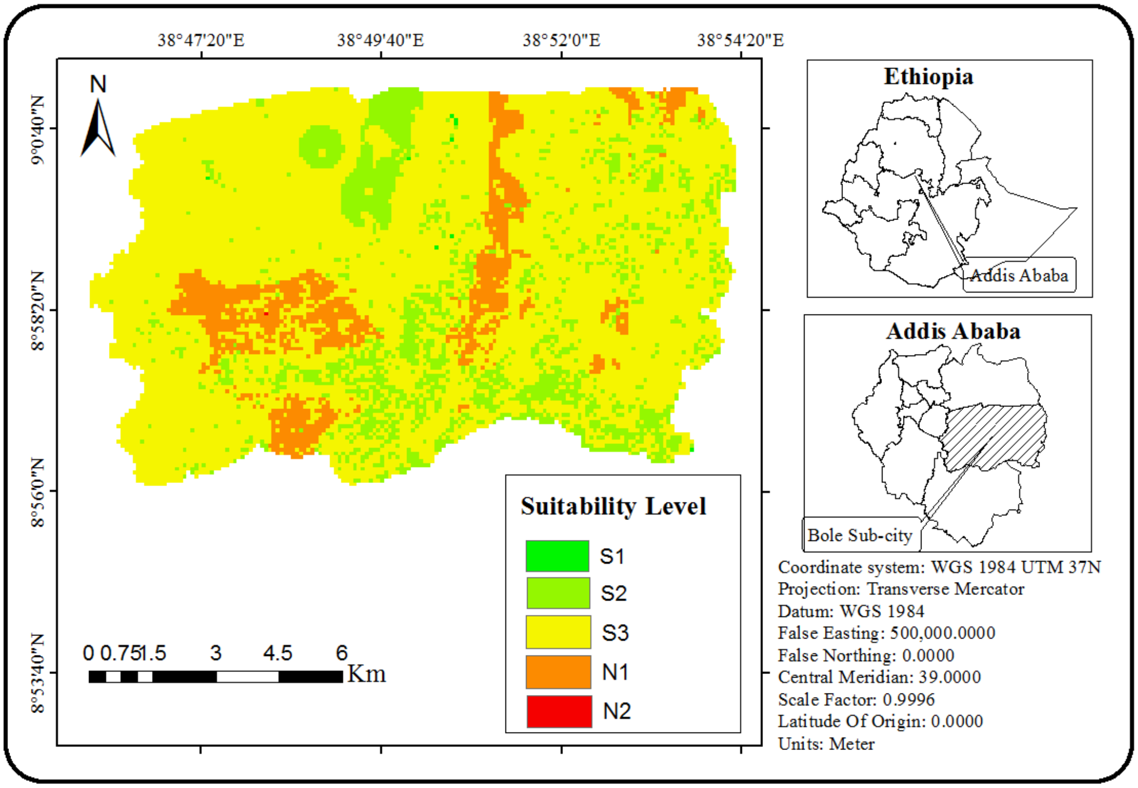


Figure 17: Final suitability map

According to GIS-based MCA, 501 and 2900 hectares are highly suitable and moderately suitable for green space development. The large area is less suitable for green space development in the existing situation which covers 49.8 % (6002 ha) of the area. The remaining 20.1% and 2.0% are unsuitable and permanently unsuitable for green space development respectively (Table 25). In the land use plan, the selected areas are mostly categorized as riverine, field crop and open space.

Table 25: Suitability area and percent of total area coverage

Level of Suitability	Area (Ha.)	Percent of total area (%)
S1	501	4.2
S2	2900	24.0
S3	6002	49.8
N1	2420	20.1
N2	240	2.0

In the revised structure plan, 15 to 20 percent was proposed for open spaces and environmental sensitive areas (parks, urban agriculture, recreation, mineral resources) (MoUDC, 2012) (Table 26). But, this is not enough for green spaces because the Ethiopian Planning Strategy and Urban Land Management Plan allocated 30% of the land for green areas, 30% for roads and infrastructure and shared public use and 40% for building construction (MoUDH, 2015).

Table 26: Proposed proportion of the respective land uses

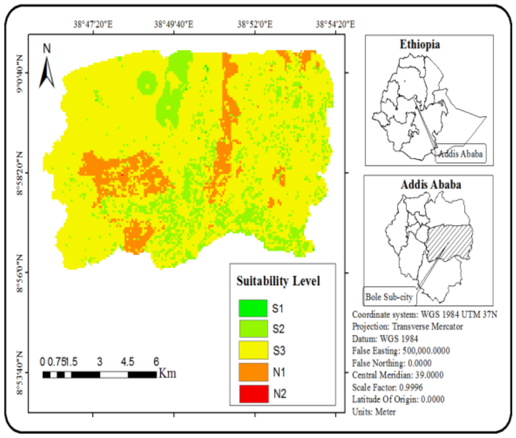
Components of Structure Plan	**Proposed percentage**
Housing	55-70
Business and commerce/ Centers and market places	5-10
Public facilities, cultural, archaeological sites and special functions	5-10
Manufacturing/ Industry and storage	5-10
Infrastructure, utilities and transportation	15-25
Open spaces and environmental sensitive areas (parks, urban agriculture, recreation, mineral resources)	15-20

Source: Revised structure plan, MoUDC (2012)

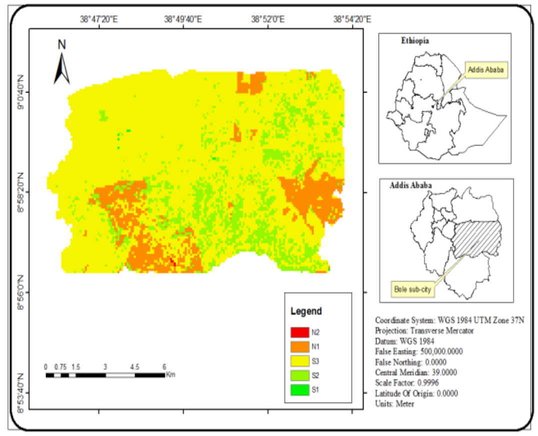
4.5. Sensitivity analysis

Sensitivity analysis determines the reliability of the model through assessment of uncertainties in the reproduction results (Chen *et al.*, 2009). It is vital to the validation and calibration of numerical models. It can be used as a tool to check the final result against slight changes in the input data. Therefore, sensitivity analysis can help reduce uncertainty in how an MCDM method operates and the reliability of its outputs by illustrating the impact of introducing small changes to specific input parameters on evaluation outcomes (Crosetto *et al*., 2000).

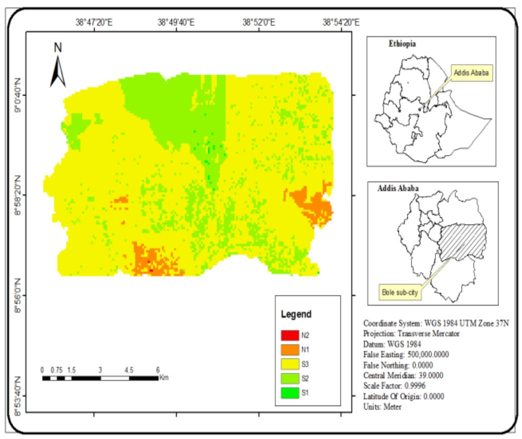
In this study sensitivity analysis was carried out by changing the weight values of each input criteria in five scenarios (Table 27 and Figure 18). The weight value for each criterion was calculated using a pairwise comparison matrix of AHP with a consistency ratio of less than 0.1.



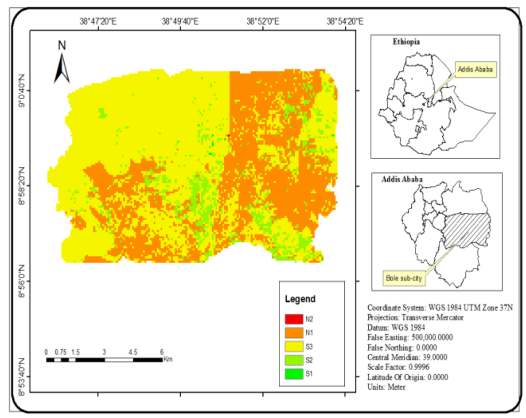
A)



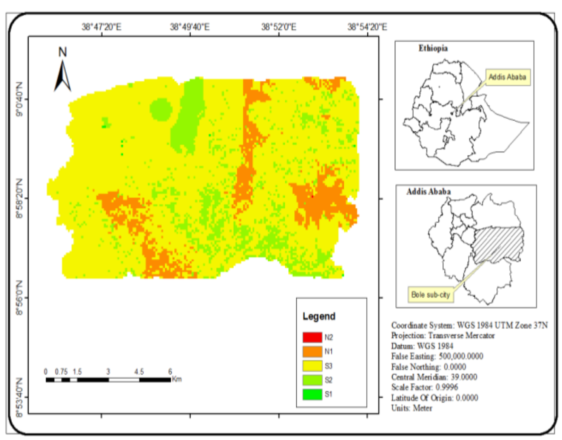
B)



C)



D)



E)

Figure 18: Sensitivity analysis map of five scenarios

In order to compare the effect of changes in weight value among five scenarios, scenario A was elected as base scenario which covers 28% of the total area. As the LULC (scenario B) increases, total suitable size diminishes from 28% to 12. In scenario C, with an increase in the population density and distance from the road, the total suitable area increased to 30 % of the total area. In scenario D, the lowest weight value was assigned to the slope and soil type, then the total suitable area decreased to 13% of the total area. Whereas in scenario E, the weights are most likely similar to scenario A and total suitable area covers 27% (Table 27).

Table 27: Weight value (%) for each input criteria in six scenarios

Criteria	**Scenario (%)**				
	A	B	C	D	E
LULC	31	40	25	35	29
Population density	20	21	24	23	19
Distance to road	11	14	20	10	16
Distance to stream	4	8	3	5	3
Distance to historical place	3	2	6	10	4
Distance to factory	9	6	2	7	8
Distance to park	4	2	9	3	5
Slope	7	2	7	4	8
Soil type	11	5	4	3	8
Consistency ratio	1	4	3	5	2
Total suitable area (%)	28	12	30	13	27

4.6. Field verification

Field verification was made to assess the ground truth of the suitable area using GIS-MCDS process with reference to the *Goro Selam sefer* area, one of the best suitable sites, and in the southern part of the sub-city *Addis sefer* also suitable site for green space development.

The LULC of the selected areas are mostly riverine categorized under forestland, plantation, bareland, grassland and some part cultivated land are relatively suitable for green space development. With respect to the distance to road, stream, historical place, noise influence, existing park, population and slope, the selected areas are identified as suitable site for green space development (Figure 19).

Figure 19: Selected areas for green space

Chapter Five

Conclusion and Recommendations

5.1. Conclusion

The urban/built-up areas in Addis Ababa have expanded dramatically while green areas are on the verge of decline. According to the new City Development Plan (2001-2010), the City has currently consumed more than 75% of its areas for development, and the potential expansion area of 10,000 ha within the city's boundary could be exhausted by 2010. This unprecedented growth is beyond the city's bearing capacity within its current socio-economic, physical and administrative situation. Added to these prime problems, the city is challenged by expanding squatter settlements, rising traffic congestion and more pollution, lack of green spaces and inadequate water supply and sanitation.

The study demonstrated a rapid and unplanned expansion and commercial development, along with population pressure, has exerted tremendous negative impacts on green space in the City of Addis Ababa in general and the study area in particular. At present the green spaces of Addis Ababa are almost transformed to urban settlements. Now, the 'forest city' definition, explaining Addis Ababa of the past, is no more acceptable. The city is heating as a result of heat island effects in many neighborhoods. Unsustainable use of land, uncoordinated urban development and insecure land tenure system might be the source of these prime problems. Added to these, lack of public awareness, low level of community participation, poor implementation of government policies, lack of budget, lack of skilled manpower, shortage of land, illegal settlement, problem of regular follow-up, problem of pollution from different sources and lack of cooperation among different stakeholders have contributed to the shrinking of green spaces in the city.

From the analysis, we can see that the rapid urbanization in the city of Addis Ababa has given little room for green area development. Land suitability analysis is a critical element in determining areas suitable for some specific purposes such as green space development. However, proposing suitable sites for green space development using suitability analysis is a cumbersome job involving multi-criteria analysis steps.

The classification achieved in this study indicates that large area is less suitable for green space development in the existing situation (49.8 % of the area) and 501 hectares are highly suitable for green space development. As demonstrated in this study remote sensing and GIS technologies can play a crucial role in urban research and help to get up-to-date information about the urban LULC dynamics with frequent coverage and low cost.

5.2. Recommendations

As witnessed from various earlier studies and including this one, remote sensing and GIS technologies are important for LULC change studies and multi-criteria decision making process. Therefore, the city administration and beautification, park and sustainable development administration agency need to respect the national standard of green space coverage of the city as outlined in the master plan; update the LULC using remote sensing and GIS technologies, and formulate guidelines to develop and manage the urban green space in the context of GIS-MCA process.

Moreover, the city administration, particularly beautification, park and sustainable development administration office of the sub-city should encourage the community and stakeholders so as to develop and maintain a community garden in line with the master plan and LDP (local development plan). The change detection of the green space coverage should also be continuously studied and implemented with the appropriate measure.

5.3. Future work

In this study, 30 m resolution of Landsat imageries were used as a result, some LULC type was generalized by other LULC type and some errors were also incurred in image classification. Therefore, future studies should consider using high resolution imageries such as IKONOS and QuickBird so as to overcome the problem. These satellite imageries are important in producing high quality and more accurate maps and results. In addition, using Esri City Engine improves urban planning, architecture, and design by ensuring 3D visualization, and hence, has the capability to better explain relationships, assess feasibility and plan for implementation of projects for quality decisions that benefit the community.

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Appendices

Appendix A: National Meteorological Agency Rainfall data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1984	0	0.4	12	12	135	334	318	180	98.8	0	0	7	1097
1985	35	0	49	132	93	111	210	261	169	30	0	0.4	1090
1986	0	38	56	217	38	175	168	222	107	32	0	2.5	1055
1987	0	49	180	86	155	72	156	98.1	57	17	0	0.4	869
1988	4.7	33	6.7	158	35	93	181	265	187	57	0	0	1022
1989	3.4	34	58	143	0	88	218	319	150	37	0	7.9	1058
1990	3.2	161	60	145	25	48	194	294	143	46	2.1	0	1122
1991	0.2	30	134	15	7.7	108	279	288	123	4.4	2.1	0	991
1992	15	28	35	59	55	82	255	223	157	64	2.2	0.4	975
1993	12	52	12	168	92	157	210	292	190	24	0	0	1208
1994	0	0	53	70	29	112	242	199	99.4	0.5	11	0	817
1995	0	81	73	133	96	77	166	257	97	0	0	29	1010
1996	21	16	134	96	125	290	346	313	211	0.2	0.4	0	1553
1997	29	0	22	67	45	128	257	161	94.7	59	15	0	877
1998	67	40	44	100	198	112	271	237	173	139	0	0	1380
1999	4.4	0	35	18	31	105	294	271	62.8	127	0	0	947
2000	0	0	18	88	95	102	193	222	158	20	7.5	0	902
2001	0	10	174	15	117	166	289	207	113	11	0	0	1103
2002	31	26	79	37	50	116	214	234	72.6	0.5	0	33	891
2003	4.8		49	112	18	111	204	238	130	4.6	0	33	905
2004		12	32		7	115	241	230	122	50	0.6	0	809
2005	55	14	42	116	165	159	174	248	77.6	26	7.2	0	1084
2006	2	37	108	94	38	115	313	331	133	36	0	0	1206
2007	9.9	21	61	87	134	158	191	305	131	37	0.1		1136
2008	0	0	0	34	75	73	295	259	193	22	53	0	1005
2009	41	0	12	46	52	78	238	270	86.1	42	2	80	947
2010	0.4	115	76	160	95	107	320	139	105	0	14	16	1146
2011	3.4	14	28		86	148	183	297	141	0	12	0	912
2012	0	0	35	75	59	73	229	282	177	1.2	0		929
2013		0	64	114	79	101	158	270	127	45	3.2	0	961
2014	0	42	30	34	62	42	180	254	95.1	35	0	0	772
	12	28	57	91	74	121	232	247	128	31	4.3	7.2	1025.06

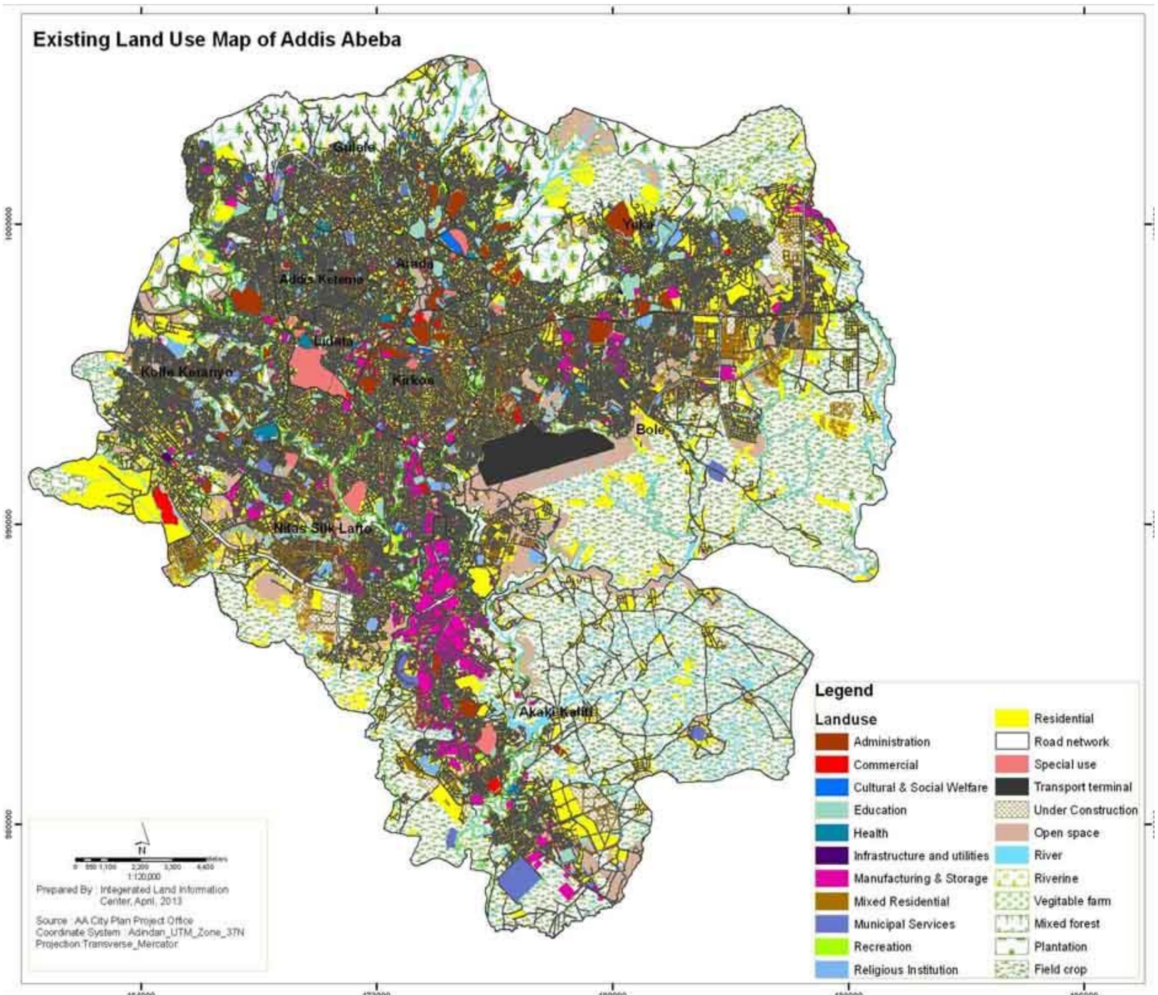
Appendix B: National Meteorological Agency maximum temperature data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1984	23	24.4	25.6	26.7	24.3	22.1	20.4	21.7	21.4	23	23.2	22.5	23.2
1985	23	23.9	25	22.9	23.5	23.3	20.1	20	21.4	22.2	23	22.9	22.6
1986	24	24.1	24.1	22.5		21.9			21.6	22.8	23.1	23.1	22.9
1987	23	24.3	23.2	23.6	23.7	22.7	22.1	21.7	23.1	23.9		24.3	23.2
1988	25		27.3	25.1	25.8	23.4	21	21	21.2	21.9	22.5	22.8	23.3
1989	23	23.2	24.5	23	24.9	23.6	20.7	21.2		22.8	23.1	22.8	22.9
1990	24	23.2	23.9	23.6	25.3	23.5	21.4	21.4	21.9	23	23.5	23.6	23.1
1991	25	24.8	25.6	25.6			21.3	21	22	23.1	22.7	22.9	23.4
1992	23	23.4	25.7	25.8	26.2		21.1	19.7	21	21.9	22.2	23.1	22.9
1993	23	23.3	26.4	24	23.8	22.6	20.9	21.1	21.2	22.9	23	23.5	23.0
1994		25.7	25.9	26.1	26.7	23.1	21.2	20.8	22	23.3	23.5	23.5	23.8
1995	24	25.4	25.1	23.9	25.2	24.5	21	21.5	22.3	23.8	24	23.9	23.7
1996	24	26.4	25	24.7	24.5	21.1	20.9	21.4	22.1	23.6	23.3	23.1	23.3
1997	23	25.2	26	24.5	26.9	24.9	21.7	21.9	23.3	23.1		24.2	24.1
1998	24	25	25.4	26.6	25.2	24.7	22.3	21.9	21.9	22.2	22.8	23.2	23.7
1999	25	26.7	25.5	27.6	26.9	24.6	20.5	20.6	22.1	21.9	22.7	22.7	23.8
2000		25.5	27.3	25.7	25.4	23.1	21.5	20.6	21.1	22.5	22.9	23.8	23.5
2001	24	25.2	24	25.5	24.3	22.5	21.5	21	22.9	24.7	24.2	24.2	23.6
2002	24	26.2	25.7	26.7	27	24.9	23	21.8	22.4	24.3	24.3	23.8	24.5
2003	24	26.2	26.3	25.1	26.8	24.5	21.2	20.8	21.9	23.7	23.6		24.0
2004	25			23.9	26.8		21.5	21.5	22.2	22.3	23.7	24	23.4
2005	24	26.6	26.4	25.9	24.1	23.4	21.1	22.1	22.4	23.6	22.9	23	23.8
2006	24	25	24.5	24.3	25.1	23.1	20.8	20.1	21.6	24.2	23.5	22.8	23.2
2007	24	24.7	25.9	24.4	25	22.4	20.7	20.2	21	22.4	22.9	22.6	22.9
2008	24	24.3	26.3	25.9	25.5	22.8	21.2	20.7	21.9	23.4	22.2	22.9	23.4
2009	23	25.2	26.9	25.9	26.4	26	20.9	20.8	22.6	22.5	23.2	22	23.8
2010	23	23.7	23.6		24.1	23.3	20.9	20.9	21.9	24.1	22.9	22.8	22.8
2011	24	25.4	24.7		24.9	23.7	21.8	20.7	21.5	24.2	23.5	22.8	23.3
2012	25	25.5	26.7	24.7	26.5	24	21.2	20.7	22	23.9	24.4		24.0
2013	25	26.3	26.3	26	25.1	23.3	21.3	20.8	22.8	23.2	23.9	23.4	23.9
2014	24	25.2	25.8	26.4	25.9	25.1	22	21.5	21.7	23.2	23.7	22.9	23.9
												G.Mean	**23.5**

Appendix C: National Meteorological Agency minimum temperature data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1984	4.8	4.4	9.8	10.4	12	11.1	10.7	10.3	9.5	6	6.2	5.2	8.3
1985	6.2	7.3	10.5	11.2	10.7	10.3	10.5	10.8	9.9	7.9	5	5.6	8.8
1986	4.4	9.8	9.3	11.5	10.4	9.7	8	7.6		3.7	5.2	6.3	7.8
1987	6	8.5	11.3	10.3	10.8	10.2	11	11.1	10.4	8.5	5.8		9.4
1988	7.4	10.9	9.4	11.5	10.2	10.4	11.6	11.2	10.4	8.1	3.9	4.5	9.1
1989	5.5	8.1	9.8	10.7	9.3	9.8	10.8	10.6	9.9	8.4	5.8	8.4	8.9
1990	6.1	10.9	9.9	10.6	9.9	9.8	10.8	10.9	10.5	7.5	6.7	4.7	9.0
1991	8.1	9.6	11.2	11		10.7	11.6	11.2	10.3	7.2	5.2	6.2	9.3
1992	8.6	10	10.8	10.7	10.5	9.8	10.5	11.6	9.7	8.1	6.2	7.3	9.4
1993	8.3	9.3	8.7	11.4	10.8	10.4	11.1	10.8	10.1	8.3	5.5	4.8	9.1
1994	5	7.3	10.6	10.9	10.9	10.9	11.6	11.2	9.6	7	6.7	4.9	8.8
1995	5.2	9.5	10.5	12	11.1	10.2	11.4	11.5	10	8.3	6.3	7.8	9.4
1996	8.9	7.7	11.1	10.5	11.1	11.3	11.1	11	9.8	7.1	6.3	5.7	9.3
1997	9.3	6.1	10.3	11.2	11.1	11.7	11.3	11.5	10.6	10		6.6	9.9
1998	9.8	11.7	12	12.1	12.6	11.2	11.7	12.3	11	9.2	4.7	3.4	10.1
1999	6.7	7.3	10.4	10.4	10.5	10.3	10.5	10.4	9.9	9.2	5.4	5.6	8.8
2000		5.8	10.2	12.1	11.1	10.1	11	10.8	10.6	8.9	6.8	8.9	9.6
2001	6.8	7.8	10.8	10.9	11.3	10.5	11.1	11.6	9.8	8.6	5.9	6.4	9.2
2002	7.7	8.7	10.9	11.4	11.8	10.8	11.2	10.9	10.5	8.9	6.5	9.6	9.9
2003	8.5	9.8	10.3	11.8	11.4	10.9	11.5	11.9	11.4	8.2	7.4	6	9.9
2004	9.9	8.7	10.3	11.9	11.1	11.2	11.4	11.5	10.9	8.3	7	7.8	10
2005	8.5	8.6	11.2	11.7	12.1	11	11.5	11.8	11.5	8.7	7.4	5.8	9.9
2006	9.1	11	11.2	12.2	11.9	11.8	11.9	11.9	11	10.3	8.7	8.6	10.8
2007	9.4	10.7	11	12	12.4	11.8	12.1	11.8	11.8	9.3	7.6	5.6	10.4
2008	8	8.4	9.1	12	12.4	11.8	11.4	11.5	11	9.8	7.8	6.8	10
2009	9	9.7	11.4	11.8	12.4	12.1	12	12	11.5	9.8	7.7	10.1	10.7
2010	8.9	11.6	11.7	12.6	13.2	12	11.9	12.5	11.5	10.1	8.4	8.1	11.0
2011	9.3	9	11		12.8	12.3	12	12.3	11.9	9.3	10.5	7.3	10.7
2012	8	8.5	10.7	12.1	12.7	12.3	12.1	11.9	11.7	9.9	9.5		10.8
2013	9.3	10.4	13	13.2	12.8	12.1	11.9	12	11.4	10.5	9.8	7.9	11.1
2014	9.5	11.7	12.1	13	13	12.8	12.5	11.8	12.2	10.5	9.1	8.4	11.3
												G.mean	9.7

Appendix D: Land Use map of Addis Ababa



Source: Integrated Land Information Center (2012)

Area coverage of Existing Land use of Addis Ababa

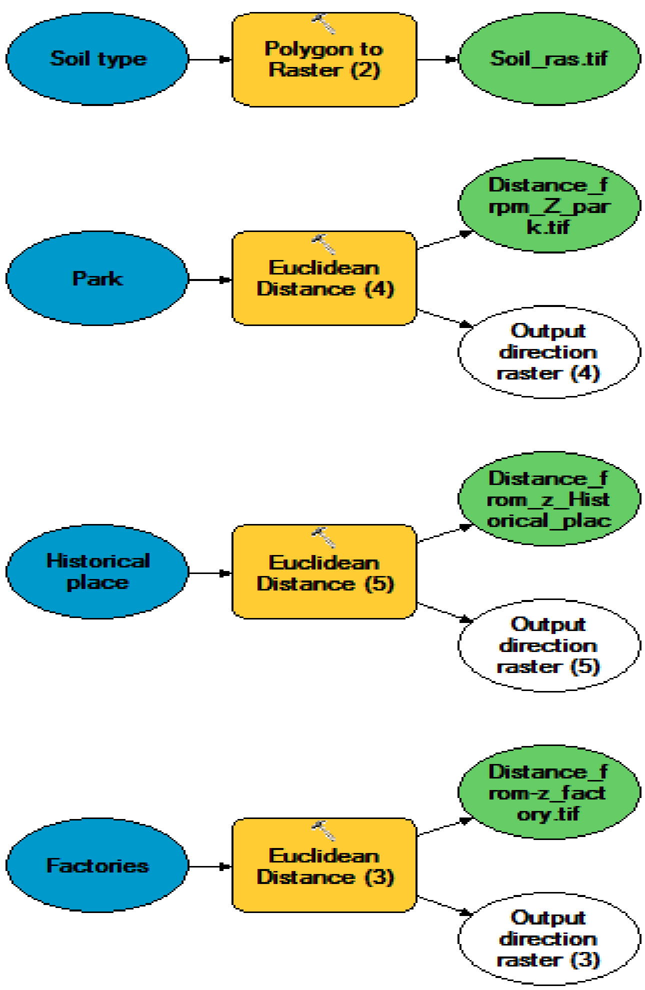
No	Land Use Type	Area (Ha)	Percentage (%)
1	Administration	978.85	1.88
2	Commercial	736.3	1.42
3	Cultural & Social Welfare	114.38	0.22
4	Education	854.41	1.64
5	Field crop	14118.85	27.17
6	Health	185.7	0.36
7	Infrastructure and utilities	23.34	0.04
8	Manufacturing & Storage	1724.35	3.32
9	Mixed Residential	812.81	1.56
10	Municipal Services	484.71	0.93
11	Open space	4405.92	8.48
12	Plantation	4086.64	7.87
13	Recreation	113.66	0.22
14	Religious Institution	615.59	1.18
15	Residential	12773.45	24.58
16	River	1090.69	2.1
17	Riverine	46.83	0.09
18	Road network	5244.54	10.09
19	Special use	345.73	0.67
20	Transport terminal	529.34	1.02
21	Under Construction	1137.39	2.19
22	Vegetable farm	306.46	0.59
23	Mixed forest	1227.93	2.36
	Total	***51957.87***	***100***

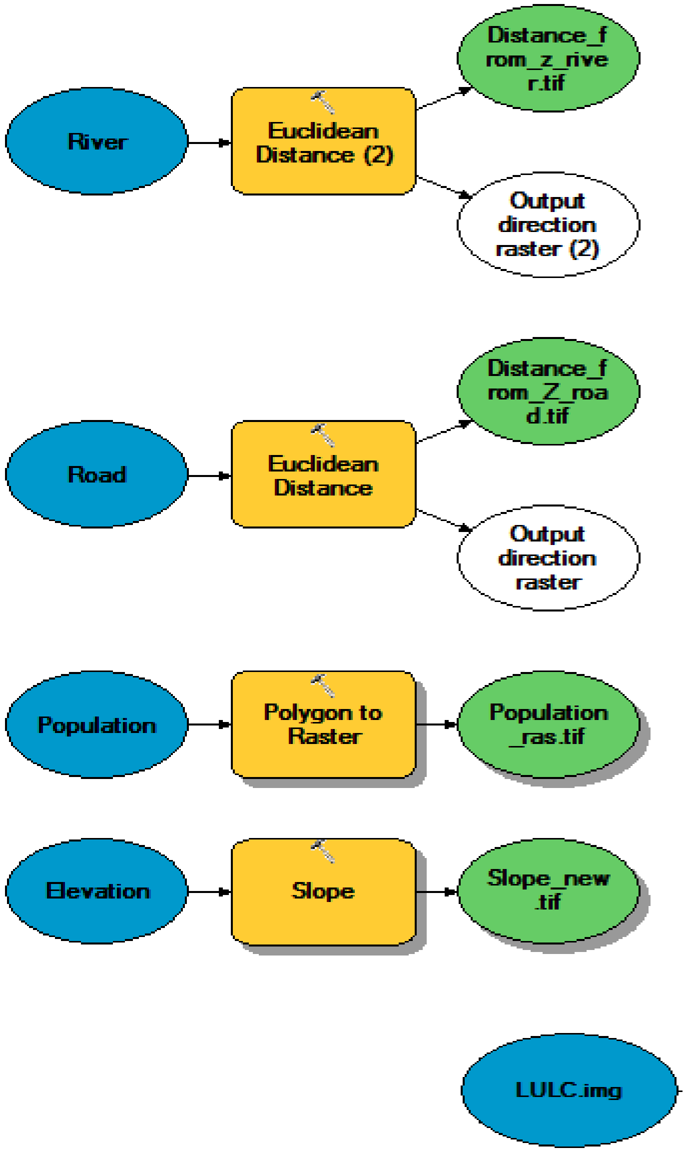
Source: Integrated Land Information Center (2012)

Appendix E: GIS Model for UGS development

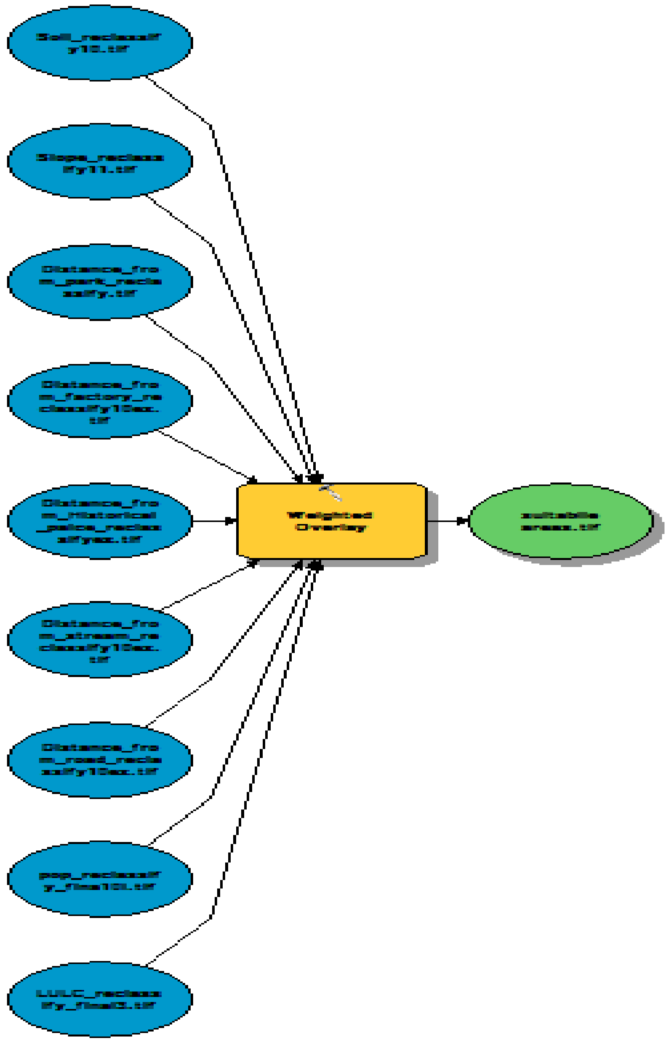
Slope Generated from DEM

Find Distance and converted to raster




River
Euclidean Distance (2)
Distance_from_z_river.tif
Output direction raster (2)
Road
Euclidean Distance
Distance_from_Z_road.tif
Output direction raster
Population
Polygon to Raster
Population_ras.tif
Elevation
Slope
Slope_new.tif
LULC.img

Reclassified and weight overlay



Urban green space suitability model building process