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## **Study of the Urban Environment and Ecosystem Services of Addis Ababa: Implications for Urban Greenspace Planning**

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This is to certify that the dissertation prepared by Tekle Woldegerima Kahsay, entitled:  
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## ABSTRACT

### **Study of the Urban Environment and Ecosystem Services of Addis Ababa: Implications for Urban Greenspace Planning**

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Urban green spaces serve as repository of biodiversity and source of ecosystem services which influence the quality of life the urban dwellers. To understand how these ecosystem services are provided one must understand the "ecological" and "cultural" driving forces that explain how the green spaces in any particular urban morphology are structured or created. The aims of this study were to: (i) characterize the urban environment of Addis Ababa through UMTs mapping and application of UMT based land surface cover assessment and (ii) analyze ecosystem services provided by the urban green spaces of Addis Ababa such as regulating and supportive functions which may help to suggest planning scenarios for the sustainable management of green spaces in the city of Addis Ababa.

UMTs maps of 2006 and 2011 were produced by digitizing ortho-rectified aerial photographs and verified with field assessment. These UMTs maps served as a base for surface cover analysis. Changes in UMTs and land surface cover between 2006 and 2011 have been detected, mapped and analyzed using various GIS techniques. Based on the UMTs and land surface cover types as well as selected ecosystem services were analyzed and used as input for urban green space planning.

The result showed the spatio-temporal structure of UMTs that provides urban ecosystem services in the selected study areas. Accordingly, a total of 11 higher level and 35 detailed urban morphology types (UMTs) have been identified and mapped for both 2006 and 2011 covering the entire urban and peri-urban areas of Addis Ababa. Within the defined higher levels UMTs in 2006, the most dominant one was agriculture covering 38%; of the total area while in 2011 residential UMTs stand out with the highest land coverage (33.3%) of the total UMTs indicating rapid conversion of other land uses to residential category. Results of land surface cover analysis showed 12 surface cover

categories. The change analysis between 2006 and 2011 revealed that the surface cover types of built structure type I, non-eucalyptus trees, dark bare-ground, light bare ground and vegetable farm have shown a positive change whereas, built structure type II, eucalyptus trees, shrub/bush vegetation, grassland and field crop cover have shown a negative change.

Results of ecosystem service analysis have shown that carbon density in the study area varied with forest categories viz. 293tonns/ha, 142tonns/ha and 132tonns/ha in the dense, medium and open forest strata respectively. The Shannon-Wiener diversity index reported as 3.24 for *Junipers* dominated forest, 2.98 for mixed forest and 2.76 for *Eucalyptus* dominated forest. Furthermore, the formation of soil erosion features are significantly different ( $p < 0.001$ ) among the three forest categories including Eucalyptus forest, Juniperus forest and Mixed forest where high incidence of soil erosion was recorded in the Eucalyptus forest. Therefore, irrespective of the environmental factors such as slop, aspect and elevating differences, there is a positive association between *Eucalyptus* forest and high soil erosion features. To ensure sustainable supply of ecosystem services and to maintain a balanced urban environment, all green spaces in the city should be networked as functional ecosystem units with diverse components. Therefore, characterizing the urban environment through UMTs and land surface cover analysis would provide essential information for an effective planning of green space.

**Key words:** *ecosystem service, greenspaces, land surface cover, planning, urban morphology types*

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## LIST OF ACRONYMS

AGB	Above Ground Biomass
BGB	Belo Ground Biomass
BT1	Building type I
BT2	Building type II
C/ha	Carbon per hectare
CLUVA	Climate Change and Urban Vulnerability in Africa
DBG	Dark bare ground
DBH	Diameter at Breast Height
DFLRI	Danish Forest and Laboratory Research Institute
EDF	Eucalyptus Dominated Forest
ETR	Eucalyptus trees
FAO	Food and Agricultural Organization
FCR	Field crops
GIS	Geographic Information System
GPS	Global Positioning System
GRA	Grassland
GTP	Growth and Transformation Program
ILRI	International Livestock Research Institute
IPCC	International Panel for Climate Change
JDF	Juniperus Dominated Forest

LBG	Light bare ground
MDG	Millennium Development Goal
MEA	Millennium Ecosystem Assessment
MXF	Mixed Forest
MUSLE	Modified Universal Soil Loss Equation
OECD	Organization for Economic Cooperation and Development
OIS	Other impervious
ORAAMP	Office for the Revision of Addis Ababa Master Plan
REDD	Reduction Emission from Deforestation and Degradation
SBV	Shrubs/bushes
SE	Standard Error
TNE	None-eucalyptus trees
UMTs	Urban Morphology Types
USLE	Universal Soil Loss Equation
VGf	Vegetable farm
WAT	Water body
WBISPP	Woody Biomass Inventory Strategic Planning Project
WHO	World Health Organization

# 1. INTRODUCTION

## *1.1 General back ground*

The major global environmental challenges are accumulation of greenhouse gases which raise the global temperature regime, environmental pollution, deforestation, degradation of ecosystems and loss of biodiversity. Population growth, industrialization and urbanization are the driving forces of environmental changes, which are causes and effects of each other and difficult to effectively resolve in isolation. Today's modern society is unsustainable because it is a self-reinforcing combination of rapid population growth and high resource consumption making the current global situation unstable and unsustainable (Nes & Golay, 1997; The World Watch Institute, 2013). These authors stated that development is essential towards satisfying the needs of each citizen in every nation, however short term development view could negatively affect long term development goals and human survival. Comprehensive and inclusive development ensures the balance between present and future generations' requirements. Development planning has hitherto concentrated on economic systems, to a lesser extent on social and barely considered environmental systems, similarly environmental planning focused on natural systems only resulting in fragmented approaches. Environmental planning, an emerging multi-disciplinary tool must remedy the shortcomings of narrow planning by introducing holistic ecosystem approach that integrate natural, social and economic systems for sustainable development.

Humans have been altering land cover since prehistory through land clearance for agriculture and livestock; however the impact of human activities on the land has grown enormously during the past few centuries altering the entire landscapes and ultimately

impacting the earth's nutrient and hydrological cycles as well as climate. Changes in land use/land cover has resulted in the modification of climate regimes as a result, climate change and variability has been observed in many parts of the world and temperature is expected to increase by 1.8 °C to 5.8°C between now and the next 100 years (IPCC, 2007; Glasson & Marshal, 2007).

Climate change, which is a long term shift in the climate of a specific location, region or planet measured by changes in average weather features, such as temperature, wind patterns and precipitation (IPCC, 2007) has topped the world's environmental agenda due to its global range magnitude of impacts. Climate change refers to general shifts in climate, while global warming refers specifically to changes in the global average surface temperature. Global warming is often misunderstood to imply that the world will warm uniformly. In fact, an increase in average global temperature also causes changes in the circulation of the atmosphere; resulting in some areas of the world warming more, others less and other areas can even cool (Bram & Jim, 2008). Climate change occurs when the climate of a specific area or planet is altered between two different periods of time. This occurs for many reasons, when the total amount of the sun's energy absorbed by the earth's atmosphere and surface is changed or the amount of heat energy from the earth's surface and atmosphere that escapes to space over an extended period of time is altered (IPCC, 2007).

Climate change may take place due to natural processes like volcanic eruptions, variations in the sun's intensity, or very slow changes in ocean circulation or land surfaces which occur on time scales of decades, centuries or longer. But human induced climate change by releasing greenhouse gases and aerosols into the atmosphere, changing

land surfaces, and depleting the stratospheric ozone layer has become the most pressing issue for our planet. (Yuen & Kumssa, 2011)

Climate change affects entire life systems, primary production by altering an ecosystem moisture regime, nitrogen availability, and length of growing season among other things. The direct effect of warming on plants and ecosystems will be complex because temperature impacts virtually all chemical and biological processes, thus the effects of temperature changes are larger and more important than any other factor (Kehlenbeck & Schrader, 2007), from which multistep indirect effects cascade and affect ecosystem processes. Plants in increased CO<sub>2</sub> environments either open their stomata less widely or keep their stomata closed more often, therefore reducing plant transpiration (Betts *et al.* 2007). Studies indicated that global net primary terrestrial production is increased due to elevated CO<sub>2</sub> (Nemani *et al.* 2003), after eventual acclimatization to higher CO<sub>2</sub> however, short term photosynthetic response is decreased. This means that initial increases in growth and yield stops, in fact, long exposure to elevated CO<sub>2</sub> leads to the accumulation of carbohydrates in the photosynthetic tissues of the plant leads to reduction in photosynthetic rates (Bisgrove & Hadley, 2002).

### ***1.2 Urbanization and environmental changes***

Human induced environmental change is a major concern of existence and its impact is most significant in towns and cities where the population is concentrated. Urbanization is considered to be a dynamo in the global economy; and is an accepted reality that growth of cities cannot be stopped, instead, the challenge is to manage urban growth so that it results in the balance of economic growth and healthy environment (Van de Voorde *et al.*, 2011). Urban environmental conditions are different to that of rural, most

significantly; the urban landscape is characterized by paving and buildings, modifies the urban mesoclimate decreases wind speed, raises temperatures, increases precipitation, lowers relative humidity and raises contaminants as compared to the rural landscape, though its extent and influences depends on the size of the city and its proportional vegetation. Yang *et al.* (2009) elucidated that the percentage of population that live in urban areas has been increasing rapidly since 1950s. According studies by the Organization for Economic Cooperation and Development (OECD, 2010), the urban population grows two to three times faster than the rural population, a trend projected to be maintained over the coming decades.

The urban environment has distinctive biophysical features in relation to surrounding rural areas; its energy exchange is altered inducing an urban heat island, increased surface sealing increased surface runoff. These changes are partly due to reductions in urban greenspaces of spatial area coverage and vegetation composition which would provide natural cooling, by shielding building facades and street surfaces from the sun, reducing the amount of energy stored in the built fabric during the day and mitigate the urban heat island effect.

The principal impacts of climate change in cities include destruction of infrastructure through flooding hazard, built environment deterioration and urban heat island intensification which affect the health and livelihood of the urban community (IPCC, 2007; Gill, 2006). Land cover changes due to urbanization are drastic where a complete transformation in to impervious surfaces has occurred, affecting energy exchange regimes and inducing climate change. The areal extent of urban land is not that large as compared with other land uses such as agriculture or forestry but its impact is significant,

due to large concentrations of population, centrality to political, cultural, economic and industrial activities.

Environmental impacts of urbanization can be categorized as direct and indirect; the direct impacts include the expansion of settlements, industrial and infrastructure land uses into natural and or agricultural lands. Urban paved and built up surfaces absorb heat and re-radiate it at night, creating urban heat islands that affect plants and human physiology and health. The indirect impacts of urban expansion like expropriation of resources from large distances, the need for sinks or dumping sites for huge volumes of wastes generated by cities are also crucial.

### ***1.3 Urban greenspace and ecosystem services***

Plants are major regulators of the global and local climate; their response to increased concentrations of atmospheric CO<sub>2</sub> through photosynthesis uptake is the most important role in mitigating climate change. Primary production occurs when chemical or solar energy is transformed to useable biomass. Most primary production on the planet occurs via photosynthesis, a process that allows plants to convert solar energy, water and CO<sub>2</sub> into carbohydrates, which ultimately produce plant tissues. Photosynthesis by terrestrial vegetation accounts for about half of the carbon annually cycled between earth and atmosphere making plants most crucial in removing CO<sub>2</sub> from the atmosphere, storing it as biomass and ultimately limiting atmospheric CO<sub>2</sub>.

Green spaces create cooler microclimates through evapotranspiration, water is released through leaf pores and when it evaporates energy is absorbed from the air creating a cooling effect. Green spaces help to reduce the impact of high temperature by providing

natural cooling, shading, shielding building facades and street surfaces from the sun which reduce energy stored in the built fabric during the day and mitigate urban heat island effect. Studies indicated that with a green space of one hectare and above in size, it can be effectively pronounced to develop a distinctive microclimate. (Gill, 2006) found that for Manchester city an additional 10% green cover in high density urban areas moderate temperatures to entirely counteract warming due to climate change until 2050. Conversely, a 10% reduction in green cover exacerbates warming effect, increasing surface temperatures by 3 to 4<sup>0</sup>C in high emissions scenarios for 2080. The impervious surfaces of urban environment absorb higher heat energy; the thermal properties of buildings, tar, asphalt, brick and concrete all with higher conductivity as compared to the vegetation in the rural areas contribute to urban heat island. Heat from buildings, vehicles and trains all added to warming cities, there is little or no evaporative cooling due to excessive runoff which limits the availability of moisture.

Urban green space, urban open space or urban green infrastructure conveying a more or less similar meaning and considered as same for this study is an important urban infrastructure referring to an interconnected network of green spaces in the forms of conservation matrix, greenspace corridors or patches which conserve natural ecosystems to provide ecosystem services to urban population. Urban green space is vital, provides recreational, educational, aesthetic and health benefits. These unsealed, permeable areas are also essential for the provision of life supporting ecosystem services, such as the maintenance of hydrological and biogeochemical cycles and regulation of climate change effects.

Green spaces protect quality of streams, rivers and water supplies, supports species diversity, wetlands, fish and wildlife habitat, contribute to ecological, social, and the overall improved health and quality of life of citizens (Stiftel & Vanessa, 2004). All these services, referred to as ecosystem services contribute to the city's economy by increasing property values, avoiding costly environmental clean ups and provide services at no cost to the public. The World Health Organization (WHO) recommended an urban green space of 9m<sup>2</sup>/inhabitant (Bisgrove and Hadley 2002). However the proportion of green areas varies greatly in different cities, for example in Europe the variation ranges from 60% in Bratislava, the capital of Slovakia, to about 5% in Madrid, the capital of Spain. In Copenhagen, green areas, including natural and forest lands account for about 23% which corresponded to 43 m<sup>2</sup>/inhabitant (DFLRI, 2011). Parks, gardens and street trees can help to reduce the impact of hot temperature by providing natural cooling, by shielding building facades and street surfaces from the sun, the amount of energy stored in the built fabric during the day is reduced, and mitigate the urban heat island effect..

According to the Danish Forest and Landscape Research Institute (DFLRI, 2011), urban green spaces are increasingly recognized as most important to the overall quality of human life due to their significant ecological and aesthetic impacts on the urban population. In the urban landscape, paving and buildings characterize the city, in which wind speed is decreased, temperatures and precipitation is raised and the humidity is lowered. With more than half of the world population has become an urbanite, the quality of urban environment and its greenspaces is increasingly recognized as key issue to redevelopment of cities. (OECD, 2010).

The primary function of urban greenspace is to ensure satisfactory open spaces for recreational, social and ecological uses; these are also of major significance to the physical environment, biodiversity and air quality (Van de Voorde *et al.*, 2011).

Thus, green space management is an essential tool for the conservation of natural ecosystem values and functions and provides associated benefits to human populations. For instance, Giugni *et al.* (2015) in the study of CLUVA research project in the African cities including Addis Ababa (Ethiopia), Dar es Salaam (Tanzania), Douala (Cameroon), Ouagadougou (Burkina Faso) and Saint Louis (Senegal) has clearly showed the value of urban green spaces in providing local climate regulation services.

#### ***1.4 Urban planning and greenspaces***

Historical records show that, there have been efforts and achievements as well, to guide the growth of Addis Ababa city by developing and implementing physical plans, popularly known as a “Master Plan”. The first master plan developed by a French architect in 1936 was not materialized, while the master plan developed by the Italians during the brief occupation period as suited to their colonial ideals was the first to be implemented on the ground. Subsequently the master plan was revised in 1956 and 1959 by British architects and Consulting Firm, in 1965 by the French Mission for Urban Studies and Habitats, and in 2000 by the Office for the Revision of the Addis Ababa City Master Plan (ORAAMP, 2000), except for the latest one, almost all the previous master plans paid little or no attention to the integration of urban greenspaces component.

The Addis Ababa city master plan under implementation (ORAAMP, 2000) laid legal, procedural and technical provisions for concerted efforts to protect and develop its

natural resources in general and the forest and other greenspaces in particular by making the environment a major component of its structural Plan. Environmentally sensitive natural resources, like the northern Entoto mountain forest as well as groundwater resource potential sites has received due attention to be protected and sustainably utilized. It also paved the way to prioritize the environment as one of its prime strategic issues in subsequent strategic planning by setting ambitious goals of preserving 41% its total land area as greenspaces, about half of it foreseen for forest and wood lands. Hence despite setbacks in practical implementation; there is now signs of natural regeneration and sprouting of both indigenous and exotic species in areas where no or little human interference exists.

#### **1.4.1 Coverage and per capita of urban green space of Addis Ababa**

Per capita green space is the area ( $m^2$ ) of accessible green spaces available per city inhabitant which is one measure of the quality of life in cities. Accessibility of a greenspace could be purely visual or the right to enter to the greenspace. Sotoudehnia & Comber (2011) explained that access is mainly measured as a physical distance or travelling time from a residential house to a greenspace and further elaborated the UK standard that everyone should live within a distance not more than 300m from nearest green area of at least 2ha in size. Thus, the full benefits of green space are obtained when the later are physically visited, and only physically accessible green spaces are considered for the determination of per capita green space. In Addis Ababa the functional recreational parks cover 69 ha and street plantation is estimated to cover 28 ha (ORAAMP, 2000). In recent years there have been additional development of recreational parks in urban renewal sites of Addis Ababa, like at Lideta 4.3 ha, at Basha

Wolde 1.17 ha, and development of some of the proposed parks like Behind St. Estifanos church 5.2ha and at the Nations and Nationalities square, 30.5 ha bringing the per capita estimated green space to 0.46 m<sup>2</sup>

However, the World Health Organization (WHO) standard is 9 m<sup>2</sup> and that of Africa is 7 m<sup>2</sup>, hence to meet the WHO standard, Addis Ababa needs additional 2430 ha of publicly accessible green space. Seventeen proposed but not developed parks distributed in eight sub cities occupy 271.5 hectares. One reasons for low per capita greenspace in Addis Ababa is lack of implementing these public parks as proposed by the outdated master plan.

#### ***1.4.2 Challenges of urban green space development in Addis Ababa***

Urban growth through expansion of built and impervious surfaces at the expense of evapotranspiring land surface covers presents numerous challenges for the maintenance of urban green space, which is brought about and explained by several reasons including:

***(i) Absence of city level green space policy:*** In Addis Ababa green space policy is not in place. The Forest Development, Conservation and Utilization Policy and Strategy of Ethiopia issued in 2007 does not consider the role of urban forest at meeting the public demand in forest products and foster the contribution of forest in enhancing the economy. The “Urban Sanitation and Green Strategy” issued by the Federal Ministry of Construction and Housing Development in 2012 recognized the absence of urban greening and beautification policy in the Ethiopian cities and towns and emphasizes the need to provide such policy in order to implement the Millennium Development Goal (MDG) and the Growth and Transformation Plans (GTPs).

**(ii) Problems of institutional arrangement:** Appropriate institutional arrangement is vital for the implementation of green space policy, strategy and programs. In Addis Ababa, green space development has been administered by different institutions including: Addis Ababa Environmental Protection Authority, Beautification, Parks and Cemetery Development and Administration Agency, the office for Urban agriculture, the Ethiopian Heritage Trust and more recently the Gullele Botanic Garden. These institutions seem to put some duplicative efforts in the management of greenspaces.

**(iii) Absence of watershed based planning and management:** The upper catchment of Addis Ababa is planted with Eucalyptus plantation, which is mostly used for production purpose. Land degradation, which is manifested in the form of soil erosion, is clearly seen under Eucalyptus plantation. Residential and commercial buildings occupy parts of the upper catchments of Addis Ababa. As a result, storm water, which should have been retained within the soil, is being changed into runoff, affecting infrastructure, and the lives of people in the central and lower stream of the city. Moreover, the three dams (Gefersa, Legedadi and Dire) that supply potable water to Addis Ababa are seriously affected by siltation and chemical pollution.

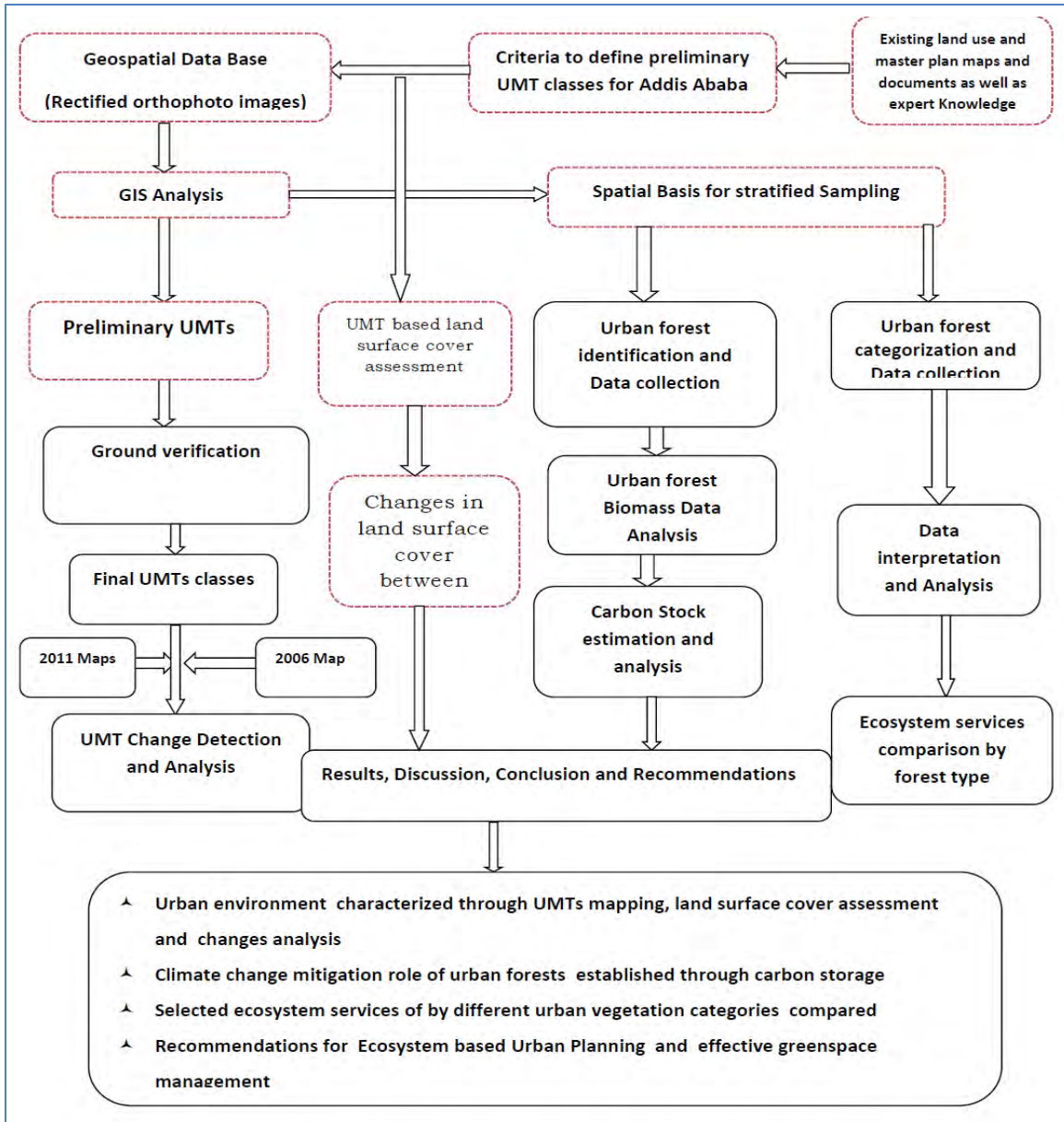
Besides the existing public parks in Addis Ababa are not designed with consideration of the landscape and ecosystem services and thus are not providing the main purposes; rather they have been rented for other functions like restaurants or used by micro and small-scale enterprises for the production of construction materials. Some are not operational and most of the operational parks do not have the necessary facility to be used by visitors.

*(v) Conversion of green space into other land use types:* The conversion of community or neighborhood green spaces and urban agriculture farms into housing and industrial estates is a serious problem in the development and maintenance of greenspaces and its functions in Addis Ababa. Flood prone areas, which should have been used for storm water management and the recharge of ground water, are now continuously converted into other land use types. Therefore, when considering the future development of the urban sphere, one very important key strategic aspect has to do with sustainability considerations that could mainstream green space management with development of other built environment (Dierg, 1999).

### ***1.5 Conceptual framework***

Characterization of the urban environment through UMTs and land surface cover analysis would provide essential information that can be used to disaggregate different components of urban environment into homogenous units that could be managed in the same planning strategies. One of these spatial components is the green space.

A geospatial database was primarily established using the orthorectified high resolution aerial photographs. Land use maps and other structure plan related documents for the city of Addis Ababa were collected as secondary data which helped to define the schematic development of UMTs. Based on the mapping of UMTs a land surface cover analysis was carried. Using the inputs from UMTs, land surface cover analysis and field data on vegetation, soil and other environmental parameters, selected ecosystem services were determined and used for suggesting new approaches for planning and management of green spaces of Addis Ababa (Figure 1).



**Figure 1** Schematic illustration of the research flow

Based on these concepts, the dissertation is organized into five main parts, the first part introduces the general situations and background of the urban environment and ecosystem services dealing with brief introduction, research problem, research objectives and research questions in relation to characterization of the urban environment.

The second part identified discrete components of the urban environment at general and detailed levels as developed through interactions between the biophysical characteristics and human induced modifications of land use practices, through mapping and analysis of UMTs.

The third part dealt with land surface cover assessment and its change analysis with respect to each UMT provided further information on the distribution of evapotranspiring and none evapotranspiring surface cover types which in turn enabled to understand the environmental performance of the different UMTs. This analysis is based on a high resolution rectified orthophoto processing to detect urban land use patterns.

The fourth part focused on the assessment of selected supporting and regulating ecosystem services provided by the urban greenspaces of the upper catchment in general and that of the forest in particular.

The final part of this dissertation has recommended new approaches towards planning and management of urban greenspaces of Addis Ababa based on the spatially disintegrated mapping, analysis and examination of changes in the urban environmental components. The existing situation of the greenspace has been looked into in terms of area shrinkage due to many competitive uses, lack of clearly defined planning and low participation of multidisciplinary professionals which also provided input to developing the recommendations.

### ***1.6 Statement of the Problem***

Worldwide the percentage of population that live in urban areas has been increasing rapidly since 1950s and lack of space makes it tempting to use green areas for new

buildings, thus there is a tendency in many large cities to consider green areas as potential building sites (Yang *et al.*, 2009). This practice of changing greenspace designated areas to built-up and other impervious uses has been common in Addis Ababa largely due to lack of adherence to strict master plan implementation.

Despite efforts to guide the development of Addis Ababa by developing and implementing a master plan since 1936, the emphasis has been on settlements and associated infrastructures while environmental issues including urban greenspaces has been neglected, which led to serious environmental problems conspicuously vegetation degradation and flooding hazards.

In Addis Ababa Greenspace development, conservation and management is characterized by reactive; haphazard; piecemeal and simple purpose (Fetene & Worku, 2013). This must be addressed and replaced by holistic, multifunctional, multi-scale and proactive approaches. To understand the likely impacts and how we can best adapt to changed conditions research at different scales that builds knowledge is crucial (Dierg, 1999; Gill, 2006). Research at city level helps to understand the nature of the urban environment in general and the planning and management of greenspaces in particular, including the multifunctional ecosystem services of greenspaces, climate change impact mitigation and developing climate resilient strategy.

### ***1.6.1 Urban morphology types and greenspace planning***

Although, urban ecosystems conservation has assumed considerable significance in many countries and has close relationship with climate related hazards (Simonds, 2007; Zhao *et al.*, 2011), the absence of sound planning is a major problem in the conservation of urban

ecosystems (Whitehand *et al.*, 2011). Since climatic variables such as rainfall, solar radiation, air temperature and wind are fundamental aspects of the functional components of a built environment; climate change and variability affect urban structures, inhabitants' health, comfort, social life, and energy consumption (Eliasson *et al.*, 2007). Thus, a combination of facets of urban form and function makes the use of green infrastructure an attractive climate adaptation strategy. Moreover, the development and maintenance of greenspaces proportionally equivalent with the built environment may help in storing and sequestering greenhouse gas emissions, reduce urban heat island effects, mitigate any possible flash water flooding effects of pollution. generally it has the potential to increase the resilience of cities to major climate change related impacts (Cavan *et al.*, 2014).

Despite its recognized importance in the study of urban ecosystems services, there were no practices of characterizing the urban environment using Urban Morphology Types (UMTs) that could contribute to the detailed analysis and proper management of greenspaces in sub-Saharan Africa including Addis Ababa (Pauliet *et al* 2014). Characterizing urban environment through UMTs can help to decide on what parts of urban areas should be conserved and used to create an environment suited to human needs and for their local, national and international significances as well (Bandarin, 2006). Understanding the structure of urban environment is also an essential element to devise indicators for assessing trends in the quantity and quality of ecosystem services as well as used to understand the extent, to which these services are being sustained or lost over time, thereby help to devise appropriate policy responses (Layke *et al.*, 2012). It is also used to develop urban management scenarios for informed spatial planning (Lindley

*et al.*, 2007) and could enforce various spatial planning policies on proper service provision (Schwarz *et al.*, 2012). More importantly UMTs are the foundations for many other classification scheme including land cover classifications and brings together facets of urban form and function to put in place suitable management strategies. The applications from the outputs of UMTs characterization would allow urban planners to determine geographical units, which are functional in terms of their biophysical processes and help to integrate spatial units with a planning orientated perspective that could mainstream human activities and natural processes (Gill *et al.*, 2008). Hence analyzing and mapping the urban morphology has paramount importance to understand the development of overall urban form in general and to plan and manage the urban green (Brown & Steadman, 1987; Steadman *et al.*, 1991; Moudon, 1997).

### ***1.6.2 Land surface cover assessment and greenspace planning***

Fast urban expansion has led to replacement of natural vegetated land surfaces by various impervious materials (Whitford *et al.*, 2001; Sterling & Ducharme, 2008; Xu, 2010). The direct impact of this is the rise of urban temperature, increased air pollution and worsening of the quality of life for urban dwellers (Gluch *et al.*, 2006). The vegetation, water and open spaces within and around cities provide many benefits for their inhabitants through reducing temperatures, by cooling through evapotranspiration, storing and reradiating less heat than built surfaces. In addition, green spaces store less heat than built and other impervious surfaces (Meiss, 1979; Oke, 1987). Thus, the greenspace to built-up surfaces ratio is important for the environmental functionality of urban areas (Gill, 2006).

Addis Ababa, the capital city of Ethiopia has been expanding in size following the growth of urban population. According to the Central Statistical Authority of Ethiopia the population of Addis Ababa has increased from 2.7 million in 2007 to 2.9 million in 2011 (UNDESA, 2011). Research findings reported that increasing human population would have brought about progress to the nation, but also brought with it the threat of environmental degradation and increased pressure on natural resources (Xu, 2010).

Fetene & Worku (2013) reported, the ORAAMP (2000) stated about 41% of the area under the city area should be a greenspace, more than half of which is to be covered by forest. However, due to its ambitious nature and limitations of implementation mechanisms a number of issues had been missed including proper classification and demarcation of green space components in the urban environment which had resulted in land degradation and new development encroachments in the upper mountainous catchment areas leading to water runoff, low levels of publicly accessible green space, informal settlements and industries on river banks polluting the water, a loss of urban agricultural lands, and fewer street trees on pedestrian roads. Accordingly, the greenspace resources of Addis Ababa have been depleted and its ecological, economic and social benefits rapidly eroded denying the urban dwellers the opportunity to maximize benefits from the existing greenspace resource.

Therefore, to generate the maximum benefit from green infrastructure it is critically important to identify the key components of the built, evapotranspiring and other impervious surfaces that contribute to complete urban ecological integrity to enhance the ecological services such as regulating and supportive functions (Hough, 2004). One of the key tools to characterize the urban environment is through the UMT based surface

cover analysis. Several studies (*e.g.* Pauleit & Duhme, 2000; Akbari *et al.*, 2003) have shown that the relative proportions of different surface covers vary with urban morphology types, which demands a characterization of the land surface cover within these mapping units.

Knowledge on urban environment with different proportions of vegetated surface would provide key understanding to determine the ecological and physical behavior of individual land parcels, and ultimately the city as a whole with their environmental functions (Whitford *et al.*, 2001; Pauleit *et al.*, 2005). In this regard, establishing UMTs has been believed as key entry to use as basis for the study and analysis of urban surface characteristics in general and the urban green space in particular. Accordingly, UMTs have been developed in the first part of this study to represent the various land use categories of Addis Ababa and a land surface cover assessment is conducted based on these UMTs which were mapped using the high resolution orthophoto for both periods of 2006 and 2011.

### ***1.6.3 Urban Green spaces and ecosystem services***

The Millennium Ecosystem Assessment (MEA) identified four types of ecosystem services (Millennium Ecosystem Assessment, 2005). These are provisioning services like food, fuel, genetic resources, and fresh water, regulating services like soil erosion protection, carbon storage and sequestration, water purification, air quality maintenance, pest control, and temperature regulation, while cultural services contribute to the cultural, spiritual, and aesthetic dimensions of people's well-being and supporting

services maintain basic ecosystem processes and functions such as habitat support to maintain species diversity, soil formation, primary productivity and, nutrient cycles.

#### ***1.6.3.1 Urban forest and carbon storage***

The impacts of greenhouse gases play an important role on earth's climate system where the temperature of the earth's surface is expected to increase following high concentration of greenhouse gases in the atmosphere (IPCC, 2006; Tolla, 2011). In response to large proportion of greenhouse gas emission, urban forest and green spaces play an important role in sequestering and storing carbon in large cities (McPherson *et al.*, 1999; McHale *et al.*, 2007; Strohbach *et al.*, 2012). Several studies (*e.g.* Malhi & Grace, 2000; Fearnside & Laurance, 2004) reported that forest sequesters and stores more carbon than any other terrestrial ecosystem and are an important natural 'brake' on climate change. Others also highlighted that significant reductions in the global flux of CO<sub>2</sub> into the atmosphere can potentially be attained through forestry practices (Hynynen *et al.*, 2005; Gustavsson & Sathre, 2006; Neilson *et al.*, 2006; Fahey *et al.*, 2010).

Trees in urban areas offer benefits in terms of atmospheric carbon reduction through capturing and retaining carbon over long periods of time. They contribute to direct carbon storage and sequestration from fossil fuel and other anthropogenic sources, besides the effect of energy conservation by urban forest are momentous on the amount of carbon released to the atmosphere (Nowak, 1993; Jim *et al.*, 2008).

Urban trees and shrubs can also contribute to capture, store and transform CO<sub>2</sub> into above and belowground biomass through photosynthesis, a process called carbon sequestration, and store carbon in the form of stems, branches, and roots (McPherson,

1998; Jo, 2002; Nowak & Crane, 2002). Despite, urban forest provides significant ecosystem services like storing and sequestering carbon released from fossil fuels and agricultural practices, until recently only limited works have been done that analyze the amount of carbon urban forest can store and the amount of carbon released to the atmosphere (Nowak, 1993). Therefore, for better decision-making on the development and management of urban forest quantification of carbon (C) storage by urban forest is critical for the assessment of the actual and potential role of urban forest in reducing atmospheric CO<sub>2</sub> (Nowak & Crane, 2002; Liu & Li, 2011).

Recently, there has been an increasing interest in estimating the amount of C storage and sequestration by urban forest in both developing and developed countries (Brack, 2002; Jo, 2002; Yang *et al.*, 2005; Myeong *et al.*, 2006). Moreover, landscape planners have given more attention on the beneficial impacts of urban forest on microclimate improvement, air quality, and carbon storage as well as on conservation of biodiversity. Thus, urban forest carbon assessment could provide multiple opportunities for improving urban development planning as well as for scientific studies (Stoffberg *et al.*, 2010; Zhao *et al.*, 2010)

### ***1.6.3.2 Urban green space and plant species diversity***

Urban forest such as in the protected reserves, parks, river sides, along streets, and in institutions can increase property values and commercial benefits (Dwyer *et al.*, 1992; Wolf, 2004). Urban forest with diverse species composition can help to create and enhance wild animal and plant habitats that can act as “reservoirs” for the conservation of endangered species (Howenstine, 1993).

In the city of Addis Ababa particularly at the upper catchment of ‘\_Kebena’ and ‘\_Akaki’ rivers, over 5000 hectares of land are designated as urban forest. However, the city is rapidly growing with industrial and other development activities (Kume *et al.*, 2010; Alemayehu, 2001). These development initiatives within and around the urban area can lead to decreases in forest area and fragmentation of forest stands, which can considerably affect the biodiversity. Previous studies (e.g. Fetene & Worku, 2013) reported that anthropogenic activities in the upper catchment of Addis Ababa have substantially affected the forest, which has contributed to the forest to have low species composition and diversity of woody species. Despite such widespread problems have been continuing over time, there are few studies on the influence of the trees on the city’s environment improvement and the level of resources allocated to the management of urban forest is greatly overlooked.

Therefore, it is critically important to study the green space of Addis Ababa with plant diversity and the species composition therein which might contribute to suggest planning solutions for the sustainable use and conservation of urban forest. Accordingly, this study was aimed to fill the knowledge gap on the ecosystem services particularly at the reserves in the upper catchment of Addis Ababa.

### ***1.6.3.3 Urban greenspaces and protection of soil erosion***

Soil erosion by rain water is central to almost all land degradation problems in the Ethiopian highlands, the Ethiopian high lands reclamation study (FAO, 1986) showed 27 million hectares of land significantly eroded, another 14 million hectares seriously eroded and other 2million hectares eroded to an irreversible level. Soil loss by rain erosion has

been quantified using models and equations like the Universal Soil Loss Equation (USLE) and Modified Universal Soil loss Equation (MUSLE) which are based on estimation of loss of soil quantity per hectare which have many limitations such as setting up of expensive erosion plots, rarely calibrated models for local conditions and unrealistic generalized assumptions leading to unreliable results (e.g. Bergsma, 1992; Kunwar, 1995; de Bie, 2000; Kunwar *et al.*, 2003). The severity and extent of soil erosion is determined by many factors like soil characteristics, degree of slope, rainfall pattern and intensity etc. However, the land cover characteristics and land use systems adapted in a particular area play a dominant role in determining the extent of soil loss and its land deterioration effects.

Evaluation of soil erosion risk by rain water using microtopographic soil erosion features, which are characterized by emerging soil incisions, shallow concentrated flows with linear channels of varying depth but with an upper limit of 30cm (Kunwar 1995, Bergsma 1997b) has been developed as an alternative to the above mentioned models which have the advantages of quick application in a given local area, indicate and compare actual erosion intensity of sites and are non expensively applicable to a range of land use systems (Bergsma,1997b; Kunwar, 1995; de Bie, 2000). These microtopographic features which do not aim at quantifying soil loss per unit area in a given time but used to actually indicate distribution and extent of soil erosion intensity on the field, include eroding clods, resistant clods, flow surfaces, prills and rill erosion features (Bergsma, 1992; Kunwar *et al.* 2003). Observation and recording different types of microtopographic erosion features allows to determine the intensity of erosion and can be compared for different land cover /land use types, thus the method can be used equally well for sites of

annual or perennial crops, forest, plantations and grazing land (Bergsma,1992; de Bie, 2000).

The severity and extent of soil erosion is determined by many factors like soil characteristics, slope, rainfall pattern and intensity etc. However the land cover characteristics and land use systems adapted in a particular area play a dominant role in determining the extent of soil lose and its effects. The type and amount of vegetation cover determines the way rainfall splash is intercepted and its impact on the formation of soil erosion features and subsequent movement of soil material (Xiao *et al.*, 1998; USDA, 2008).

### ***1.7 Significance of the Study***

Developing strategies for urban green space management in the urban environment is a way of ensuring healthy ecosystem that could fit with the demand of urban dwellers and the balance of nature itself. This research showed the importance of characterizing the urban environment through its different structural units in analyzing the greenspace proportions. Spatial and attribute data on urban characteristics using urban morphology types (UMTs) mapping and analysis, its spatial and temporal changes as well as characteristics and changes in land surface covers has been systematically organized and analyzed. The research work focused to understand the nature and importance of the urban environment and its ecosystem services including plant diversity, the carbon storage capacity and erosion controlling roles of particular green spaces. The outcome would help to establish the application of urban morphology types mapping and analysis and land surface cover assessment to discretely characterize the many components of the

urban environment. Besides, it is envisaged to contribute to ecosystem approach based urban planning where environmental issues in general and greenspaces concerns in particular are fully considered, by influencing urban development policy and implementation.

### ***1.8 Research objectives***

The general objective of this research is to study the urban environment of Addis Ababa through the application of UMTs mapping and land surface cover assessment as well as to analyse selected regulating and supportive ecosystem services and their use for greenspace planning.

#### ***Specific objectives***

1. Study the urban environment of Addis Ababa by characterizing through UMTs into distinctive different components using UMTs mapping and its spatial and temporal change analysis,
2. Understand the evapotranspiring environmental performance of the urban environment through the application of UMTs based land surface cover analysis and its temporal and spatial changes.
3. Analyze ecosystem services such as carbon stock, habitat support as well as soil erosion protection functions provided by the urban green spaces of Addis Ababa as categorized in to forest types.
4. Forward recommendations to assist ecosystem based urban planning approaches for effective urban green space management

### ***1.9 Research Questions***

This study has been conducted to address the following questions:

1. What is the spatial and temporal extent of UMTs of Addis Ababa between 2006 and 2011?
2. What is the distribution of land surface cover types across the UMTs and its changes between 2006 and 2011?
3. What is the carbon stock of the peri -urban forest of Addis Ababa?
4. What is the contribution of peri urban forest in supporting the floristic diversity of Addis Ababa?
5. What is the contribution of the forest of the Gullele Botanic Garden in controlling soil erosion?

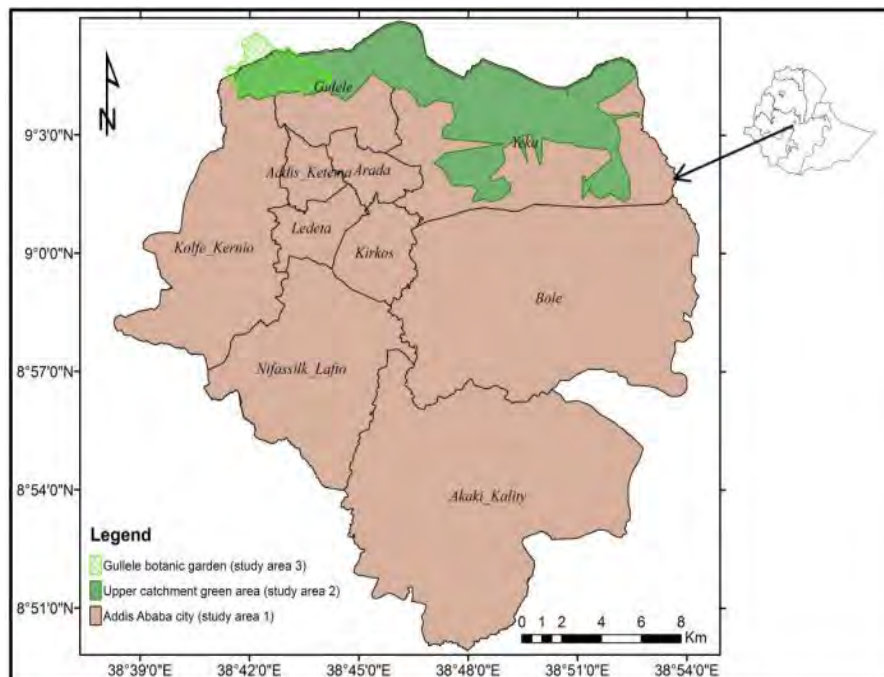
## 2. MATERIALS AND METHODS

### 2.1 Description of the study area

This study has been conducted in Addis Ababa, the capital city of the Federal Democratic Republic of Ethiopia located at the central part of the country. The data collection and analysis process has employed several hardware and soft wares including clinometer to measure the DBH of woody plants, compass to make sure the direction of field sampling process, metric tape to setup the plots as well as AutoCAD 2007, ArcGIS 9.3, SPSS and Sigma Plot soft wares.

#### 2.1.1 Location and topography

Addis Ababa is located between 8°45′ and 9°49′ North latitudes and 38°39′ and 38°54′ East longitudes, within the central part of Ethiopia situated to the western end of the great rift valley and encompassing a total land area of 520 km<sup>2</sup> (Figure 2).



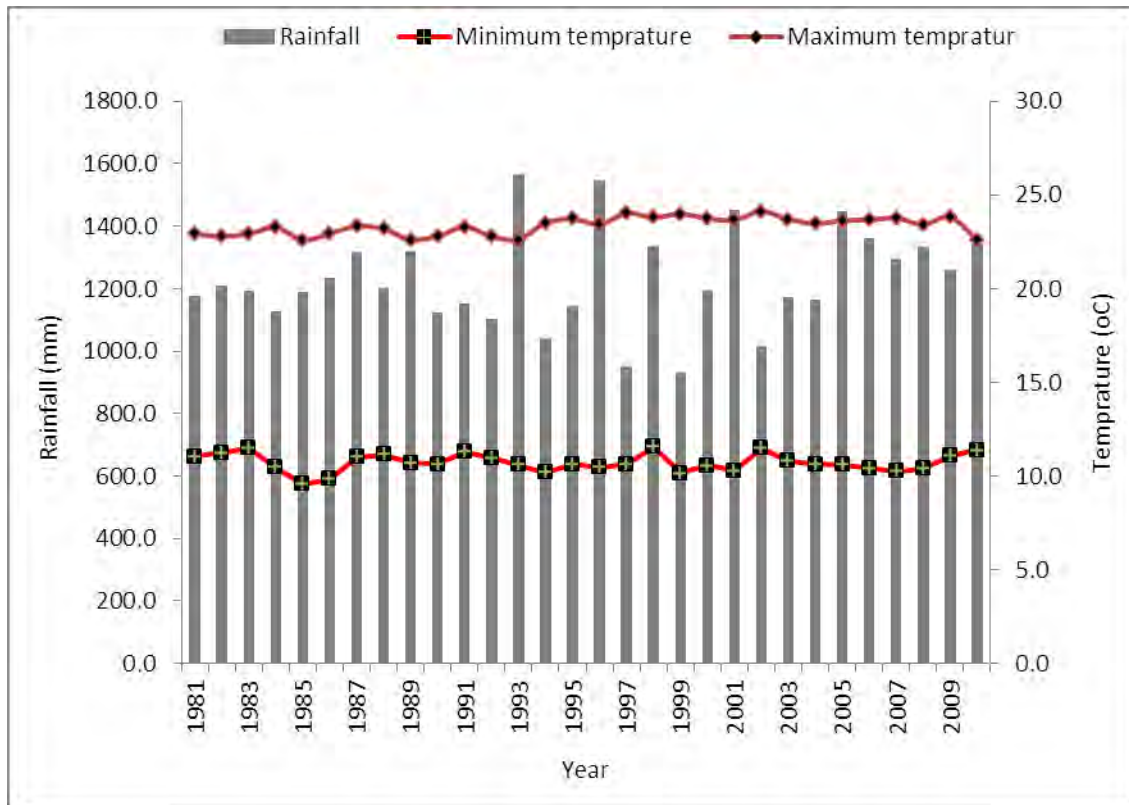
**Figure 2** Map of study area

There is a high topographic variability particularly between the northern and the southern parts of the city, where elevation and slope decreases from north to south. The northern part of the city is part of the Entoto Mountains that stretch east-west direction and characterized by steep slopes with high mountains and flat topped plateaus while the southern part is gentle slope to flat.

Addis Ababa has an elevation ranging from 3200 m.a.s.l at the highest peak of Entoto Mountain to 2200 m.a.s.l at the lower southern part of Akaki plains.

### ***2.1.2 Climate***

A result from the analysis of 30 years climatic data (rainfall and temperature) indicated that Addis Ababa has experienced both dry and wet climate conditions. In fact it did not show clear temporal climate change with respect to rainfall over the periods under consideration; rather it showed rainfall variability from year-to-year. However, the trends from 2005-2010 showed an increasing rainfall well above average and in the 1980s it was almost below average. The total annual rainfall ranged from 929.4mm in 1999 to 1567.9mm in 1993 where the average annual rainfall for the past three decades was 1230.3mm. Climatic data from the National Meteorological Agency of Ethiopia indicated that the mean annual, maximum and minimum temperature in the city of Addis Ababa between 1981 to 2010 was 23.3 °C and 10.7 °C respectively (Figure 3).



**Figure 3** Climatic diagrams of Addis Ababa

Climate change projections (Lindley *et al.*, 2015) also indicated no significant changes in the seasonality of rainfall except slight changes in monthly rainfall while seasonal temperatures are projected to increase by 1.5-2°C although differences in temperature and rainfall patterns occur across Addis Ababa depending on elevation and prevailing winds (Cavan *et al.*, 2014).

### 2.1.3 Drainage, soils and mineral resources

Addis Ababa lies along the water divide between Awash and Abay rivers and its rugged mountainous upper catchment facing the northeast and north-south directions forms part of the Awash River basin. This watershed is represented in part by the Entoto range on the northern fringes of Addis Ababa, which is a combination of deep gorges, incised river

valleys and rolling plains. A number of rivers like big and small Akaki and Kebena, flow through the city from north to south direction and feed the Awash River. This watershed has endowed Addis Ababa with many major rivers and streams viz. Kebena, Little Akaki and Big Akaki as major ones and many streams like Ginfile, Bantiket, Kechene as medium to small streams all flowing from north, northwest and northeast of Addis Ababa, converging at the south and draining to the Awash River.

Various soil types are observed within the city and its surrounding. The northern part of Addis Ababa, which is characterized by steep slopes and where the parent materials are highly resistant to weathering are predominantly red clay soils. The southern, central and south western parts of the city are mostly black cotton soils or vertisol, which show marked shrink and swell in relation to their moisture regime. The vertisol is very difficult to plough and requires additional inputs and considerations for agricultural use. Addis Ababa is underlain by rocks of volcanic origin mostly basalts and ignimbrites as well as clays abundant in the northwestern part of the city and has become important source of inputs for the construction industry.

#### ***2.1.4 Green spaces, floral and faunal resources***

Historically Addis Ababa was covered with natural indigenous vegetation which belongs to Afro-montane forest and woodland. The natural forest had been dominated by indigenous trees such as *Juniperus procera*, *Olea europaea subsp. cuspidate*, *Hygния abyssinica*, *Hypericum revolutum* and *H. quartinamum*, *Podocarpus falcatus* and *Acacia abyssinica* in some of the more disturbed valleys. *Erica arborea* appears where the altitude goes over 3,000 m.a.s.l. Shrubs include species with fleshy fruits like *Rosa*

*abyssinica* and *Carissa spinarum* which attract fruit eating birds. The number of herbs both in the undergrowth of the forest and in the meadows is very large. In addition to the above mentioned species *Vernonia amygdalin*, *Croton macrostachyus* and *Euphorbia abyssinica* are common inside the grounds of churches, palaces and other historical institutions. The indigenous vegetation provides great value as wildlife reservoir and maintains the ecological balance of the environment.

At the turn of the 20<sup>th</sup> century, with the city development and population growth nearly all the woody vegetation within and around the city were removed due to agricultural expansion and the need for fuel and construction wood by the town dwellers and the surrounding farmers. A continued urban sprawl further demanded its toll on urban forest and green spaces for many years and until now. Despite efforts in designating of greenspaces with the city master plan, its implementation guidelines and procedures as well as its multiple benefits particularly for the urban poor who depend on forest for livelihoods and seriously affected by environmental degradation, only few patches of natural vegetation remained in the forest, around historical churches, palaces, compounds of old embassies, schools and recreational parks, while the entire Entoto range has been mainly covered with Eucalyptus plantation, viz. *Eucalyptus globules*, *Eucalyptus camendulesis*, *Eucalyptus citrodora* respectively in abundance and other commonly existing exotic plants include *Pinus*, *Accacia*, *Cupressus*, *Ficus*, *Grevillea*, *Jacaranda* and *Albizzia species*. It should also be worthy to mention that Addis Ababa specifically the Entoto area has been a sanctuary habitat for various wildlife resources.

### ***2.1.5 Socioeconomic development and governance***

Addis Ababa, the capital and largest city of Ethiopia founded in 1887 during the reign of Emperor Menelik, now a chartered city, enjoys an autonomous legislative, executive and judicial power with partial accountability to the federal government. Its population of 3,041,002 people in 2011 is set to increase to 4.7 million by 2025, corresponding with an average annual growth rate of 3.3% (UNDESA, 2011). Its administrative hierarchy is structured into three tier arrangement, the city level being the highest which oversee the ten sub cities, a middle level body accountable to the city and oversee the districts the grass root level administrative bodies ranging 10 to 12 in number under each sub city and currently totaling 116. Addis Ababa hosts the African Union, the United Nations Economic Commissions for Africa and other international and multilateral institutions, because of which it has earned the name, diplomatic capital of Africa.

### ***2.2 Methods***

Based on the purpose of the study, availability of resources to collect data, the study area was purposely grouped into three categories to study the urban environment, assess ecosystem services and to put planning strategies for the management of green spaces. These include the whole part of Addis Ababa for the analysis of UMTs and land surface cover types (study area 1), the peri urban upper catchment forest area for the analysis of carbon storage (study area 2) and the Gullele Botanic Garden, which is part of the upper catchment forest to analyse selective ecosystem services (study area 3) (Figure 2).

### **2.2.1 Urban Morphology types (UMTs) Mapping**

UMTs mapping for the City of Addis Ababa was conducted based on aerial photograph interpretation. This approach has been increasingly adopted for urban ecological studies of major cities in Europe (*e.g.* Gill *et al.*, 2008; Pauleit & Breuste, 2011) and it is recognized as a useful framework for characterizing the urban structure and its green component. UMT mapping has considerable benefit for assessing the detail urban structure, which are typically not included on land use maps. It is indicated that understanding UMTs enable to combine and or link human induced activities and natural processes within a spatial unit with the underlying assumption that UMTs have characteristic physical features and typical human activity indicators arising from land use practices (Gill, 2006).

Although many urban ecologists and planners adopted the general UMT methodology (Gill *et al.* 2008), a new classification was developed for Addis Ababa to suite to its unique settings in relation to the regional climate variations and level of urbanization (Lindley *et al.*, 2015). Accordingly, a first set of UMT classes were developed through the collaboration of the Climate Change and Urban Vulnerability in African Cities (CLUVA [www.cluva.eu](http://www.cluva.eu)) project researchers and stakeholders in a meeting and field visit to pertinent sites. Then UMT classification schemes were applied using reference aerial photography, local knowledge and additional geospatial data and grouped into primary and detailed levels of UMTs.

For the purpose of this study the reference years considered were 2006 and 2011; due to the availability of a high resolution aerial photographs from the Addis Ababa City

Institute of Urban Planning and Information. The UMT maps were produced by digitizing the ortho-rectified aerial photographs and verifying with field assessments as well as communicating with local stakeholders (Gill, 2006; Lindley *et al*, 2015) following the method developed by the University of Manchester and the Technical University of Munich and tested primarily for Manchester and Munich Cities (Gill *et al.*, 2008, Pauleit & Breuste, 2011).

UMT mapping and description for the Addis Ababa involved several steps beginning with critical review of existing master plan documents evolved through broad land use classifications. After the initial analyses showed that existing land use classes were not detailed enough for the objectives set by the research project, (partially to test the UMTs applied in Manchester and Munich for African cities) a new classification scheme was developed and a pilot study taking a transect covering representative set of urban morphological types running from the forested mountainous northern part, towards the southern industrial and farming sites was carried. The transect piloting enabled for developing a refined classification scheme besides providing an overall estimation for task finalization i.e. the time, man power and other resources needed for digitizing, ground truthing etc. Transect piloting was undertaken using aerial photographs of 2006 secured from the Addis Ababa city Institute for Urban Planning and Information. These aerial photographs were taken in December 2005 by Geo-Maps at a spatial resolution of 0.2m and processed to a rectified ortho-photo image in 2006 at the scale of 1:2000 for the purpose of developing land information systems.

Discussions within the CLUVA team as well as concerned city administration stakeholders on the outcome of the transect piloting led to minor changes from the originally

developed UMT classification categories. Reasons for modifying the classification scheme include consistent use of names and terminologies appropriate with realities on the ground as well as facilitate easy communication with local urban planners and development practitioners, being the main users of the research outcomes. Following the effective completion of transect piloting final UMTs units scheme was developed and preparation of the geospatial data base, preparations for digitizing, including exercise and training in digitizing and ground truthing works was the final stage to proceed to on screen digitizing using AutoCAD 2007 as well as editing and visualization with ArcGIS 9.3 software at a scale of 1:15000. Once the piloting and readjustments of the UMTs classification was accomplished characterization of the urban environment of Addis Ababa through UMTs mapping for 2006 and 2011 was conducted using rectified ortho-photo images.

### ***2.2.2 Urban Morphology Types change detection and analysis***

Changes in UMTs of Addis Ababa between 2006 and 2011 has been detected, mapped and analyzed using various GIS techniques which went through several steps viz. compiling vector and raster datasets, optimization and standardization of datasets, generation and classification of difference map and production of the final change map. The data used for generating change map is the vector files of UMTs maps of 2006 and 2011 sourced from aerial photos (ortho rectified images). The areal extent of Addis Ababa being reasonably large data processing was possibly prone to topological errors, thus, steps of schema optimization, topology running on both vector datasets, raster dataset creation from vector files, overlay analysis and classification through attribute data manipulation were undertaken with strict precautions to ensure accuracy.

The first task preceded all digital data processing works was schema optimization where coordinate systems of the two vector files representing UMTs of 2006 and 2011 were brought to a uniform file structure by optimizing their properties and coordinate systems (Rolf, 2004). Displaying topological relationships, errors, exceptions and editing in data automation framework to create, maintain, and validate topological integrity of the output map was conducted in Arc GIS environment. By running topology, features in the datasets with no slivers, overlaps were removed and data integrity maintained. Some pocket features with no attributes in both data sets were verified and updated using source raster images. The vector datasets was converted into respective raster datasets to produce difference map through image analysis. Once the two raster files had been generated through conversion, difference map showing the changed and unchanged features, was produced through image analysis which requires a pixel over pixel comparison and computed using perfectly aligned image data sets.

The main task in generating the final output of a change map was to carry out an overlay analysis which is the important analytical process in ArcGIS. In the process of generating the change map, all features and their attributes were written to the output file. The process of overlay analysis determines the spatial reference for processing and projections of all input feature classes into the spatial reference (Rolf, 2004).

Based on the comparison analysis of the 2006 and 2011 UMT maps, the dynamism of each UMT class was classified and for each higher level or primary and detailed UMTs the spatial extent was calculated with respect to the referenced years. Accordingly, the magnitude and rate of change between the years 2006 and 2011 was computed. The magnitude of change was computed just by taking the differences in spatial extent

between the two referenced years and the rate of change for each UMT was calculated based on the following equation (Long *et al.*, 2007; Martinez *et al.*, 2009):

$$\Delta = \frac{T2 - T1}{T1} \times 100$$

Where:  $\Delta$  = Rate of change (%)

T1 = Amount of UMT cover in time 1

T2 = Amount of UMT cover in time 2

Conversion matrix for higher level or primary UMTs was employed to analyze the source and destination of each Urban Morphology type. The UMTs conversion matrix analysis was conducted and each UMTs change values were analyzed to clearly show the source and destination of urban morphology types.

### ***2.2.3 Land surface cover analysis***

The fundamental prerequisite for land surface cover assessment is the UMT mapping (Gill, 2006; Nowak *et al.*, 2003; Pauleit & Duhme, 2000; Breuste, 2009), which allows delineation of morphological or physiognomic homogeneous units designated as UMTs. This must be undertaken earlier and from which samples are drawn for precise results (Nowak *et al.*, 2003). It has been tested for Manchester city (Gill, 2006) and involves assessment of the land surface cover based on Urban Morphology Types (UMTs) in which land cover types are traced from the UMTs, using a combination of GIS and statistical techniques. The methodology involves several sequential steps applying GIS and statistical techniques where classification of primarily typical land surface cover types are established using specific defining characteristics.

A stratified random sampling technique was employed in conjunction with aerial photograph interpretation of the different surface cover types. The UMTs mapping of 2006 and 2011 derived from aerial photographs were served as a base for surface cover analysis. Akbari *et al.* (2003) suggested that a sampling method based on aerial photograph interpretation was the most accurate approach. The entire city area was divided into fairly homogeneous UMT units that could reduce the variance of the estimates, thereby leading to more precise results (Nowak *et al.*, 2003). Determining how many points should be allocated to each UMT class was not straightforward. Gill (2006) and Gill *et al.* (2008) demonstrated that use of an acceptable level of standard error was found to be robust to validate that point sample numbers represent land surface cover proportions. The following formula was used to come up with the acceptable level of the standard error,

$$SE = \frac{\sqrt{pq}}{n}$$

Where

p is the proportional cover,

q = 1 - p, and n is the number of samples (Table 1).

Gill (2006) found that use of different sample sizes for different proportional covers resulted in different level of standard errors and demonstrated that a random distribution of 400 sample points within a given UMT unit achieved a maximum standard error to achieve the required 95% confidence, where the true value is within  $\pm 5\%$  of that sampled. Thus a random distribution of 400 sample points over a given UMT category regardless of its area coverage and level of proportional cover would result in the required standard

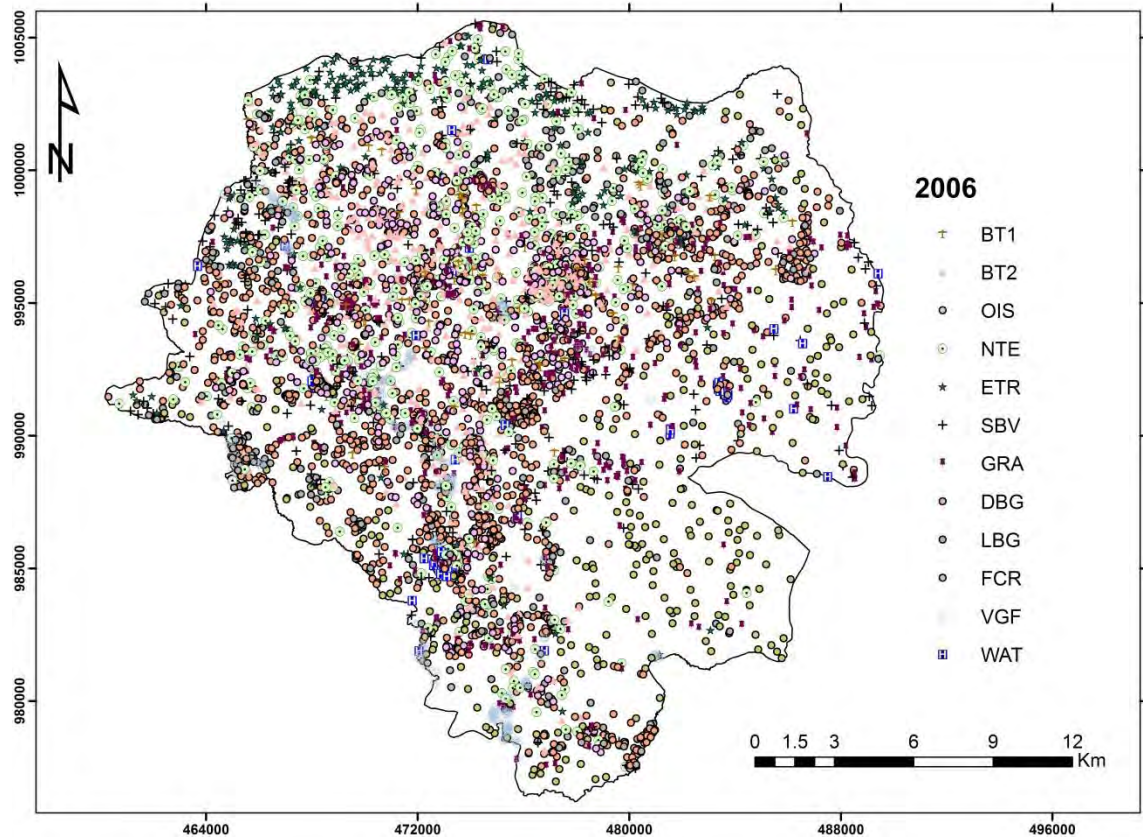
error. A summary of the work by Gill (2006) to achieve the required standard error is shown below:

**Table 1** SE for different sample sizes with proportional covers of 10% and 50%

Sample size (n )	Standard Error (SE) at two different proportional (p ) covers	
	at 10%	at 50%
100	0.03	0.05
200	0.021	0.035
400	0.015	0.025

Source: Gill (2006)

The study by Gill (2006) indicated that it is possible to achieve the required standard error using different number of sample points in relation to the area size of a given UMT which also enabled efficient use of time and resources. Thus it was further tested and standardized by the CLUVA research during the initial period of this study taking the density of sample points used in the Manchester work (11,600 sample points for the entire area of 1300km<sup>2</sup>) which is about 9 points/ km<sup>2</sup>) in to consideration distribution of sample points at the rate of 10/km<sup>2</sup> keeping a minimum of 100 and a maximum of 400 sample points per UMT resulted with acceptable or required standard error in one of the CLUVA test cities, Dar es Salaam City (Pauleit *et al.*, 2014).



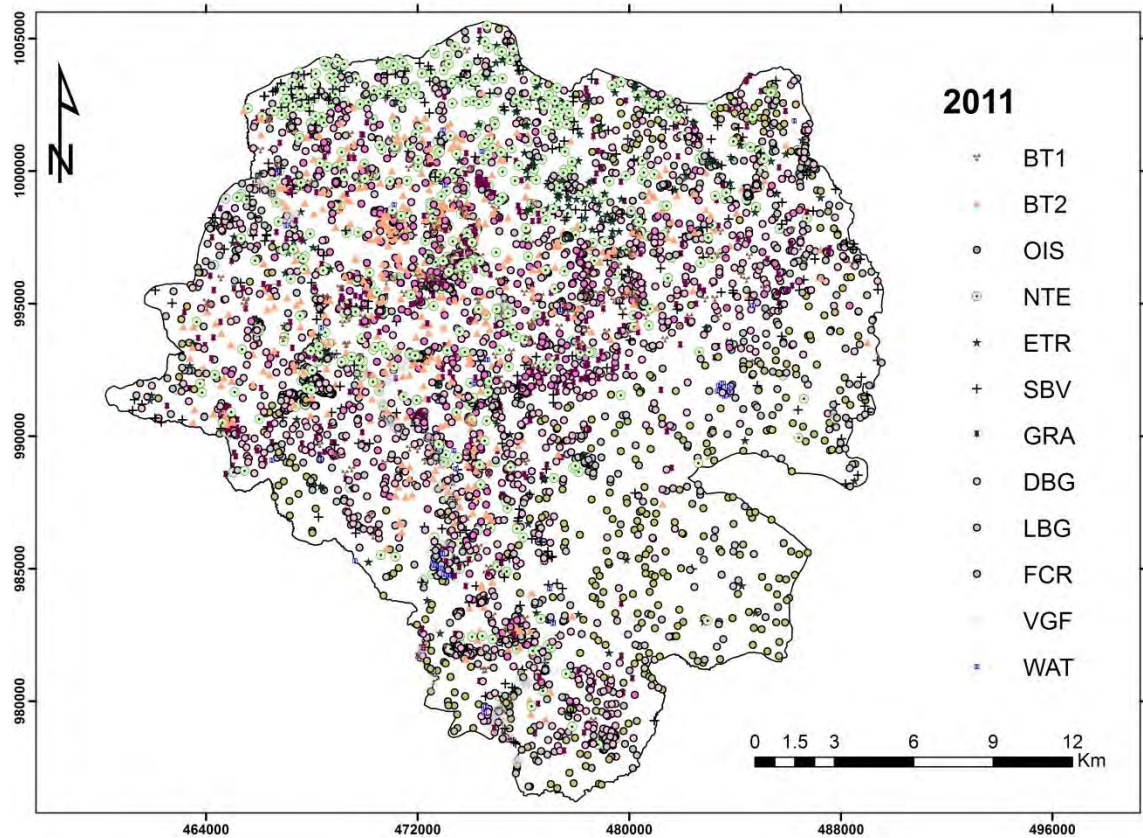
**Figure 4** Distribution of 2006 land surface cover sample points

Thus in the present study a random sampling to achieve 95% confidence ensuring that the true value is within  $\pm 5\%$  of that sampled has been applied for the proportional covers of 10% and 50% and randomly distributed irrespective of the area covered by the UMT category and the size and arrangement of the surface cover categories. A Summary of the test result is shown below.

**Table 2** SE for different sample sizes with proportional covers of 10% and 50%

Sample size (n)	Standard Error (SE) at two different proportional (p) covers	
	at 10%	at 50%
100	0.030	0.050
200	0.021	0.035
300	0.017	0.029
400	0.015	0.025

A total of 7500 sample points were then distributed over the 35 detailed UMTs for an area of 520km<sup>2</sup> bringing the density of sample points to 15/km<sup>2</sup> well above the average used in the Manchester city study (Gill, 2006; Gill *et al.*, 2008).



**Figure 5** Distribution of 2011 land surface cover sample points

The delineation of UMTs characterized the urban environment in to discrete land use based morphological or physiognomic units (Gill, 2006; Breuste, 2009) through which it also was possible to visualize the major land surface cover types where some UMTs found to be dominated by built-ups, others by impervious surface and or vegetated cover. However a given UMT is found to include many land surface cover types, thus a further environmental characterization is achieved through land surface cover assessment. This analysis enables to establish land surface cover types within a given UMT and compare

land surface covers between UMTs which gives crucial information to understand and determine the environmental functions related to land surface cover types (Gill *et al.*, 2008).

Determining the type of land surface cover classes depends mainly on the intended use of the data and the resolution of the image. The data requirement by different working groups in the CLUVA project and the resolution of the orthophoto image to identify different land cover classes were important criteria in defining the current twelve land surface cover classes for Addis Ababa using different techniques and software like ENVI4.3 and ArcGIS 9.3. The methodology involved several steps through the application of GIS and statistical tools including determination of sample points to each UMT class, preparation of spatial data base, dissolving of same UMT polygons, defining typical representative land cover classes with source image characteristics.

A multi-part polygon output (i.e. with one single polygon record) was used to dissolve the polygon feature by UMT class and a set of random points using the new single UMT, multi-part feature class (layer) was created as a constraining layer.

The twelve land surface cover categories developed for Addis Ababa include: built structure I (well planned and high rise buildings), built structure II (informal, generally unplanned, and non-high rise buildings), other impervious, other none-eucalyptus trees, eucalyptus trees, shrubs, grass, dark bare ground, light bare ground, field crops, vegetable crops, water body) for both 2011 and 2006 (Figure 6). Determining the type of land surface cover classes depends mainly on the intended use of the data and the resolution of the image. The data requirement by different working groups in the CLUVA project and

the resolution of the orthophoto image to identify different land cover classes were important criteria in defining the current twelve land surface cover classes for Addis Ababa using different techniques and soft wares like ENVI4.3 and ArcGIS 9.3. The methodology involved several steps through the application of GIS and statistical tools including determination of sample points to each UMT class, preparation of spatial data base , dissolving of same UMT polygons, defining typical representative land cover classes with source image characteristics (Gill *et al.*, 2008).

A multi-part polygon output (i.e. with one single polygon record) was used to dissolve the polygon feature by UMT class and a set of random points using the new single UMT, multi-part feature class (layer) was created as a constraining layer.

Once land surface cover classes were established, a geospatial data base using the rectified orthophoto employed to map and analyse the UMTs for both periods of 2006 and 2011 were created. With the help of GIS techniques each UMT unit is independently selected and the many polygons belonging to same UMT were dissolved in to one unit. The predetermined number of sample points was then randomly distributed within the dissolved UMT units. Finally each point was traced and named using the ArcGIS select method, by the appropriate land surface cover class to which it belongs.

Built structure type II



Built structures type I



Other impervious surfaces



None-eucalyptus trees



Eucalyptus trees



Shrubs/bushes



Dark bare ground



Light bare ground



Grassland



Field crops



Vegetable fields



Water body



**Figure 6** Land surface cover types

***Description of surface cover types***

<b><i>Land surface cover</i></b>	<b><i>Description</i></b>
<i>Built structure type I (BT1)</i>	This land cover represents buildings of well-planned and high raising type
<i>Built structure type II (BT2)</i>	This land cover represents buildings of informal and none high rising types.
<i>Other impervious (OIS)</i>	Surfaces which are sealed and do not allow water to pass through like roads, pavements, airports
<i>None eucalyptus trees (TNE)</i>	This cover type consists trees of mixed types other than eucalyptus, which is characterized by areas with contiguous vegetation cover.
<i>Eucalyptus trees (ETR)</i>	This represents the Eucalyptus dominated forest trees, In many cases eucalyptus and other tree species are found to be in combination and it is likely to be difficult to come up with precise cover class between these two
<i>Shrubs/bushes (SBV)</i>	This represents smaller trees and shrubs with low canopy cover and relatively smaller growth height
<i>Grassland (GRA)</i>	These are found adjacent to farms and also as pockets in the forest areas. Compared to what is grassland else where it is not wide and typical

but it varies from the field crops and vegetable farms and is relatively green throughout the year used as grazing land by farmers

*Dark bare ground (DBG)* This represents bare ground surfaces without any vegetation cover and field patterns. Most of these areas are abandoned old quarry sites

*Light bare ground (LBG)* These areas are surfaces with no vegetation cover and no cultivated field patterns. Most of these represents the freshly opened quarry sites but also depends on the soil type. In the Northwest and Western part of Addis where there is a dominantly brown soil even if the quarry site is new it appeared as dark bare ground

*Field crops (FCR)* These areas include tef (*Ergrostis teff*), the most important staple food in many parts of Ethiopia) and wheat farming land which are fed with rainfall once per year. The fields are green only between June and September (rainy season)

*Vegetable farm (VGF)* The land cover here is cultivated vegetable. Associated areas are recorded through the UMTs, mostly located along the riversides where the most common types of vegetables,

like tomato, potato, cabbage, etc. are grown using irrigation, and thus it is green almost throughout the year

*Water body (WAT)*

This is to be recorded as a land cover class but this is of minor importance in the context of Addis Ababa. Water cover associated with rivers and streams are expected to make negligible contributions to land cover assessments in a limited number of UMT classes

**Table 3** Randomly distributed sample points count by land surface cover types

No.	Land surface cover	Land surface cover		point counts	point (%)
		Land surface cover	Abbreviation		
1	Building type I		BT1	173	2.31
2	Building type II		BT2	984	13.12
3	Other impervious		OIS	891	11.88
4	None-eucalyptus trees		TNE	736	9.81
5	Eucalyptus trees		ETR	270	3.60
6	Shrubs/bushes		SBV	417	5.56
7	Grassland		GRA	788	10.51
8	Dark bare ground		DBG	1892	25.23
9	Light bare ground		LBG	701	9.35
10	Field crops		FCR	333	4.44
11	Vegetable farm		VGf	244	3.25
12	Water body		WAT	71	0.95
Total				7500	100

## ***2.2.4 Assessment of ecosystem services***

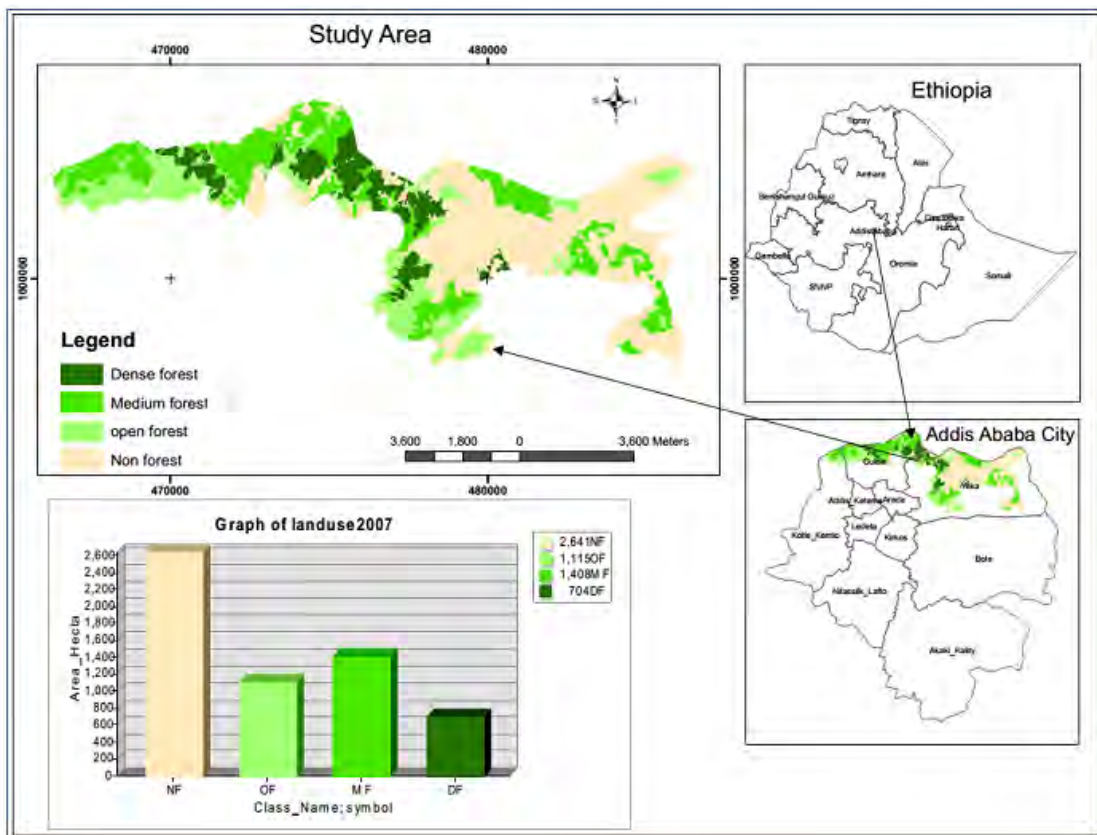
### ***2.2.4.1 Estimation of biomass and carbon storage***

The study area for biomass and carbon study was purposely focused on the upper catchment forest of Addis Ababa. This area was selected for biomass study because it is relatively protected, having mosaic forest land and is able to fit to analyse carbon storage. Even though, the study area is considered to be within a relatively uniform ecosystem conditions, the vegetation cover shows some spatial variability in the form of patches with different tree stock density, which has a direct relationship with carbon stock estimation. Thus, such heterogeneity of the sites needs to be stratified in to more homogeneous forest or vegetation cover types.

In this study for the purpose of woody biomass study, the vegetation in the upper catchment area was considered and stratified into dense, medium and open based on the tree stock density (WBISPP, 2000). This stratification system reduces the variation within the forest types and increases the precision of the population estimate (Husch *et al.*, 1982).

The forest categorization in to dense, medium and open forest strata began first by studying how the method was applied by the WBISPP (2000) in woody biomass vegetation inventory in many parts of Ethiopia in general and around Addis Ababa in particular followed by a reconnaissance survey to look and bring homogeneity and reduce heterogeneity of the population of the study area. Secondly, the image characteristics of the forest cover were carefully examined using a rectified orthophoto. The on screen study and inspection of the orthophoto helped to identify the different strata based on

forest stock of the sites. Thirdly, field evaluation (ground truth verification) was conducted by taking GPS points with respect to the vegetation type under consideration and finally, classification into three forest strata and calculation of total area as well as of each stratum were made (Figure 6). Then, transect lines were laid along the elevation gradient to put sample plots for the collection of vegetation data that could be used to calculate biomass and carbon stock.



**Figure 7** Forest category based on canopy cover types

The required number of plots for the study area was determined based on the total target survey area taking it as a "compilation unit" and the forest types were mapped using the orthophoto in conjunction with reconnaissance survey and ground truthing to arrive at "optimum" allocation of plots. The "optimum" allocation was done in proportion to (i)

the standard deviation of the weighted mean of the woody biomass stock in the specific forest stratum (in air dried tons/ha) and to (ii) the weighted area of the given forest stratum to the total forest area of the compilation unit. The required number of sample plots for the whole compilation unit was calculated using the following formula (eq. 1) for a "stratified random sampling that enabled to achieve an optimal allocation of plots (Husch *et al.*, 1982).

$$N = t^2 \{ \sum (W\delta) \}^2 / EV^2 \dots \dots \dots (eq. 1)$$

*Where:*

*t* = *t of Student:* the t value from the table of Student is for a specific level of probability, usually a level of probability of 95% confidence is targeted for in forest inventories.

*w* = *Proportion of a forest strata:* the proportion of a forest stratum i.e. occupied by a given forest strata in the compilation unit which is obtained from the image interpretation.

*δ* = *standard deviation:* the standard deviation or the coefficient of variation in (%) is the air dried wood biomass of the forest stratum calculated from the woody biomass inventory and strategic planning project (WBISPP 2000, and 2005).

*EV* = *Sampling error:* The sampling error of the estimated woody biomass stock at the specified level of probability, in this case 95%, the stock being air dried in tons/ha. The sampling error is commonly first defined in terms of percentage instead of the real value in terms of tons per ha.

The required (%) usually targeted for the main types of forest inventories is worked by taking the sampling accuracy or precision of 100% minus the level of sampling error (%). The common level of precision in forest inventories is thus a maximum precision of 100% minus an acceptable level of standard error of 15% = 85%. To convert the sampling error in Percent (**EV %**) into a real value of tons/ha the following equation is used,

$$EV = E(\%)MCU(Y) \dots \dots \dots (eq. 2)$$

Where MCU (Y) is the weighted mean value of the compilation unit, obtained by summing the average stock values (M(Y)) of each forest stratum and multiplied by the proportion (**W**), of a given forest stratum in the total area or compilation unit.

$$MCU(Y) = \sum\{W * M(Y)\} \dots \dots \dots (eq. 3)$$

It should be noted that the weighted sampling error of all the forest strata in a compilation unit should not exceed 15% of the true mean at 95 percent level of probability. To allocate the required number of plots per forest strata the following formula has been used:

$$n = \frac{\{(w * \delta)\}}{* [\sum\{(w * \delta)\}]N} \dots \dots \dots (eq. 4)$$

Where: n = number of plots required per forest stratum

W = proportion of area covered by a specific forest stratum in the given compilation unit

δ = Standard deviation of the mean weight of the biomass stock of a strata

N = total number of sample plots required for whole compilation unit (total study area).

**Table 4** Area data from satellite image interpretation

Stratum	Area (ha)	W	M(Y)	$\delta$
Dense forest	704	704/3227 = 0.2181	151	65
Medium forest	1408	1408/3227 = 0.4363	101	65
Open forest	1115	1115/3227 = 0.3455	70	65
Total	3227	-	-	-

Using  $M(Y)$  and  $\delta$  from the above table (1) and t from the student table (shown above as t = 1.96 for a large population with 95% probability), the total number of sample plots for the compilation unit is estimated using equation number one which is repeated here

$$N = t^2 \{ \sum (W\delta) \}^2 / EV^2 \dots \dots \dots (eq. 1)$$

and by substituting the values step by step as below the total number of samples required was worked out.

(a)  $\{ \sum (w \delta) \}^2 = (0.2181 * 65) + (0.4363 * 65) + (0.3455 * 65) = 64.9$

(b)  $t = 1.960$  (for large population with 95% probability) and  $t^2 = 3.8416$

The real value of the sampling error ( $EV^2$ ) in tons/ha is calculated using the formula,

$$EV^2 = EV\% * MCU(Y)$$

and by substituting the values in to the equation,  $MCU(Y) = \sum \{ W * M(Y) \} = (0.2181 * 151) + (0.4363 * 101) + (0.3455 * 70) = 84.75$

**EV** = acceptable margin of error = 20% of the average stock of the whole compilation unit. i.e.  $20\% \text{ of } MCU(Y) = 0.2 * 84.75 = 16.95$ . Then by substituting the values in to equation 1.  $N = \frac{(1.96)^2 * (84.75)^2}{(16.95)^2} \approx 100 \text{ plots}$ .

The allocation of the required number of plots to each forest strata (n) has been performed using the equation,

$$n = \{(w * \delta) / [(w * \delta)]\}N.$$

**Table 5** Allocation of the required number of plots to each forest strata

<b>Stratum</b>	<b>W</b>	<b>δ</b>	<b>W* δ</b>
Dense forest	0.2181	65	14.17
Medium forest	0.4363	65	28.35
Open forest	0.3455	65	22.45
<b>Total</b>	-	-	<b>64.97</b>

Substituting the values for each stratum and approximating to the nearest value the outcomes are 40 plots for the medium forest, 35 plots for the open forest and 25 plots for the dense forest, making a total of 100 plots for the entire study area. The number of transects in a given forest stratum was also determined by dividing the total number of plots in a stratum to the number of transect lines which become 9, 7 and 5 transects for medium, open and dense forest categories respectively and plots were laid in each transect accordingly.

The start point of each transect line in the study area 2 (section 2.1.1) were located randomly, however, this was balanced against ease of access with cost considerations,

location of the forest in relation to its proximity to road access. Rectangular plots of main plot 20m x 20 m to collect data of woody plants of diameter at breast height (dbh)  $\geq$  20 cm and a sub-plot of 7m x 7m for woody plants having dbh between 10cm and 20 cm as well as another sub plot of 2mx2m for all those woody plants having dbh between 5 cm and 10cm were employed (Brown *et al.*, 1989). Plots were located at every 100 meters along the transect line. The use of a gap between plots enabled to statistically treat plots as independent of each other, besides; it make easy and efficient to design and reduce confusion, possible errors, helping to produce a reliable data.

In all strata, species, dbh, plant height, GPS coordinate points; altitude, slope were recorded. Samples of 100 plots were investigated in this study and the plot number of each urban forest type was determined according to the area of each forest type and its within-type variance of urban forest structure, including species diversity and dbh distribution of trees.

The estimations of above and below ground carbon depend on the above ground biomass of living trees and the type of forest structure as well as species composition. Therefore, to determine carbon storage, it is essential to identify the species composition in the forest and study the forest structure. Plant identification was conducted using Flora of Ethiopia and Eritrea (Hedberg *et al.*, 2004) and useful trees and shrubs for Ethiopia (Bekele *et al.*, 1993) as guiding references. For those species difficult to identify in the field, fresh specimens were collected and then pressed properly for identification at the National Herbarium of Addis Ababa University. This was accomplished by comparing the species which could not be directly identified on site, taken to the national herbarium and compared with herbarium specimens already identified and described.

To quantify above and below ground woody biomass for the surveyed woody vegetation, biomass equations were used to calculate the dry biomass. The biomass of an individual tree carbon stock in living trees is typically calculated using allometric equations that express aboveground tree biomass as a function of diameter at breast height (DBH) (Brown *et al.*, 1989 & 1997; Luo, 1996; Wang, 2006). These equations provide for the calculations to be performed for each stratum. Tree biomass is converted into a hectare value using size of corresponding plots. Carbon content is 0.50 of biomass and total biomass was calculated by forest stratum (Brown, 1997; FAO, 1997).

For above ground biomass estimation, different mathematical equations have been developed and used by many researchers (Brown *et al.*, 1989; Negi *et al.*, 1988; Clark; *et al.*, 2001; Phillips *et al.*, 2002; Chave *et al.*, 2004). These biomass equation methods are nondestructive and are most suitable methods for carbon stock estimation (Brown, 1997; FAO, 1997). The equation taken for the present study is,

$$Y = 34.4703 - 8.0671(\text{DBH}) + 0.6589(\text{DBH}^2)$$

Where, Y is above ground biomass,

DBH is diameter at breast height;

Out of the various allometric equations the above one has been selected for this study, due to the fact that it has been developed and tested to estimate above ground biomass of woody vegetation (Brown *et al.*, 1989) in regions where the climate is dry with an annual rainfall of <1500 mm and the woody vegetation is with a dbh of  $\geq 5$ cm. The amount of biomass in each species using the above equation was calculated and summed up to find the total biomass stock in each plot and then converted to a per hectare basis. To come up with the total biomass below ground it was calculated based on above ground-below

ground biomass relations function. One of the most common applications of the relationship between root (below-ground) and shoot (above-ground) biomass is the root-to-shoot ratio (Cairns *et al.*, 1997; Brown, 2002). Thus, to simplify the process for estimating below ground biomass, ratio of root-to-shoot of 1:5 was used (MacDicken, 1997) because 20% of the above ground biomass is equal to the total amount of below ground biomass, in other words below ground biomass is proportional to 20% of the above ground biomass. In this regard, below ground biomass was estimated by multiplying the above ground biomass by a factor of 0.2 (belowground biomass = aboveground forest biomass  $\times$  0.2).

*Estimation of carbon density:* the total carbon stock is calculated by summing the carbon stock densities of the individual carbon pools (above and below ground) of the three forest stratum (dense, medium and open) using the Pearson *et al.* (2005) formula who suggested that carbon stock density can be calculated as:

$$C \text{ density} = CAGB + CBGB$$

*Where,*

C density = Carbon stock density for all pools [tone C/ ha]

C AGB = Carbon stock in above -ground [tone C/ha]

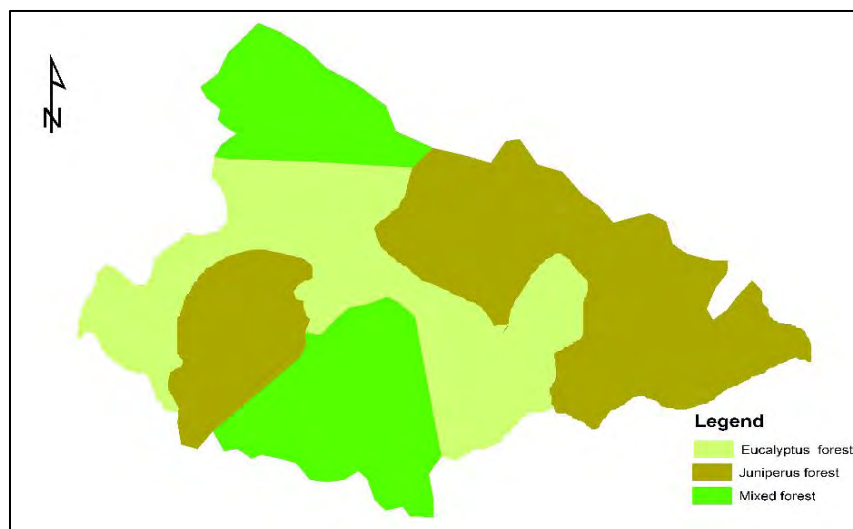
C BGB = Carbon stock in below-ground [tone C/ha]

Then, the carbon stock of different pools per hectare was converted into total carbon stock for each stratum and for the entire study area by multiplying the total area of the three forest stratum.

#### 2.2.4.2 Floristic composition and species diversity

Floristic diversity assessment was also purposely conducted in the upper catchment forest of Addis Ababa particularly within the designated Gullele Botanic Garden. This study site was selected because it is relatively under conservation and with clear distinction of forest types and is expected to be with diversified plant species that could serve as a habitat for wildlife and protection of the environment, as development of the Gullele Botanic Garden on the northern outskirts of Addis is aimed to conserve the Ethiopian flora which has long been recognized as an important center of diversity and domestication for cultivated plants containing gene pools of immeasurable value to breeding programs (Senbeta& Teketay, 2001).

For the collection of vegetation data, initial biophysical assessment was conducted and the forest was categorized into *Eucalyptus* dominated, *Juniperus* dominated and mixed forest types (Figure 8). Based on this stratification a systematic sampling scheme was followed using a transect line laid along the elevation gradient.



**Figure 8** Figure Forest category of Gullele Botanic Garden

The first transect was selected randomly and the others were laid down systematically with 100m vertical interval between sample points and 300 m distance between the transect lines. Accordingly, 68 sample plots were put throughout the three forest categories. Then, using a plot size of 20mx20m woody species were recorded for their species name, dbh, height and number of individuals. Five composite plots of 1mx1m size (four in the corner and one in the center) were also established to collect data for herbs and grasses.

Species density was recorded in a plot and converted into a per hectare basis with respect to the species type under consideration. Species diversity was analyzed using Shannon-Wiener information function which is the most widely used diversity index in ecology (Shannon & Wiener, 1963). It is calculated from the proportional abundances of each species (abundance of the species divided by total abundances) as depicted in the following equation.

$$H' = - \sum_{i=1}^s p_i \log(p_i)$$

Where:  $H'$  is the standard symbol for Shannon index,

S is number of species and

$p_i$ , is the proportion of species i.

Species richness was taken from all species encountered in each plot it was determined as the number of species per unit area. Shannon's equitability (E) was calculated by dividing  $H'$  by  $H_{\max}$  (here  $H_{\max} = \log S$ ).



vegetation was not considered besides the area under litter, surface stone and rock outcrops was deducted. At each sub plot the area coverage proportion i.e. the percent area of the bare ground of each three of the selected microtopographic soil erosion features viz. flow surfaces, prerills and rills (Kunwar, 1995; Bergsma, 1997b; Woldegerima, 1998) were carefully estimated.

The soil erosions features data estimated as percentage of the bare soil part of the sub plot was brought in to whole plot level so that analysis and results will be on a uniform area basis instead of on the bare soil part which vary from one plot to another. The relationship between the forest categories and the microtopographic soil erosion features were then statistically analyzed to establish the role and variation among forest categories in providing the erosion protection ecosystem services. The results show the percentage area coverage of the bare ground by each soil erosion feature of the.

### **3. RESULTS**

#### ***3.1 Higher and detailed level Urban Morphology Types (UMTs)***

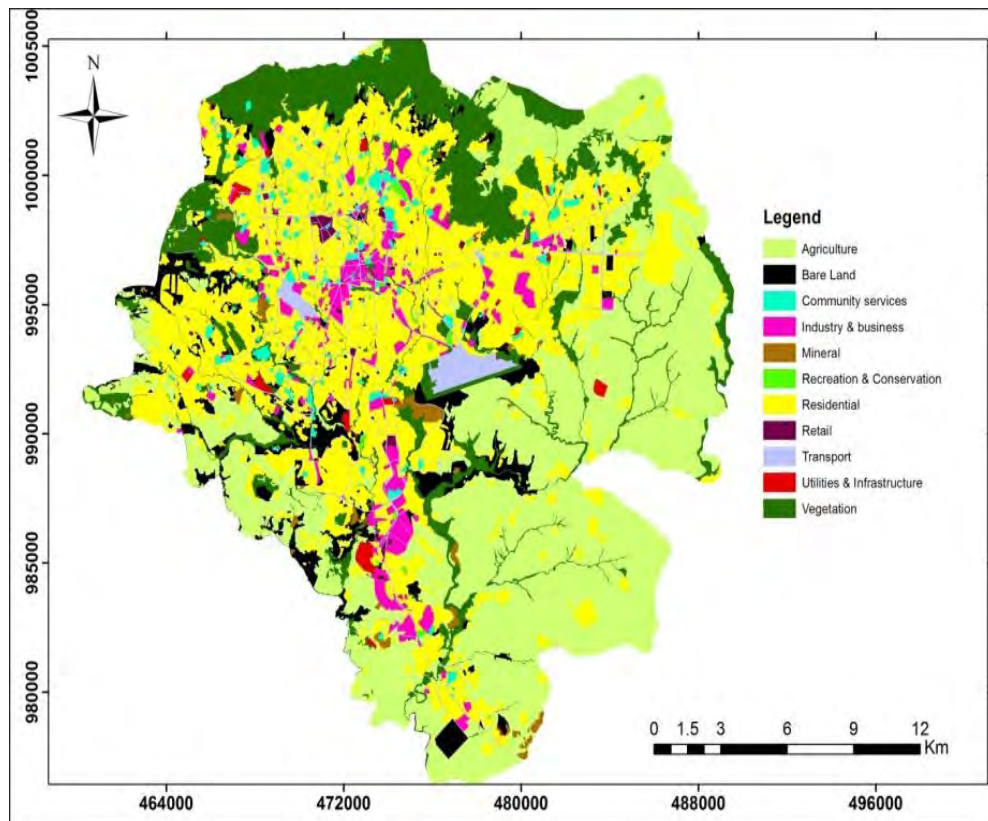
A total of 11 higher or primary level and 35 detailed urban morphology types (UMTs) have been identified and mapped for both 2006 and 2011 covering the entire urban and peri-urban areas of Addis Ababa stretching over a total land area of 520 km<sup>2</sup>. Out of the defined higher level UMTs industries and business was dominant in terms of number of sub categories which encompassed seven detailed UMTs. On the other hand the bare land and minerals are the least dominant, where the primary and detailed UMTs categories remained the same.

**Table 6** UMT classification scheme adapted for Addis Ababa

No.	Higher level UMT	Detailed level UMT	
1	Agriculture	1.1	Filed Crop
		1.2	Vegetable farm
2	Vegetation	2.1	Plantation
		2.2	Mixed forest
		2.3	Riverine
		2.4	Grass land
3	Minerals	3.1	Mineral and quarries
4	Recreational	4.1	Park
		4.2	Stadium and festival
5	Transport	5.1	Road
		5.2	Bus Terminal
		5.3	Train Station
		5.4	AirPort
6	Utilities and infrastructure	6.1	Energy distribution
		6.2	Water treatment plant
		6.3	Refuse disposal
		6.4	Cemetery
7	Residential	7.1	Condominium and multi-story
		7.2	Villa and single stories
		7.3	Mud and wood construction
		7.4	Mixed residential
8	Community services	8.1	Education
		8.2	Medical
		8.3	Religion site
9	Retail	9.1	Formal Shopping
		9.2	Open Market
		9.3	Mixed Shopping
10	Industry and business	10.1	Manufacturing
		10.2	Office
		10.3	Palace
		10.4	Hotel
		10.5	Storage and distribution
		10.6	Garage
		10.7	Mixed industry and business
11	Bare land	11.1	Bare Land

### 3.1.1 The UMTs mapping of 2006

The result of the UMT mapping of 2006 for Addis Ababa (Figure 2) showed the spatial distribution of the various UMTs. For instance, in the Northern part of the city vegetation UMT was the dominant cover type whereas the South and South-eastern and the North and North South part of the city was dominated by field crop and vegetable farms detailed UMTs respectively, both within the agriculture primary UMT. The central part of the city is predominantly a built-up with higher density residential UMT typically located closer to the north-central and north-west part of the city.

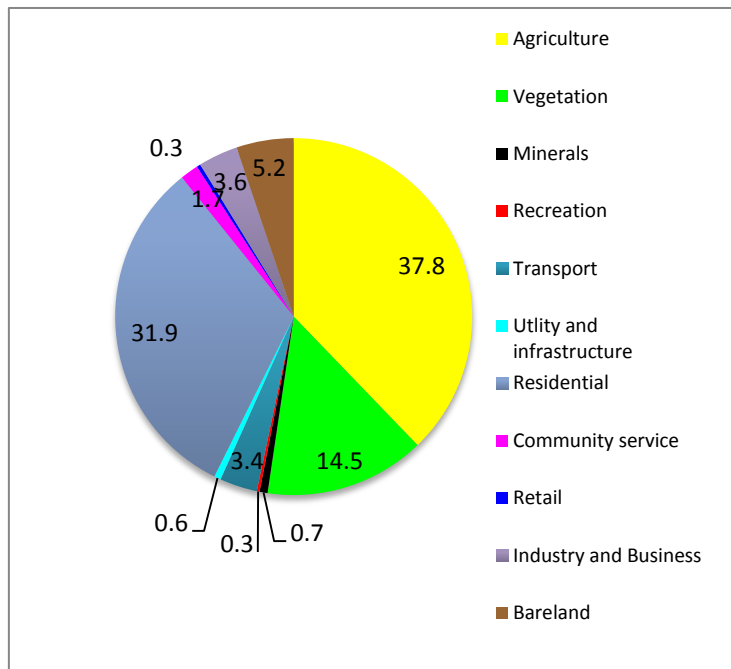


**Figure 9** Primary Urban Morphology Types Map of Addis Ababa (2006)

A major industrial and business UMT can be seen to the south and south-central part of the city of Addis Ababa while retail UMT dominates at the central part of the city. The

Bole International airport a detailed UMT of the transport higher UMT is visibly located at the eastern end of the city while the road infrastructure is concentrated at the central part with fewer appearances to the out warding expansion areas. Very few recreational UMTs are visible in the central part of the city serving as recreational and conservation areas in the form of Parks and open spaces.

The result also revealed that, in 2006 at the higher level UMTs agriculture became the most dominant category covering a total area of 19,639 hectares (38%) followed by residential with area coverage of 16,569 hectares (32%) showing these two land use categories alone covered 70% of the total land. Vegetation (15%), bare land (9%), industry and business (4%) and transport (3%) UMTs followed with substantial area coverage while the remaining viz. minerals, recreational, utilities, community service and retail UMTs categories are found to be with lower area coverages of 1% and below out of the total (Figure10).



**Figure 10** Graph showing Percentage area coverage of higher level UMTs (2006)

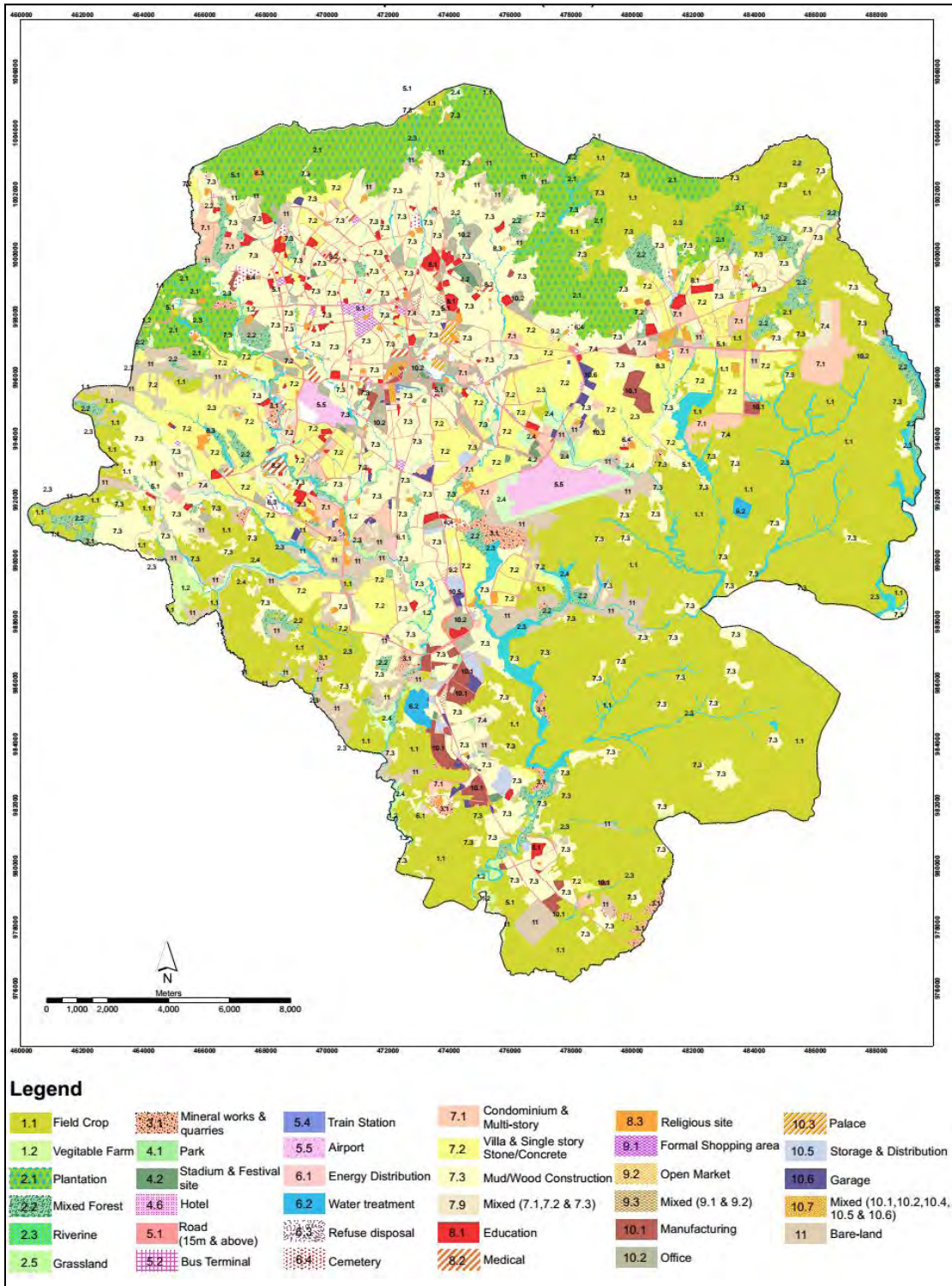
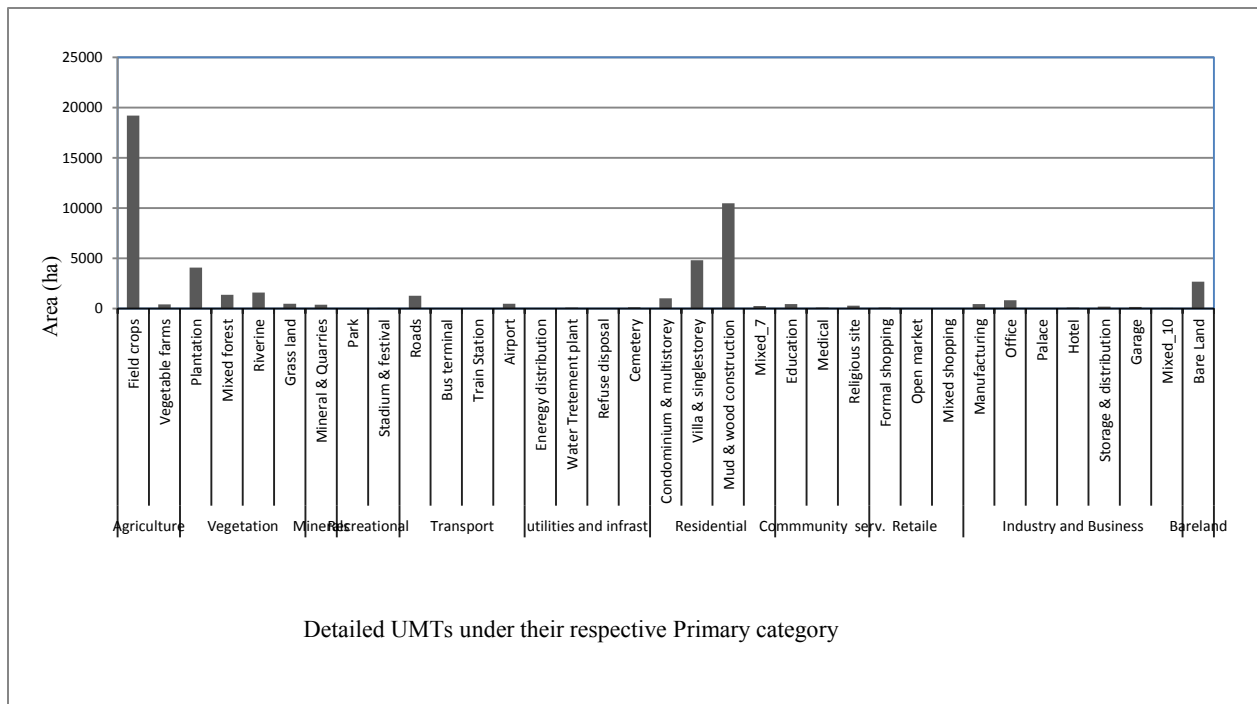


Figure 11 Detailed level UMTs map of Addis Ababa (2006)

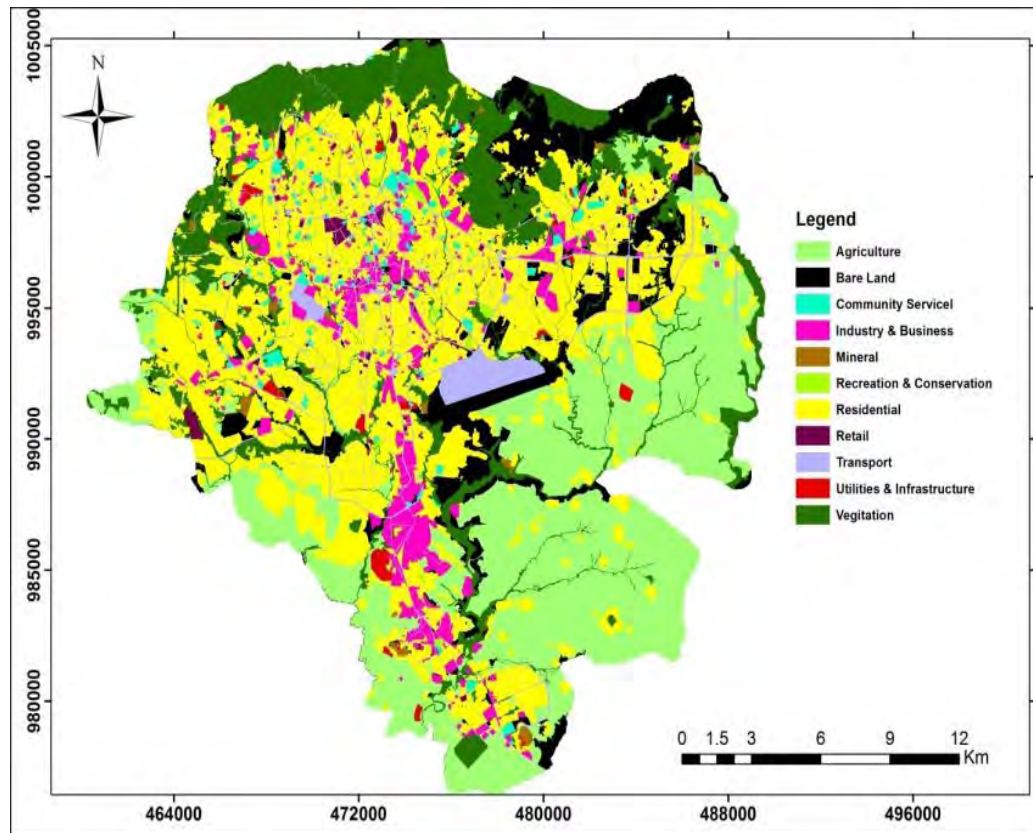
The detailed UMTs mapping and analysis indicated that field crops covered 37% of the total land area followed by mud and wood constructed residential building category with 20% coverage. Villa and single stories, plantation forest and bare land covered 9%, 8% and 5% respectively while all the remaining thirty UMTs categories covered the rest 21% area each with 3% and below (Figure 12).



**Figure 12** Graph showing the area coverage of detailed UMTs (2006)

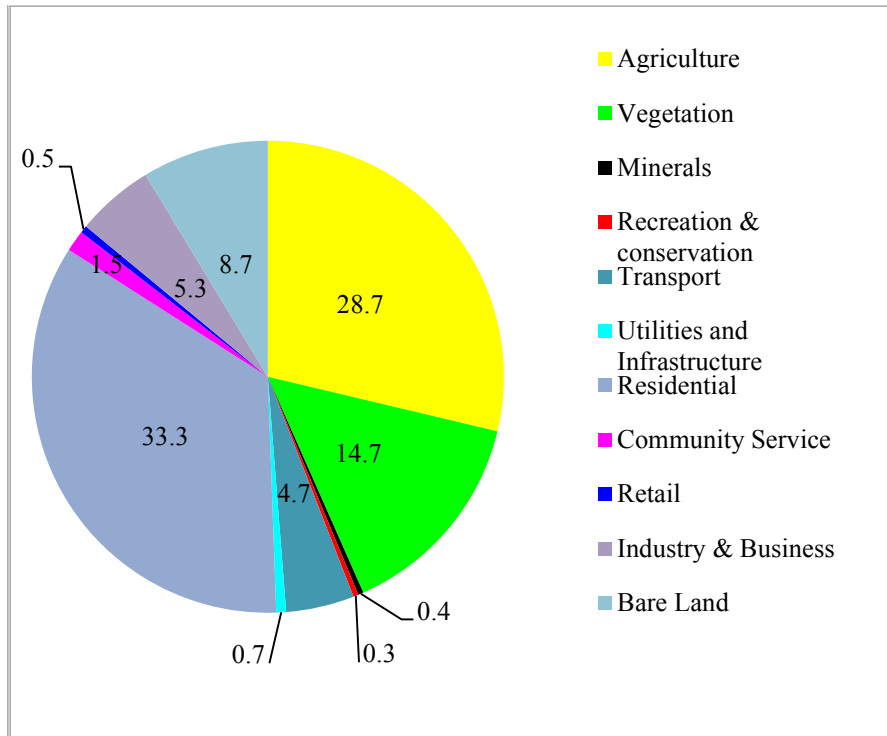
### 3.1.2 The UMTs mapping of 2011

At primary or higher level, in 2011 residential UMT stand out with the highest land coverage (33.3%) followed by agricultural UMT (28.7%) both covering above 60% of the overall land, other UMTs with substantial land cover include vegetation 14.6% and bare land 8.7%.



**Figure 13** Higher level Urban Morphology Types Map of Addis Ababa (2011)

All the remaining seven higher level UMTs contributed 13.4% of the total with varying coverage of each between 0.7% and 5% (Figure 14).



**Figure 14** Graph showing percentage of area coverage by higher level UMTs of 2011

Results of detailed UMTs analysis showed that out of the 35 classes, six categories dominantly cover over 75% of the total area. These dominant detailed UMTs include: field crop (28.1%), mud and wood constructed residential (16%), villa and single storey based residential (13.2%), bare land (8.7%), plantation forest (6.5%) and condominium and multi-storey buildings (5.3%), while the rest twenty nine UMTs categories occupy just less than a quarter of the total land area each one's coverage ranging between 0.02% to 3.47% (Figure 15).

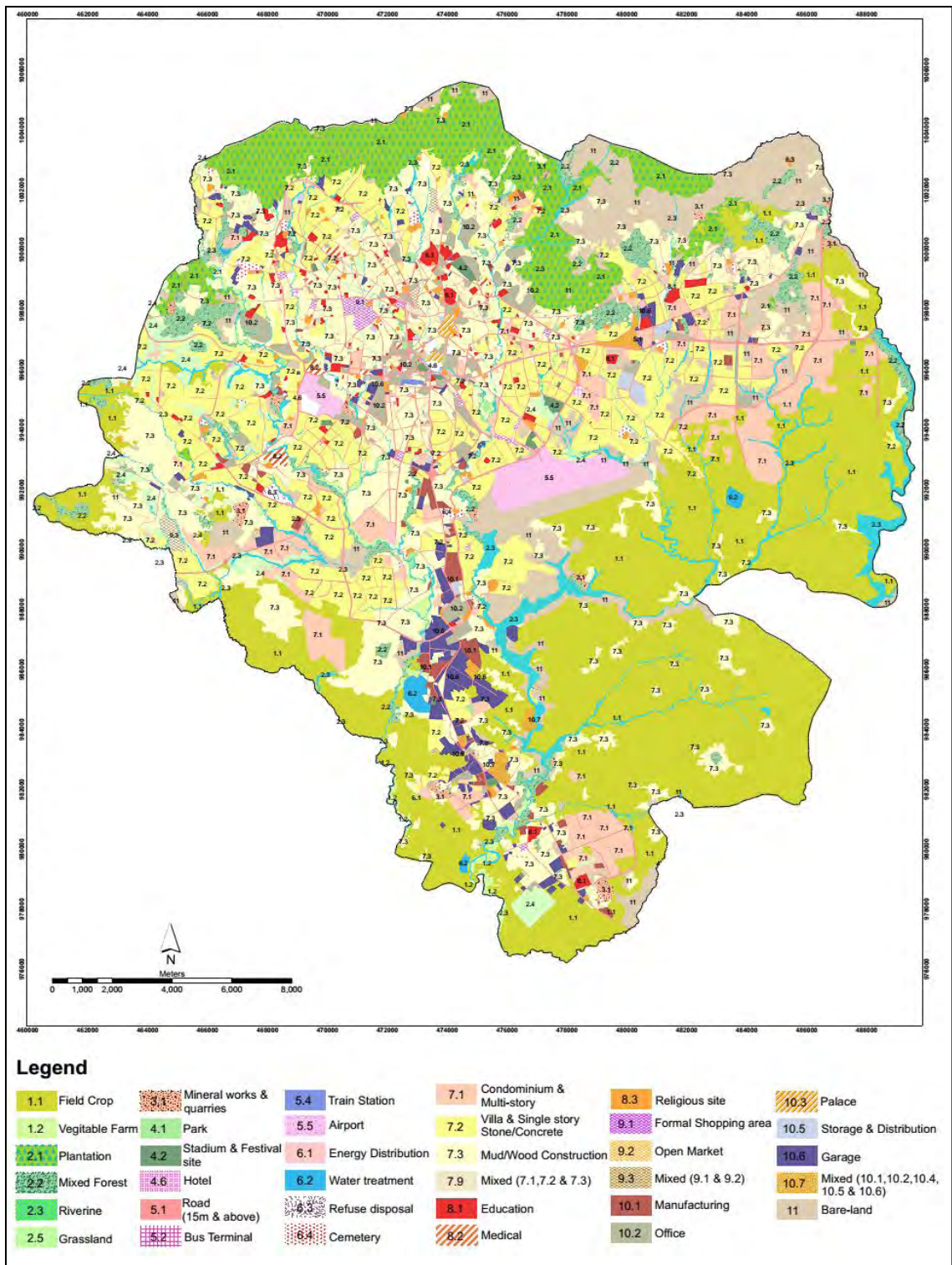
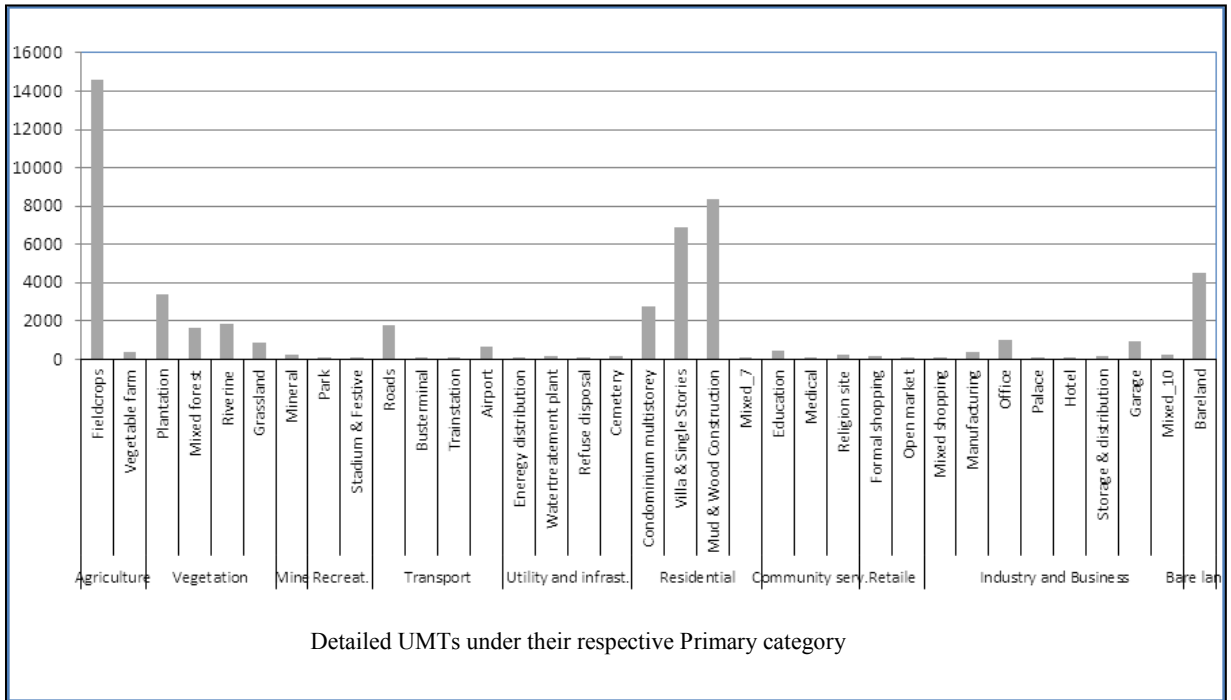


Figure 15 The detailed UMTs map of 2011



**Figure 16** Graph showing the area coverage of detailed level UMTs (2011)

### 3.2 Changes in Urban Morphology Types

#### 3.2.1 Changes in higher level UMTs between 2006 and 2011

The results of UMT mapping for Addis Ababa for 2006 and 2011 and its change analysis showed that (Figure 17) bare land UMT is expanding in this period as compared to that of 2006. Similarly, the residential and industrial related built-up areas are also increasing in their spatial extent in the central and south-central parts of the city.



UMTs, like agriculture and minerals have declined steadily, while changes in other UMTs such as; industry, retail, recreation and transport have showed progressive increase in spatial extent between 2006 and 2011 (Table 7), other UMTs including utilities & infrastructure as well as residential also showed positive trends in their spatial expansion, while the mountainous northern and north western part of the city commonly referred as the upper catchment area, predominantly covered by plantation forest remained positive with no significant change.

**Table 7** Changes in higher level UMTs between 2006 and 2011

	2006		2011		Change & 2011(ha)	Rate of change (%)
	Area (ha)	Area (%)	Area (ha)	Area (%)		
Primary UMTs						
Agriculture	19639.4	37.8	14920.3	27.6	-4719.1	-24.0
Vegetation	7559.2	14.5	7616.1	14.1	56.9	0.8
Minerals	376.0	0.7	191.7	0.4	-184.3	-49.0
Recreation & conservation	131.9	0.3	181.4	0.3	49.5	37.5
Transport	1768.9	3.4	2426.9	4.5	658.0	37.2
Utilities & Infrastructure	317.9	0.6	349.4	0.6	31.5	9.9
Residential	16568.5	31.9	17978.1	33.3	1409.6	8.5
Community Service	858.4	1.7	759.9	1.4	-98.5	-11.5
Retail	180.0	0.3	261.2	0.5	81.2	45.1
Industry & Business	1866.8	3.6	2770.3	5.1	903.4	48.4
Bare Land	2695.0	5.2	4506.6	8.3	1811.6	67.2
Total	51962	100	51962	100		

### ***3.2.2 Changes in the detailed level of UMTs between 2006 and 2011***

The results of change analysis between 2006 and 2011 have shown a considerable decrease in some detailed UMTs such as: field crops, vegetable farm, plantation forest, mineral & quarries, energy distribution, mud & wood construction, mixed residential, open market and storage & distribution. However, a substantial increase has been detected in other detailed UMTs with more than 100% increase including in the expansion of bus terminal, condominium and multistory houses, mixed shopping, garage and mixed industry & business (Table 8).

**Table 8** Changes in detailed level UMTs between 2006 and 2011

No.	Detailed UMTs	2006		2011		Change between 2006 & 2011(ha)	Rate of change (%)
		Area (ha)	Area (%)	Area (ha)	Area (%)		
1	Field crops	19209	37.0	14579	28.1	-4630	-24
2	Vegetable farm	432	0.8	341	0.7	-91	-21
3	Plantation forest	4068	7.8	3373	6.5	-695	-17
4	Mixed forest	1378	2.7	1614	3.1	236	17
5	Riverine vegetation	1613	3.1	1804	3.5	190	12
6	Grassland	499	1.0	825	1.6	326	65
7	Mineral & Quarries	376	0.7	192	0.4	-184	-49
8	Park	50	0.1	69	0.1	19	38
9	Stadium & Festival sites	82	0.2	112	0.2	30	37
10	Roads	1285	2.5	1773	3.4	488	38
11	Bus terminal	6	0.0	22	0.0	16	244
12	Train station	7	0.0	12	0.0	5	72
13	Airport	470	0.9	619	1.2	149	32
14	Energy distribution	50	0.1	38	0.1	-12	-24
15	Water treatment plant	107	0.2	134	0.3	27	25
16	Refuse disposal	29	0.1	30	0.1	2	5
17	Cemetery	132	0.3	147	0.3	15	11
18	Condominium & multistory	1014	2.0	2739	5.3	1725	170
19	Villa & Single Stories	4820	9.3	6884	13.2	2064	43
20	Mud and wood const.	10478	20.2	8340	16.0	-2138	-20
21	Mixed residential	258	0.5	15	0.0	-242	-94
22	Education	456	0.9	429	0.8	-26	-6
23	Medical	114	0.2	107	0.2	-7	-6
24	Religion site	289	0.6	224	0.4	-65	-23
25	Formal shopping	108	0.2	141	0.3	32	30
26	Open market	33	0.1	13	0.0	-20	-61
27	Mixed shopping	39	0.1	107	0.2	69	178
28	Manufacturing	458	0.9	373	0.7	-86	-19
29	Office	832	1.6	997	1.9	165	20
30	Palace	42	0.1	44	0.1	2	4
31	Hotel	88	0.2	93	0.2	5	6
32	Storage & distribution	212	0.4	133	0.3	-79	-37
33	Garage	159	0.3	935	1.8	776	489
34	Mixed industry & business	76	0.1	196	0.4	120	158
35	Bare land	2694	5.2	4507	8.7	1813	67
<b>Total</b>		<b>51962</b>	<b>100</b>	<b>51962</b>	<b>100</b>		

### ***3.2.3 Area conversions among major UMTs between 2006 and 2011***

Analysis of UMTs conversion used to determine the general trend of land use related changes that took place between 2006 and 2011 and is used to analyze the source and destination of each UMT type. The analysis clearly provided detail information on the source of change and its destination including which UMT lost land to which UMT or in other words which category goes to where. To discuss the result of the conversion between UMTs, a matrix that shows and compares the spatial and temporal distribution of primary UMTs that undergone between 2006 and 2011 is shown (Table 9). The comparison of UMTs changes between the two periods helped to give a clear picture on the spatial extent of UMTs that goes to other types as a result of several factors. The row of the table represented the initial stage as 2006 and the column of the table represents the final stage of 2011. The diagonal values of the table depict the unchanged values, which are found in both time data (Table 9).

Accordingly, conversion values were sorted by area and these results indicate that increases in vegetation, recreation and conservation, transport, utilities and infrastructure, residential, retail, industry and business. However, the conversion has shown decrease in agriculture, vegetation and minerals and quarries. The highest growth in the conversion matrix was recorded for residential UMT which mainly came from conversion of agricultural land uses and bare land during the five year period between 2006 and 2011. Residential area increased from 14,258 hectares to 17,978 hectares showing increment by 21% and gaining substantial land areas from agriculture (2035 hectares), bare land (646 hectares), vegetation (386 hectares). But it also lost significant area to industry and

business (788 hectares), transport (440 hectares), utilities and infrastructure (14 hectares), community service (136 hectares), retail (86 hectares).

**Table 9** Area conversion matrix of primary UMTs between 2006 and 2011

UMTs	UMT classes of 2011											
	Vegetation Area (ha)	Agriculture Area (ha)	Minerals Area (ha)	Recreation and conservation Area (ha)	Transport Area (ha)	Utilities and infrastructure Area (ha)	Residential Area (ha)	Community service Area (ha)	Retail Area (ha)	Industry and business Area (ha)	Bare land Area (ha)	Class Total (ha.)
Vegetation	6036.50	282.00	16.40	22.10	226.10	11.00	385.80	21.00	8.00	116.60	431.20	7556.50
Agriculture	474.00	13941.60	48.70	5.30	137.20	21.30	2034.60	12.30	0.90	197.05	2766.00	19639.40
Minerals	30.60	15.10	66.40	0.00	0.70	1.50	14.84	0.10	0.00	7.50	239.10	376.00
Recreation and conservation	1.90	0.80	0.00	107.30	1.50	0.00	8.20	1.70	0.01	10.80	0.00	131.90
Transport	11.10	5.20	8.00	1.60	1471.30	1.20	174.50	7.80	6.50	58.40	15.60	1761.20
Utilities and infrastructure	7.10	0.38	0.00	0.00	3.09	279.50	11.98	1.10	0.00	11.70	2.96	317.90
Residential	130.00	23.00	10.90	21.00	439.60	14.20	14258.10	135.60	86.04	232.00	54.00	16607.70
Community service	34.90	0.10	0.90	11.40	13.00	7.70	142.30	538.10	4.05	76.20	27.60	856.40
Retail	0.30	0.00	0.00	0.01	6.20	0.01	25.20	6.20	104.90	31.80	0.30	175.00
Industry and business	13.30	11.80	0.01	6.70	75.80	4.10	276.20	20.20	15.90	1393.20	27.10	1844.60
Bare land	574.90	503.60	39.90	5.80	52.20	8.80	646.30	15.60	34.90	78.40	732.90	2693.70
Class Total (ha.)	7615.90	14919.40	191.70	181.40	2426.40	349.40	17978.10	759.90	261.20	2770.30	4506.60	51960.80

UMT Classes of 2006

### **3.3 Land surface cover Analysis**

#### **3.3.1 Proportion of land surface cover types (2006)**

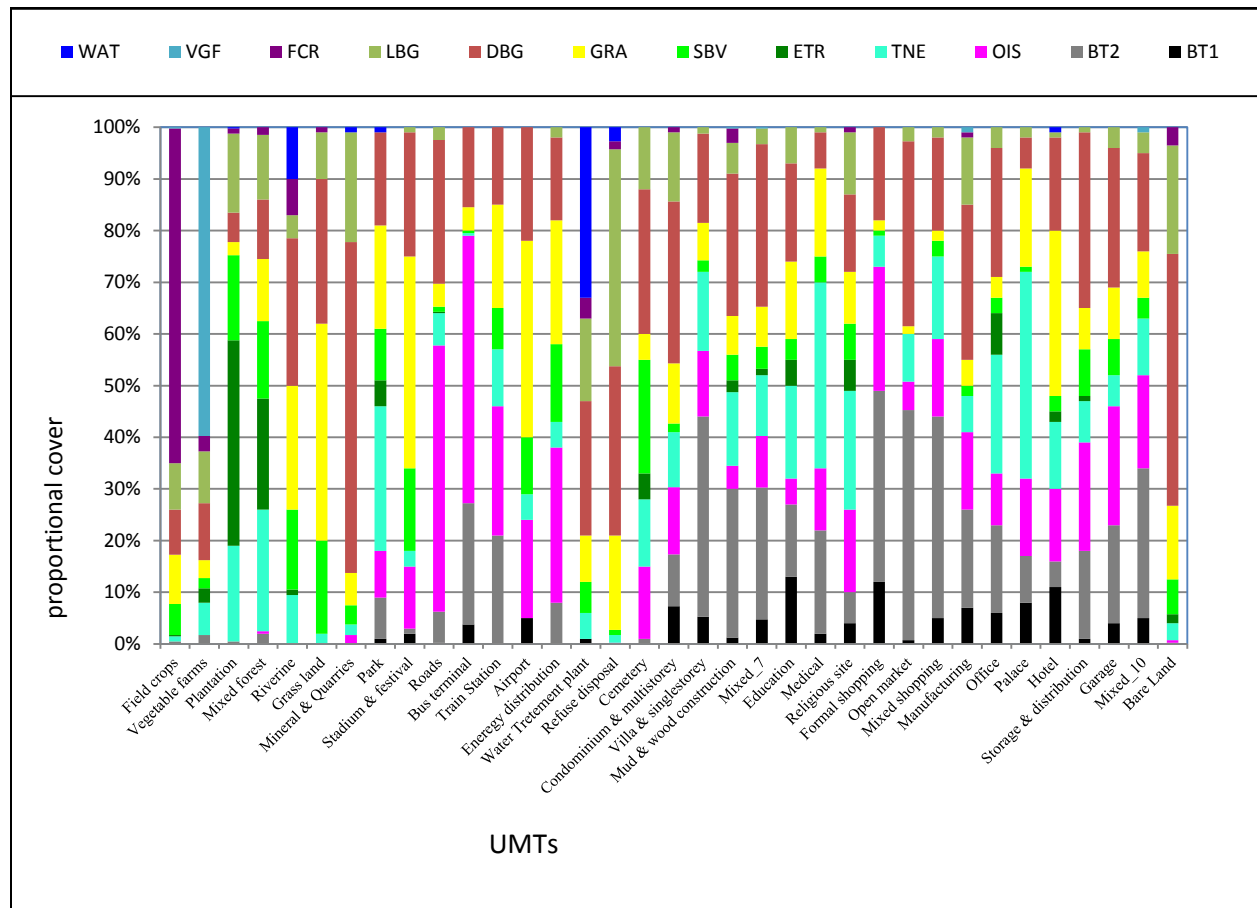
The proportional land surface cover of the 2006 UMT categories of Addis Ababa reveals a complex picture with 12 distinct surface cover types (Figure 18).

**Built structure I:** (well planned and high rise buildings) covers up to 13% of the surfaces in some UMT categories. High proportions with more than 10% proportional coverage are found in UMTs like education (13%), formal shopping (12%) and hotel (11%). Others have relatively lower proportion which include as palace (8%), manufacturing (7%), office (6%), air ports, villa & single-story, mixed shopping (5% each), bus terminal, religious site, garage (4% each), stadium, medical (2% each) and park, water treatment plant, mud & wood construction, open market, storage & distribution (1% each).

**The built structure II:** (informal, generally unplanned, and non-high rise buildings) have a high proportional cover in open market (45%), followed by villa & single-story, mixed shopping (39% each), formal shopping (37%), mud & wood construction (29%), bus terminal (24), train station (21%), medical (20%), manufacturing, garage (19% each), Office, Storage & distribution (17% each), education (14%) and Condominium & multistorey (10%). Built structure II are uncommon in other UMTs such as field crops, vegetable farms, plantation, mixed forest, park, stadium & festival, roads, and religious site with less than 10% proportional cover.

**Other impervious surfaces:** typically a high proportional surface covers in the UMT's of roads and bus terminal (52% each). They also have a high proportional cover in energy distribution

(30%), train station (25%), formal shopping (24%), Garage (23%), storage & distribution (21%).



**Figure 18** Proportion of land surface covers by detailed UMTs (2006)

**Trees (non-eucalyptus):** covers higher proportion of the UMT areas in palace (40%) followed by medical (36%), Park (28%), mixed forest (24%) and religious site (23%), yet in the other UMTs showed less than 10% proportional cover. For instance, the proportional non-eucalyptus tree cover in open market is 9%, storage & distribution (8%), manufacturing (7%), vegetable farms (6%), formal shopping (6%), airport (5%), stadium & festival (3%), grass land (2%) and field crops (1%).

***Eucalyptus tree***: typically higher in UMTs of plantation (40%) followed by mixed forest (22%) but less than 10 % in other UMTs.

***Shrub and bush vegetation***: cover is generally less than 10% in the majority of UMTs, except in cemetery (22%), grassland (18%), plantation (17%), riverine (16%), and mixed forest (15%).

***Grassland cover***: is highest in grass land (42%), stadium & festival (41%), airport (38%) and hotel (32%), whereas grassland cover is typically less than 5% in vegetable farms (4%), plantation (3%), formal shopping, open market and mixed shopping (2%).

***Dark bare-ground***: highest proportional cover on UMTs of mineral & quarries (65%) followed by bare land (49%), open market (36%), storage & distribution (34%), refuse disposal (33%), condominium & multistorey (31%) and manufacturing (30%), whereas dark bare-ground typically covers less than 15% in plantation (6%), medical (7%), field crops (9%), vegetable farms (11%) and mixed forest (12%).

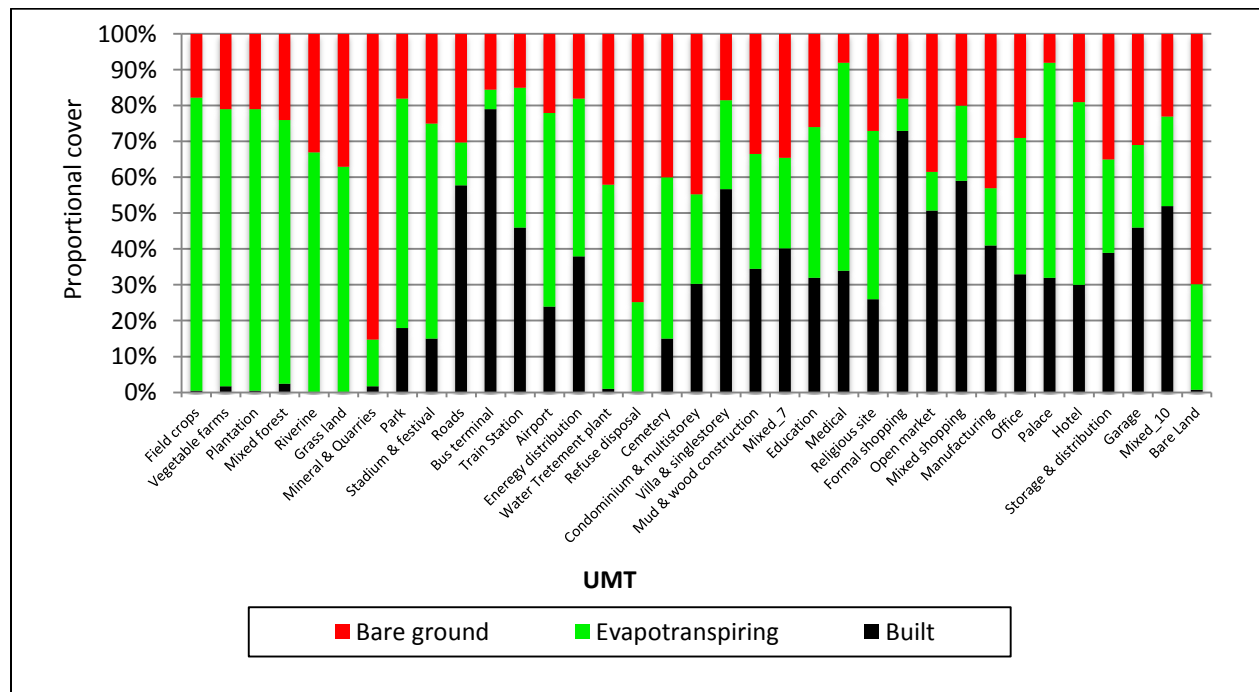
***Light bare-ground***: Covers less than 15% in many UMTs except, in refuse disposal (42%), bare-land, mineral & quarries (21% each), water treatment plant (16%) and plantation (15%).

***Field crops***: generally cover less than 5% except for in field crops (65%) and never occur in other UMTs such as mineral & quarries, park, stadium & festival, roads, bus terminal, train station, airport, energy distribution, cemetery, villa & single-storey, education, medical, formal shopping, open market, mixed shopping, office, palace, hotel, storage & distribution and garage.

***Vegetable farm***: is dominantly found in the vegetable farm UMT (60%) and rarely found in other UMTs except in manufacturing (1%).

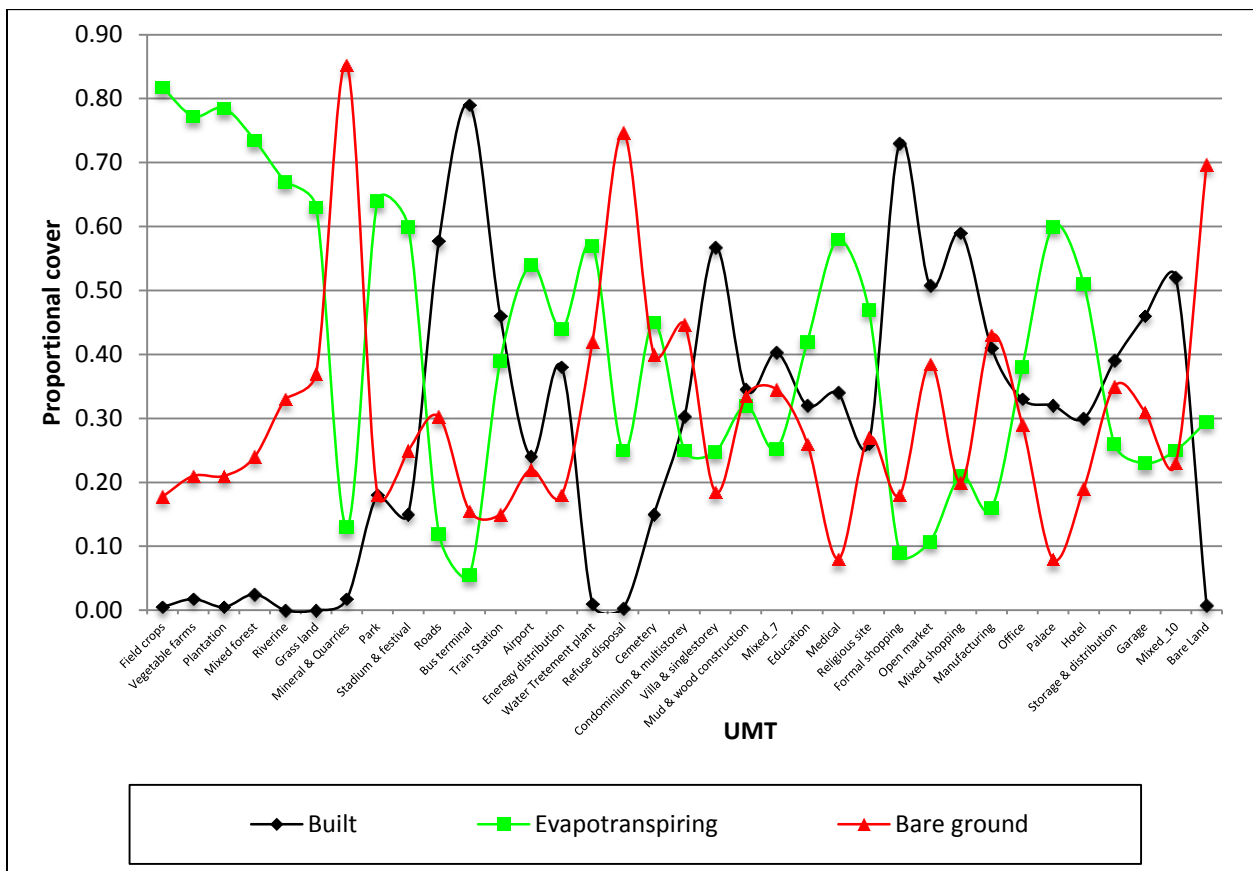
**Water surfaces:** generally cover less than 5% except for in water treatment plant (33%) and riverine (10%) but never detected in other UMTs.

The data is also combined to show the relative proportions of built and impervious surfaces (built structure I, built structure II and other impervious surfaces), evapotranspiring surfaces (tree non-eucalyptus, eucalyptus tree, shrub and bush vegetation, grassland, field crops, vegetable farm and water), and bare ground (dark bare ground and light bare ground) (Figure 19). It is clear that there is considerable variation over the UMTs that showed a marked difference in the proportion of the three broad groups of land surface covers (built, evapotranspiring and bare ground).



**Figure 19** Proportions of built, evapotranspiring, and bare ground surface cover (2006)  
 (See section 2.2.3 for abbreviated land surface cover types)

In general, the proportion of land surface cover is higher in particular UMTs with more than 50% proportion (Figure 7). For instance, built surface cover is fairly high in the UMTs such as road, bus terminal, villa & single-storey, formal shopping and mixed shopping. Apparently, evapotranspiring surface cover is higher at field crops, vegetable farms, plantation, mixed forest, riverine, grassland, park, stadium & festival, airport, water treatment plant, medical and palace UMTs. Similarly, bare ground surface cover is higher at mineral & quarries, refuse disposal and bare land UMTs.

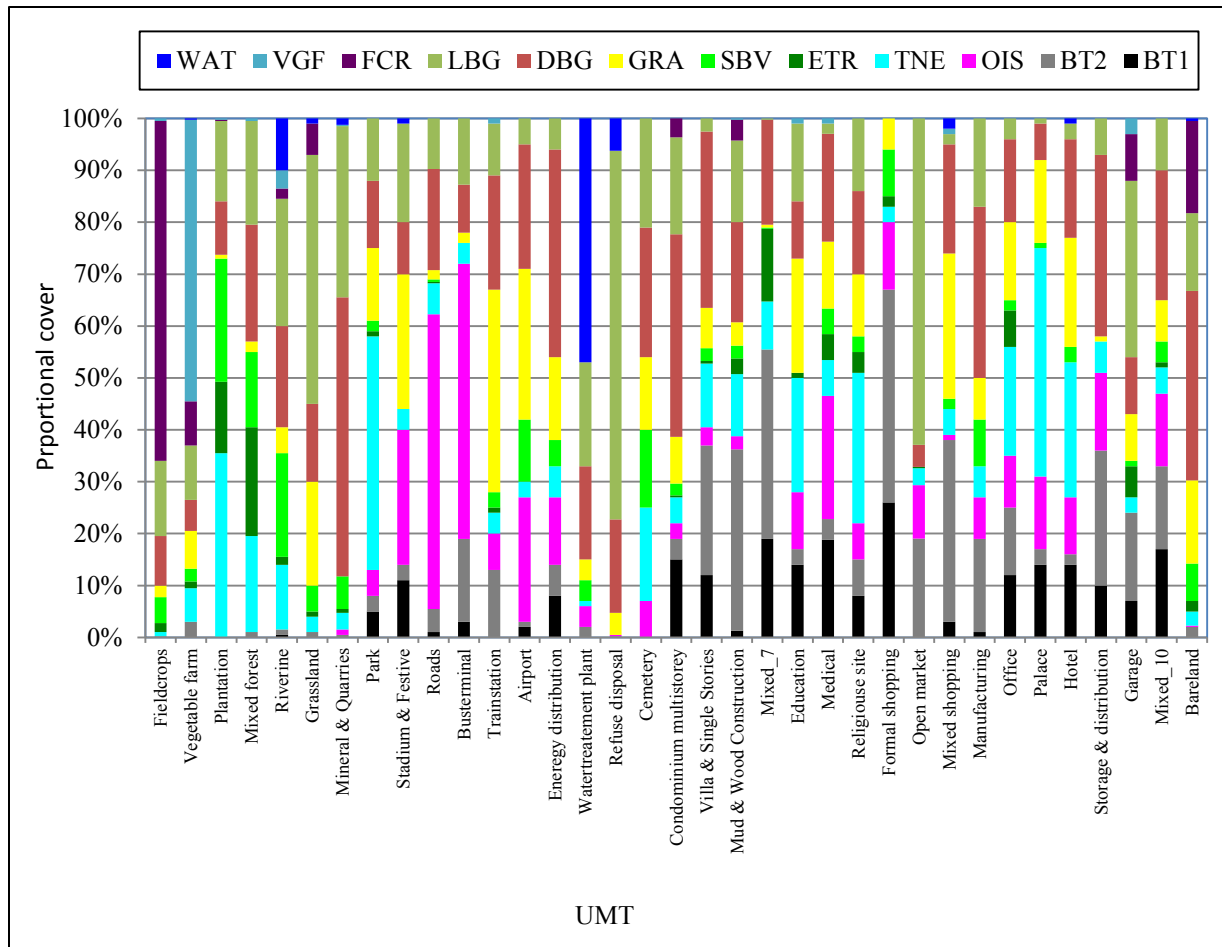


**Figure 20** Proportions of built, evapotranspiring, and bare ground surface cover, 2006

### 3.3.2 *Proportion of land surface cover types (2011)*

The proportional surface cover over the 2011 UMT categories of Addis Ababa also reveals a 12 distinct surface cover types (Figure 21).

***Built structure I:*** cover up to 26% of the surfaces within the UMT categories. High proportions are found in formal shopping (26%) whereas, and medical has (19%), condominium multistorey (15%), hotel, palace, education (14% each), manufacturing (7%), office, villa & single-story (12% each), stadium, (11% each) and, water treatment plant, mud & wood construction, open market, storage & distribution (10% each), energy distribution, religious site (8% each), garage (7% each), park (5%), mixed shopping, bus terminal (3% each), air ports (2%), manufacturing, mud & wood construction, roads and riverine (1% each).



**Figure 21** Proportions surface covers in the UMTs, 2011

**The built structure II:** in 2011 this surface cover type has a high proportional cover in formal shopping (41%), followed by mud & wood construction, mixed shopping (35% each), storage & distribution (26%), villa & single-story (25%), open market (19%), train station (21%), medical (20%), manufacturing (18%), garage (17%), bus terminal (16), train station, office (13% each), and in the other UMTs it is occurred below 10% proportion. Built structure II are uncommon in other UMTs such as vegetable farms, mixed forest, park, stadium & festival, energy distribution, roads, medical, palace, education, bare land, riverine, grassland and religious site with less than

10% proportional cover. However, built structure II cover type does not exist in field crops, plantation, refuse disposal and cemetery.

**Other impervious surfaces:** typically cover high proportions in UMT's like the roads (57%) followed by bus terminal (53%). They also have a proportional cover in stadium & festival (26%), airport, medical (24% each), storage & distribution (15%), palace (14%), energy distribution, formal shopping (13% each), education, hotel (11% each), open market, office (10% each) and below 10% proportional cover in other UMTs.

**Trees (non-eucalyptus):** in 2011 this surface type covers higher proportion of the UMT areas in park (45%) followed by palace (44%), plantation (36%), religious site (29%), hotel (26%), education (22%), office (21%), mixed forest (19%), cemetery (18%), riverine (13%), villa & single storyes, mud & wood construction (12% each), yet in the other UMTs showed less than 10% proportional tree cover. For instance, the proportional non-eucalyptus tree cover in medical and vegetable farms (7% each), roads, energy distribution, manufacturing, storage & distribution (6% each), condominium multistorey and mixed shopping (5% each), stadium & festival, bus terminal and train station (4% each), grassland, mineral & quarries, airport, formal shopping, open market, garage and bare land (3% each), field crops and water treatment plant (1% each).

**Eucalyptus tree:** the 2011 surface cover type of eucalyptus tree is typically higher in mixed forest (21%) followed by (plantation 14%) but less than 10 % in other UMTs.

**Shrub and bush vegetation:** covers 44% in plantation followed by riverine (20%), mixed forest and cemetery (15% each), airport (12%) and this land surface generally occurred in less than 10% of other UMTs.

**Grassland cover:** is highest in train station (39%), airport (29%), mixed shopping (28%), stadium & festival (26%), education (22%), hotel (21%), grass land (20%), energy distribution, palace, bare land (16% each), office (15%), park, cemetery (14% each), medical (13% and religious site (12%). Grassland cover is lower in the other UMTs typically with less than 10% surface cover.

**Dark bare-ground surface:** allotments have highest cover for mineral & quarries (54%) followed by energy distribution (40%), condominium & multistorey (39%), bare land (37%), storage & distribution (35%), villa and single storyes (34%), manufacturing (33%), cemetery (25%), airport (24%), mixed forest (23%), train station (22%), medical, mixed shopping (21% each), riverine and roads (20% each), mud & wood construction and hotel (19% each), water treatment plant and refuse disposal (18% each), religious site and office (16% each), grassland (15%) whereas dark bare-ground typically covers less than 15% in Park (13%), Education and Garage (11% each), field crops, plantation and stadium & festival (10% each), bus terminal (9%), palace (7%), vegetable farms (6%) and open market (4%).

**Light bare-ground:** in 2011 light bare-ground has been occurred in majorities of UMTs. For instance higher light bare-ground proportion is recorded in refused disposal (71%) followed by open market (63%), grassland (48%), garage (34%), mineral & quarries (33%), riverine (25%), cemetery (21%), mixed forest and water treatment plant (20% each), stadium & festival and Condominium multistorey (19% each), manufacturing (17%), plantation and mud & wood construction (16% each), field crops, education, bare land (15% each), religious site (14%), bus

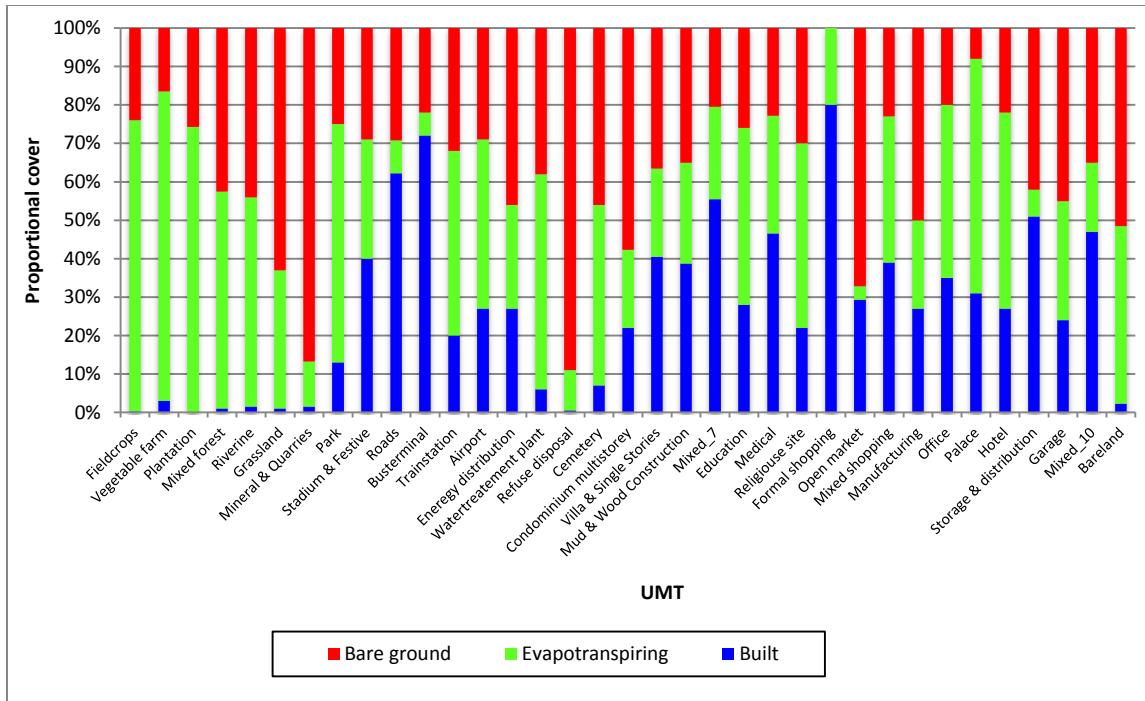
terminal (13%), park (12%), vegetable farm (11%), roads, train station and storage & distribution (10% each.)

**Field crops:** most often occurred in field crops (66%), bare land (18%), vegetable farm and garage (9% each), grassland (6%), Condominium multistorey and mud & wood construction (4% each) and riverine (2%). and never occur in other UMTs.

**Vegetable farm:** is dominantly found in the vegetable farm UMT (54%) and occurred in small quantity typically less than 5% in riverine (4%), garage (3%) and field crops, mixed forest, train station, education, medical and mixed shopping (1% each) but rarely found in other UMTs.

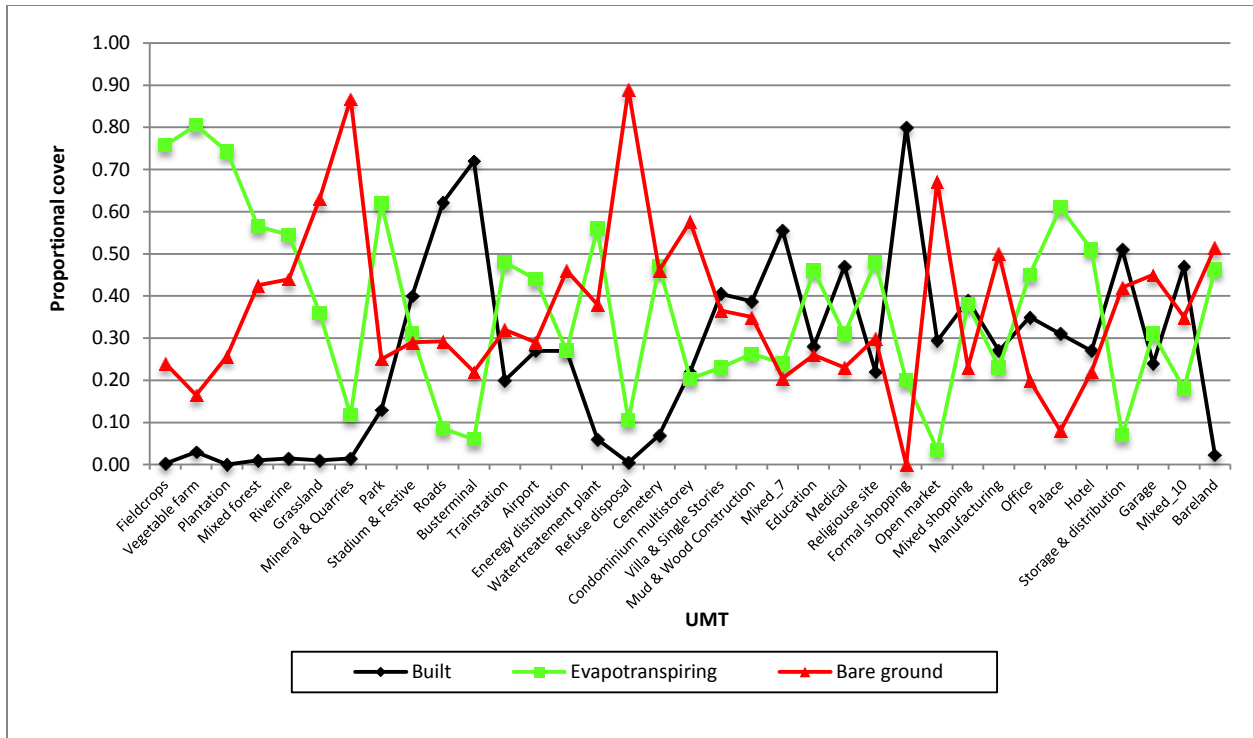
**Water surfaces:** generally cover high proportion in water treatment plant (47%) and in low proportion in riverine (10%), refuse disposal (6%), mixed shopping (2%) and grassland, mineral & quarries, stadium & festival, hotel and bare land (1% each) but never detected in other UMTs.

The combined results from the relative proportions of built surfaces (built structure I, built structure II and other impervious surfaces), evapotranspiring surfaces (tree non-eucalyptus, eucalyptus tree, shrub and bush vegetation, grassland, field crops, vegetable farm and water), and bare ground (dark bare ground and light bare ground) showed variation among different UMTs under consideration (Figure 22).



**Figure 22** Proportion of built, evapotranspiring, and bare ground surface cover, 2006

The analysis has shown that the proportion of built surface cover in 2011 is fairly high (Figure 23) in the UMTs such as road, bus terminal and formal shopping with surface cover proportion of more than 50%. Evapotranspiring surface cover is higher at the UMTs of field crops, vegetable farms, mixed forest, plantation, riverine, park, water treatment plant and palace UMTs. Similarly, bare ground surface cover is higher at grassland, mineral & quarries, refuse disposal, condominium multistorey, open market and bare land UMTs.



**Figure 23** Proportion of built, evapotranspiring, and bare ground surface cover, 2011

### 3.4 Changes in land surface cover types between 2006 and 2011

#### 3.4.1 Changes in the built land cover surfaces between 2006 and 2011

In the study periods the built structure type I has increased in area by 1062 ha between 2006 and 2011. The substantial change in the built surface cover was dominantly explained by the increment of built structure type I in the UMTs of villa and single storeys by 573 ha, condominium and multistorey by 297 ha, office by 70 ha, garage by 59 ha, formal shopping by 24 ha, medical 18 ha, road, 15ha, storage and distribution by 11 ha, stadium & festival 11 ha with a decrease, mud and wood construction by 27 ha (Table 10).

**Table 10** Changes in area (ha) in the built land surface cover between 2006 and 2011

UMTs	Land surface cover types								
	BT1			BT2			OIS		
	2011	2006	Change	2011	2006	Change	2011	2006	change
Field crops	0	0	0	36	96	-60	0	0	0
Vegetable farm	0	0	0	10	8	3	0	0	0
Plantation	0	0	0	0	20	-20	0	0	0
Mixed forest	0	0	0	16	28	-11	0	7	-7
Riverine	9	0	9	18	0	18	0	0	0
Grassland	0	0	0	8	0	8	0	0	0
Mineral & quarries	0	0	0	1	0	1	2	7	-5
Park	3	1	2	2	4	-2	3	5	-1
Stadium & festival	12	2	11	3	1	3	29	10	19
Roads	18	3	15	80	77	3	1006	661	345
Bus terminal	1	0	1	4	2	2	12	3	8
Train station	0	0	0	2	2	0	1	2	-1
Airport	12	23	-11	6	0	6	149	88	61
Energy distribution	3	0	3	2	4	-2	5	15	-10
Water treatment plant	0	1	-1	3	0	3	5	0	5
Refuse disposal	0	0	0	0	0	0	0	0	0
Cemetery	0	0	0	0	1	-1	10	19	-8
Condominium multistorey	411	114	297	110	101	8	82	132	-50
Villa & Single Stories	826	253	573	1721	1868	-147	241	615	-374
Mud & wood construction	104	131	-27	2919	3012	-93	208	471	-263
Mixed residential	3	12	-9	6	66	-60	0	26	-26
Education	60	59	1	13	63	-51	47	23	25
Medical	20	2	18	4	23	-19	26	14	12
Religion site	18	12	6	16	17	-2	16	46	-31
Formal shopping	37	12	24	58	38	19	18	25	-7
Open market	0	0	0	2	15	-12	1	2	0
Mixed shopping	3	2	1	38	15	23	1	6	-5
Manufacturing	4	32	-28	67	86	-19	30	68	-38
Office	120	49	70	130	140	-10	100	82	17
Palace	6	3	3	1	4	-2	6	6	0
Hotel	13	10	3	2	4	-3	10	12	-2
Storage and distribution	13	2	11	35	36	-1	20	44	-24
Garage	65	6	59	159	29	130	0	36	-36
Mixed industry & business	33	4	29	31	22	9	27	14	14
Bare land	0	0	0	90	7	83	11	13	-2
<b>Total</b>	<b>1795</b>	<b>734</b>	<b>1062</b>	<b>5592</b>	<b>5788</b>	<b>-196</b>	<b>2068</b>	<b>2450</b>	<b>-382</b>

On the other hand, built structure type II surface cover has decreased in size by 196 ha between 2006 and 2011. Remarkable decrease was noticed in the UMTs of villas and single storyes by 147 ha, mud and wood construction by 93 ha, field crops by 60 ha, education by 51 ha, plantation by 20 ha, medical by 19 ha, mixed shopping by 19 ha, open market by 12 ha, mixed forest by 11 ha and office by 10ha.

### ***3.4.2 Changes in the evapotranspiring surface cover between 2006 and 2011***

The analysis of evapotranspiring surface cover showed substantial changes between 2006 and 2011 in the majority of surface cover types (Table 11). Accordingly only non-eucalyptus trees, vegetable farm and water body have increased by 124 ha, 54 ha and 71 ha respectively.

However, the evapotranspiring surface cover has dominantly shown a decrease in the eucalyptus trees by 761 ha, in the shrub/bush vegetation by 303 ha, in the grassland by 1639 ha and in the field crops by 2042 ha.

The increment of evapotranspiring surface cover in the study period is dominantly explained by non-eucalyptus trees expansion in plantation, the increment of vegetable farm along the riverine and the increment of water body due to water treatment plant UMTs. On the other hand the decline of evapotranspiring surface cover in the study period is dominantly explained by reduction of eucalyptus trees in the plantation forest, decrease of shrub and bush vegetation in the filed crop and mud & wood construction, decrease of grassland cover in the field crop UMTs.

**Table 11** Changes in the evapotranspiring surface cover (ha) between 2006 and 2011

UMTs	TNE			ETR			SBV			GRA			FCR			VGF			WAT		
	2011	2006	Change	2011	2006	Change	2011	2006	Change	2011	2006	Change	2011	2006	Change	2011	2006	Change	2011	2006	Change
Field crops	109	192	-83	255	48	207	729	1152	-424	328	1825	-1497	9549	12437	-2887	73	48	25	0	0	0
Vegetable farm	22	27	-5	4	12	-8	9	9	0	25	15	10	29	13	16	185	258	-73	1	0	1
Plantation	1197	753	445	464	1617	-1153	801	671	130	25	102	-77	8	41	-32	8	0	8	0	10	-10
Mixed forest	299	323	-25	339	296	43	234	206	28	32	165	-133	0	21	-21	8	0	8	0	0	0
Riverine	225	153	72	27	16	11	361	250	111	90	387	-297	36	113	-77	63	0	63	180	161	19
Grassland	25	10	15	8	0	8	41	90	-49	165	210	-45	50	5	45	0	0	0	8	0	8
Mineral & Quarries	6	8	-1	1	0	1	12	14	-2	0	24	-24	0	0	0	1	0	1	2	4	-1
Park	31	14	17	1	3	-2	1	5	-4	10	10	0	0	0	0	0	0	0	0	1	-1
Stadium & Festival	4	2	2	0	0	0	0	13	-13	29	34	-5	0	0	0	0	0	0	1	0	1
Roads	106	80	26	4	3	1	9	13	-4	31	58	-27	0	0	0	0	0	0	0	0	0
Bus terminal	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Train station	0	1	0	0	0	0	0	1	0	5	1	4	0	0	0	0	0	0	0	0	0
Airport	19	23	-5	0	0	0	74	51	23	180	176	4	0	0	0	0	0	0	0	0	0
Energy distribution	2	3	0	0	0	0	2	8	-6	6	12	-6	0	0	0	0	0	0	0	0	0
Water treat plant	1	5	-4	0	0	0	5	6	-1	5	10	-5	0	4	-4	0	0	0	63	35	28
Refuse disposal	0	0	0	0	0	0	0	0	0	1	5	-4	0	0	0	0	0	0	2	1	1
Cemetery	26	17	9	0	7	-7	22	29	-7	21	7	14	0	0	0	0	0	0	0	0	0
Condominium	137	108	29	9	0	9	64	17	47	247	118	129	100	10	90	0	0	0	0	0	0
Villa & Single sto.	843	735	108	34	0	34	172	108	64	534	349	185	0	0	0	0	0	0	0	0	0
Mud & Wood cons.	1001	1493	-492	250	236	14	209	524	-315	375	786	-411	334	288	46	21	26	-5	0	0	0
Mixed residential	1	30	-29	2	3	-1	0	11	-11	0	20	-20	0	0	0	0	1	-1	0	0	0
Education	94	82	13	4	23	-19	0	18	-18	94	68	26	0	0	0	4	0	4	0	0	0
Medical	7	41	-34	5	0	5	5	6	0	14	19	-5	0	0	0	1	0	1	0	0	0
Religion site	65	66	-2	9	17	-8	7	20	-14	27	29	-2	0	3	-3	0	0	0	0	0	0
Formal shopping	4	6	-2	3	0	3	13	1	12	8	2	6	0	0	0	0	0	0	0	0	0
Open market	0	3	-3	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0
Mixed shopping	5	6	-1	0	0	0	2	1	1	30	1	29	0	0	0	1	0	1	2	0	2
Manufacturing	22	32	-9	0	0	0	34	9	25	30	23	7	0	5	-5	0	5	-5	0	0	0
Office	209	189	20	70	66	4	20	25	-5	150	33	117	0	0	0	0	0	0	0	0	0
Palace	19	17	2	0	0	0	0	0	0	7	8	-1	0	0	0	0	0	0	0	0	0
Hotel	24	11	13	0	2	-2	3	3	0	20	28	-8	0	0	0	0	0	0	1	1	0
Storage & distrib.	8	17	-9	0	2	-2	0	19	-19	1	17	-16	0	0	0	0	0	0	0	0	0
Garage	28	9	19	56	0	56	9	11	-2	84	16	68	84	0	84	28	0	28	0	0	0
Mixed indu& busin.	10	8	1	2	0	2	8	3	5	16	7	9	0	0	0	0	1	-1	0	0	0
Bare land	124	88	36	90	47	43	327	182	145	721	384	337	800	94	706	0	0	0	23	0	23
<b>Total</b>	<b>4674</b>	<b>4552</b>	<b>124</b>	<b>1637</b>	<b>2398</b>	<b>-761</b>	<b>3173</b>	<b>3476</b>	<b>-303</b>	<b>3311</b>	<b>4950</b>	<b>-1639</b>	<b>10990</b>	<b>13034</b>	<b>-2042</b>	<b>393</b>	<b>339</b>	<b>54</b>	<b>283</b>	<b>213</b>	<b>71</b>

### 3.4.3 Changes in the bare ground land surface cover between 2006 and 2011

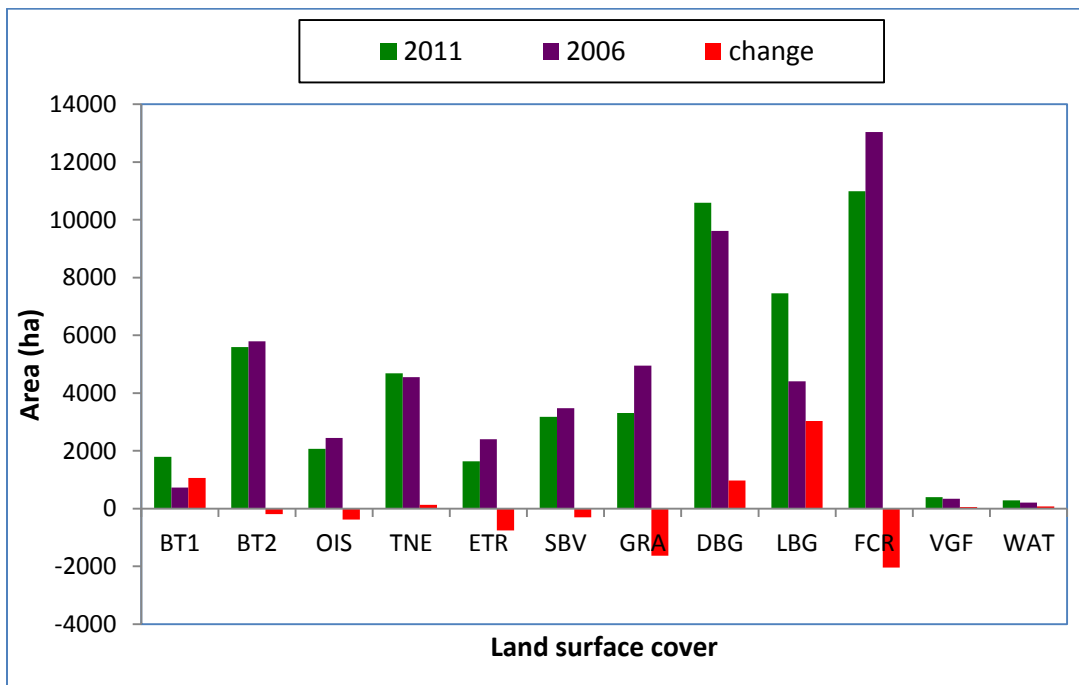
The bare ground surface cover analysis showed an increasing trend between 2006 and 2011 (Table 12). The dark bare ground has increased by 968 ha and substantial change was observed for the increment of light bare ground by 3038 ha between the study periods.

**Table 12** Changes in the bare ground surface cover (ha) between 2006 and 2011

UMTs	Land surface cover types					
	DBG			LBG		
	2011	2006	Change	2011	2006	Change
Field crops	1385.0	1680.6	-295.6	2114.0	1728.7	385.3
Vegetable farm	20.5	47.5	-27.1	35.8	43.2	-7.4
Plantation	345.7	233.9	111.8	522.8	620.4	-97.6
Mixed forest	363.3	158.2	205.0	322.9	172.0	150.9
Riverine	351.8	459.8	-108.1	442.0	72.6	369.4
Grassland	123.7	139.7	-16.0	396.0	44.9	351.1
Mineral & Quarries	103.0	240.7	-137.6	63.3	79.9	-16.7
Park	9.0	9.0	0.0	8.3	0.0	8.3
Stadium & festival	11.2	19.6	-8.4	21.3	0.8	20.5
Roads	345.8	356.4	-10.7	172.9	32.1	140.8
Bus terminal	2.0	1.0	1.1	2.8	0.0	2.8
Train station	2.7	1.1	1.6	1.2	0.0	1.2
Airport	148.6	102.0	46.6	31.0	0.0	31.0
Energy distribution	15.3	8.0	7.3	2.3	1.0	1.3
Water treatment plant	24.1	27.7	-3.7	26.7	17.1	9.7
Refuse disposal	5.5	9.4	-4.0	21.6	12.1	9.5
Cemetery	36.7	37.0	-0.3	30.9	15.9	15.0
Condominium multistorey	1068.1	317.6	750.6	511.2	135.1	376.1
Villa & Single Stories	2340.7	831.4	1509.2	172.1	60.2	111.9
Mud & Wood Construction	1605.4	2881.3	-1276.0	1313.5	628.7	684.8
Mixed residential	3.1	81.1	-78.0	0.0	7.7	-7.7
Education	47.2	86.2	-39.0	64.4	31.7	32.6
Medical	22.4	8.0	14.5	2.1	1.1	1.0
Religion site	35.8	43.3	-7.5	31.3	34.7	-3.3
Formal shopping	0.0	18.6	-18.6	0.0	0.0	0.0
Open market	0.6	11.8	-11.2	8.2	0.9	7.3
Mixed shopping	22.6	7.0	15.6	2.1	0.8	1.4
Manufacturing	123.0	135.6	-12.6	63.4	58.8	4.6
Office	159.5	205.5	-46.1	39.9	32.9	7.0
Palace	3.1	2.5	0.5	0.4	0.8	-0.4
Hotel	17.7	15.9	1.8	2.8	0.9	1.9
Storage & distribution	46.5	71.1	-24.6	9.3	2.1	7.2
Garage	102.9	41.8	61.1	317.9	6.2	311.7
Mixed industry & business	48.9	14.4	34.5	19.6	3.0	16.5
Bare land	1644.9	1313.2	331.7	676.0	565.7	110.3
<b>Total</b>	<b>10586</b>	<b>9618</b>	<b>968</b>	<b>7450</b>	<b>4412</b>	<b>3038</b>

A considerable increase of dark bare ground was noticed in the villa & single storey UMTs and extensive increase of light bare ground is explained in the mud & wood construction UMTs.

The figure below showed the combined surface cover types (built, evapotranspiring and bare ground) changes over the periods 2006 and 2011. In this regard, the surface cover types of built structure type I (BT1), trees non-eucalyptus (TNE), dark bare ground (DBG), light bare ground (LBG), vegetable farm (VGF) and water body (WAT) have shown a positive change whereas, built structure type II (BT2), other impervious surfaces (OIS), eucalyptus tree cover (ETR), shrub and bush vegetation (SBV), grassland (GRA) and field crop cover (FCR) have shown a negative change indicating the cumulative decline effect of these surface cover types (Figure 11).



**Figure 24** Land surface cover change between 2006 and 2011

(See section 2.2.3 for abbreviated land surface cover types)

### ***3.5 Assessment of selected ecosystem services***

The green spaces of Addis Ababa have been providing several ecosystem services. In this study supportive and regulation functions are considered by taking the upper catchment forest of Addis Ababa.

#### ***3.5.1 Estimation of biomass and carbon storage***

The total area of the upper catchment designated for urban forest was 5868 hectares which comprises 28% of the total proposed green space of the city. However in this study only 3227 hectares were found under forest cover while 2641 hectares remained under crop cultivation, grazing and settlement uses. To estimate the carbon storage of the green space in the upper catchment of Addis Ababa, woody plant species were taken into consideration as biomass is derived from the basal area of individual woody plants.

##### ***3.5.1.1 Woody plant species composition***

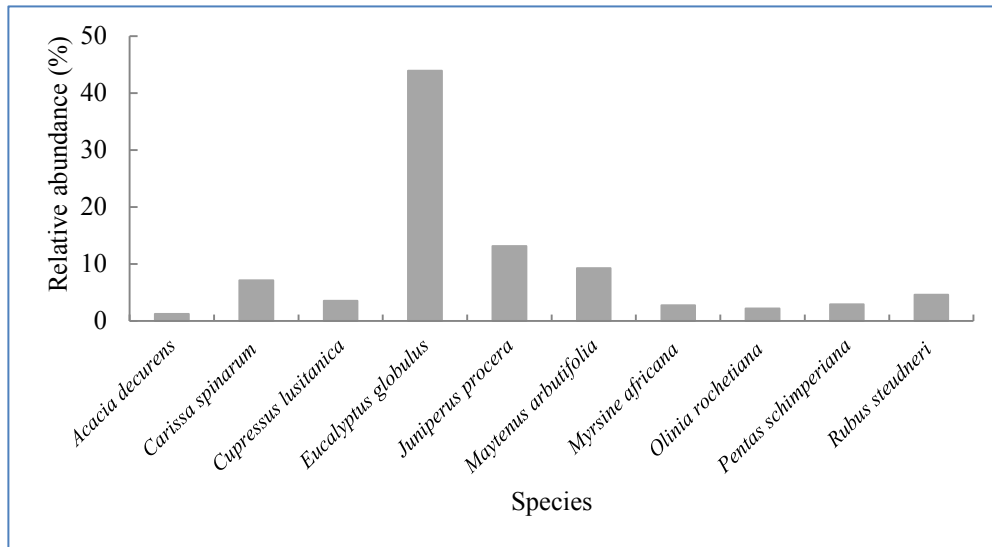
In this study, 37 woody species representing 25 families, 13 and 24 species with tree and shrub habit respectively were recorded in the upper catchment of Addis Ababa (Table 13).

**Table 13** List of woody species for biomass study at the upper catchment forest

No.	Family	Species	Habit
1	Fabaceae	<i>Acacia abyssinica</i> Hochst. Ex Benth	Tree
2	Fabaceae	<i>Acacia decurrens</i> (Wendl.f.) Willd.	Tree
3	Fabaceae	<i>Acacia saligna</i> Labill. (Wendl.)	Tree
4	Sapindaceae	<i>Allophylus abyssinica</i> (Hochst.) Radlk.	Shrub
5	Melanthaceae	<i>Bersama abyssinica</i> Fresen.	Shrub
6	Logonaceae	<i>Buddleja polystachya</i> Fresen.	Shrub
7	Apocynaceae	<i>Carissa spinarum</i> L.	Shrub
8	Rutaceae	<i>Clausena anisata</i> (Willd.) Benth.	Shrub
9	Euphorbiaceae	<i>Croton macrostachyus</i> Hochst. Ex A. Rich	Tree
10	Cupresaceae	<i>Cupressus lusitanica</i> Mill.	Tree
11	Solonaceae	<i>Discopodium penninervium</i> Hochst.	Shrub
12	Sterculiaceae	<i>Dombya torrida</i> (J.F Gmel. ) P. Bamps	Shrub
13	Flacortiaceae	<i>Dovyalis abyssinica</i> (A.Rich.) Warb	Shrub
14	Meliaceae	<i>Ekebergia capensis</i> Sparrm.	Tree
15	Myrtaceae	<i>Eucalyptus camaldulensis</i> Dehnh.	Tree
16	Myrtaceae	<i>Eucalyptus globulus</i> Labill	Tree
17	Myrtaceae	<i>Eucalyptus grandis</i> Maiden.	Tree
18	Hypericaceae	<i>Hypericum revolutum</i> Vahl	Shrub
19	Cupresaceae	<i>Juniperus procera</i> Hochst ex Endl	Tree
20	Myrsinaceae	<i>Maesa lanceolata</i> Forssk.	Shrub
21	Celastraceae	<i>Maytenus andata</i> (Loes.) Sebsebe	Shrub
22	Celastraceae	<i>Maytenus arbutifolia</i> (A.Rich.) Wilezek	Shrub
23	Celastraceae	<i>Maytenus senegalensis</i> (Lam.) Exell	Shrub
24	Myrsinaceae	<i>Myrsine africana</i> L.	Shrub
25	Myrsinaceae	<i>Myrsine melanophloes</i> (L.) R.Br.	Shrub
26	Oleaceae	<i>Olea europaea</i> subsp. <i>cuspidata</i> (Wall. ex G. Don) Cif.	Tree
27	Loganiaceae	<i>Nuxia congesta</i> R. Br. Ex Fresen.	shrub
28	Oliniaceae	<i>Olinia rochetiana</i> A.juss	Tree
29	Santalaceae	<i>Osyris quadripartita</i> Decn.	Shrub
30	Rubiaceae	<i>Pentas schimperi</i> (Hochst) Weiringa	shrub
31	Pittosporaceae	<i>Pittosporum viridiflorum</i> Sims	Shrub
32	Anacardiaceae	<i>Rhus glutinosa</i> A.rich.	Shrub
33	Rosaceae	<i>Rosa abyssinica</i> Lindley.	Shrub
34	Rosaceae	<i>Rubus apetales</i> Poir.	Shrub
35	Rosaceae	<i>Rubus steudneri</i> Schwcinf.	Shrub
36	Araliaceae	<i>Schefflera abyssinica</i> (A.Rich.)Harms.	Tree
37	Asteraceae	<i>Vernonia amygdalina</i> Del.	Shrub

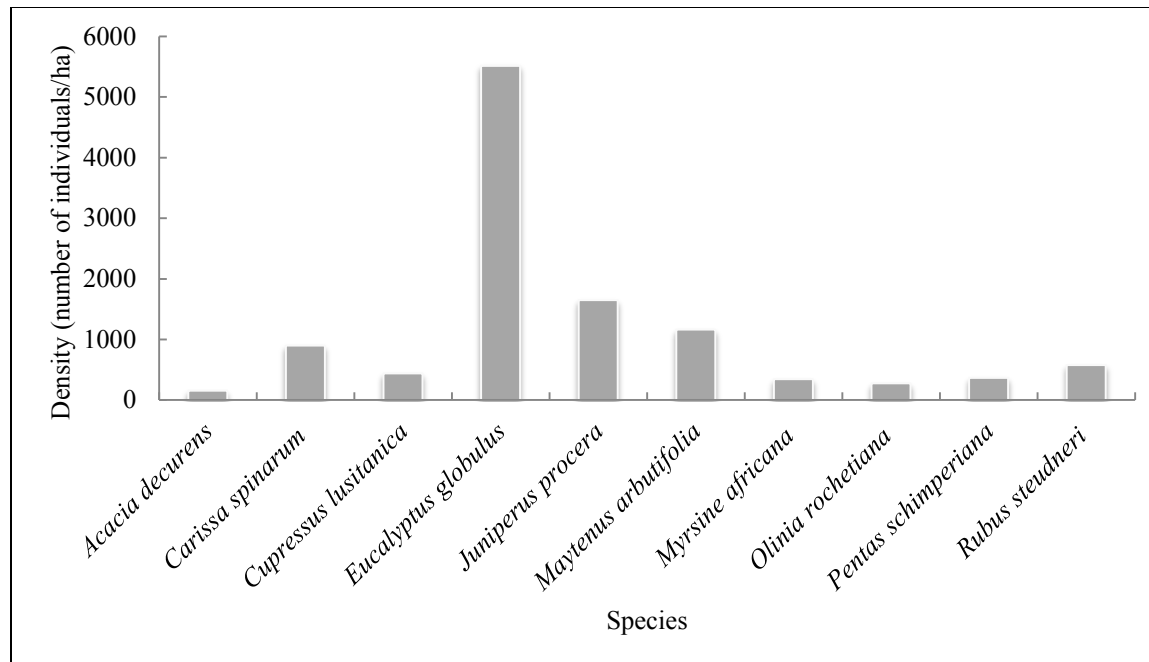
### 3.5.1.2 Abundance and density of woody species

The highest relative abundance was recorded for *Eucalyptus globulus* (43.94%) followed by *Juniperus procera* (13.15%). The lowest relative abundance was recorded for *Buddleja polystachya* (0.17%) (Figure 25).



**Figure 25** Ten most abundant species of the study area

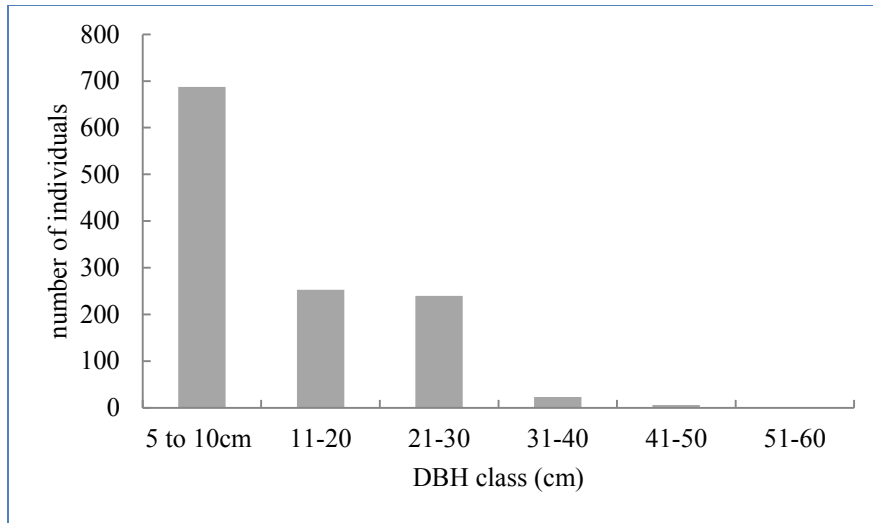
The density of woody species in the upper catchment forest of Addis Ababa ranges from 21 individuals/ha for *Olea europea* to 5513 individual trees/ha for *Eucalyptus globulus*. The figure below indicates the ten most abundant species of the study area and the result showed that *Eucalyptus globulus* is the dominant species and *Juniperus procera* is the second dominant species in the upper catchment of Addis Ababa with the density of 5513 individual trees /ha and 1650 individual trees/ha respectively (Figure 26).



**Figure 26** The ten most dense species of the study area

### 3.5.1.3 Diameter distribution

The result showed that diameter at breast height (DBH) varies from species to species and the average DBH of tree species ranged from 5.3cm for *Olinia rochetiana* to 52cm for *Eucalyptus globulus*. Out of the recorded 1210 individuals, 523 individuals attained diameter at breast height (DBH) >10cm. However, it is observed that the dominant woody species in the study area with small diameter at breast height (DBH) (e.g. 5 to 10cm) constitute larger number of individuals as compared to those with larger diameter classes (Figure 27).



**Figure 27** Number of woody species classified by diameter class distribution

**3.5.1.4 Above and below ground biomass**

The total tree biomass of upper catchment forest of Addis Ababa was estimated at 1,104,850 tons of dry matter (Table 14). Total biomass was higher for the dense forest followed by medium and open forest categories which is correlated with the nature of the forest category irrespective of the surface area coverage which follow the sequence of medium, open and dense forest from larger to smaller area .i.e. 1408ha ,1115ha and 704ha respectively. The mean above ground biomass (AGB) and belowground biomass (BGB) of the three stratum was estimated at 281 tons/ha and 62 tons/ha respectively, the overall biomass density being 343 tons/ha.

**Table 14** Above and below ground biomass distribution among the three forest strata

Forest strata	Area (ha)	Above -ground biomass (tons )	Below-ground biomass (tons)	Total biomass (tons)
Dense forest	704	337,667	74,287	411,953
Medium forest	1,408	327,984	72,157	400,141
Open forest	1,115	239,964	52,792	292,756
Total	3,227	905,615	199,235	1,104,850

### 3.5.1.5 Carbon storage and density

The total carbon stored by upper catchment forest of Addis Ababa was estimated at 552,415 tons, out of which dense forest, medium forest and open forest accounted for 37%, 36% and 27%, respectively (Table 15). The maximum aboveground carbon (AGC) stock was recorded for dense forest with total carbon of 205,977 tons. Below ground carbon stock (BGC) followed the same trend as the above ground carbon stock in that the highest BGC stock was recorded for dense forest with the carbon stock of 37,143 tons.

**Table 15** Carbon storage distribution among the three forest strata (tonns/ha)

Forest strata	Area (ha)	Above -ground carbon ( tons)	Below-ground carbon (tons)	Total Carbon (tons)	Carbon density (tons/ha)
Dense forest	704	168,833	37,143	205,977	293
Medium forest	1,408	163,990	36,079	200,068	142
Open forest	1,115	119,974	26,396	146,370	132
Total	3,227	452,797	99,618	552,415	172

The average carbon density of the upper catchment forest of Addis Ababa was estimated at 172 tons/ha. The results indicated that the carbon storage varied among different urban forest types (dense, medium and open) with different species composition. The highest carbon density was recorded in the dense forest (293 tons/ha) (Table 15) and among species types *Eucalyptus globulus* took the highest share of carbon density (257 tons/ha) followed by *Juniperus procera* (96.8 tons/ha) (Table 16). However this must be understood that the allometric equation employed to calculate the amount of biomass stored by the urban forest of the study area is not species specific, rather it is a general model for dry forest, thus species wise comparison of biomass and carbon storage is not straight forward.

**Table 16** Average C stock density of different species among the three forest strata

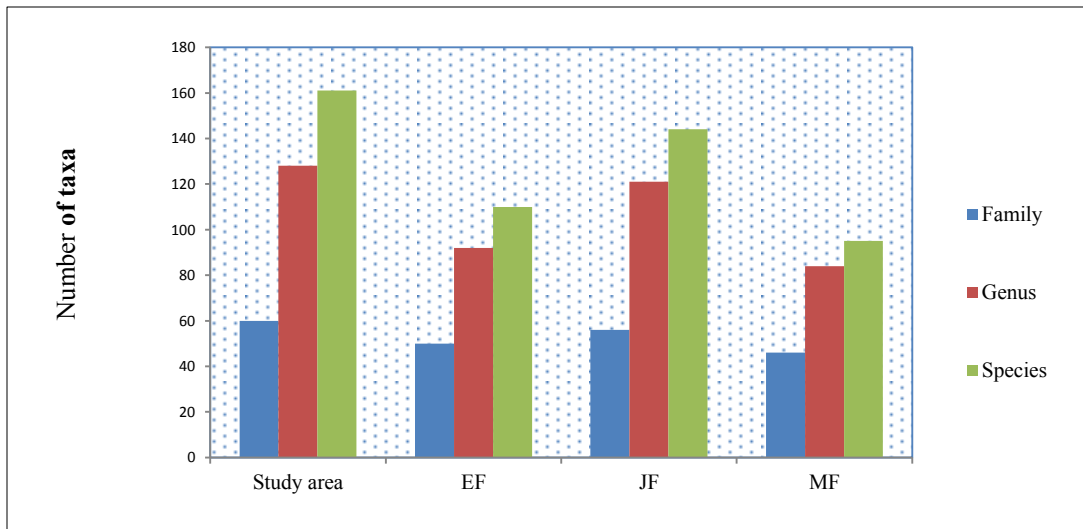
No	Species	C density (tons/ha)			Total
		Dense forest	Medium forest	Open forest	
1	<i>Acacia abyssinica</i>	0.60	0.76	0.52	1.88
2	<i>Acacia decurens</i>	-	-	3.66	3.66
3	<i>Acacia saligna</i>	-	-	0.04	0.04
4	<i>Allophylus abyssinica</i>	3.39	-	-	3.39
5	<i>Bersema abyssinica</i>	-	-	2.22	2.22
6	<i>Buddleja polystachya</i>	-	1.06	-	1.06
7	<i>Carissa spinarum</i>	30.35	9.54	-	39.89
8	<i>Clausena anisata</i>	-	0.04	-	0.04
9	<i>Croton macrostachyus</i>	1.87	2.33	-	4.20
10	<i>Cupressus lusitanica</i>	-	5.04	0.14	5.18
11	<i>Discopodium penninervium</i>	-	1.88	1.18	3.06
12	<i>Dombya torrida</i>	-	-	1.12	1.12
13	<i>Dovyalis abyssinica</i>	5.17	0.09	-	5.26
14	<i>Ekebergia capensis</i>	-	-	1.36	1.36
15	<i>Eucalyptus camaldulensis</i>	-	-	0.29	0.29
16	<i>Eucalyptus globulus</i>	104.93	77.16	74.95	257.04
17	<i>Eucalyptus grandis</i>	-	-	0.60	0.60
18	<i>Hypericum revolutum</i>	-	-	2.39	2.39
19	<i>Juniperus procera</i>	56.02	14.94	25.85	96.81
20	<i>Maesa lanceolata</i>	0.66	0.32	-	0.98
21	<i>Maytenus andata</i>	-	0.82	-	0.82
22	<i>Maytenus arbutifolia</i>	36.60	12.68	3.19	52.47
23	<i>Maytenus senegalensis</i>	-	-	0.04	0.04
24	<i>Myrsine africana</i>	11.07	7.17	6.23	24.47
25	<i>Myrsine melanophloes</i>	-	0.06	1.18	1.24
26	<i>Nuxia congista</i>	4.95	-	-	4.95
27	<i>Olea europaea subsp. Cuspidata</i>	-	-	0.43	0.43
28	<i>Olinia rochetiana</i>	10.53	1.97	0.09	12.59
29	<i>Osyris quadripartita</i>	-	-	0.46	0.46
30	<i>Pentas schimperiana</i>	18.05	-	-	18.05
31	<i>Pittosporum viridiflorum</i>	-	0.83	1.12	1.95
32	<i>Rhus glutinosa</i>	-	-	1.12	1.12
33	<i>Rosa abyssinica</i>	10.98	1.94	1.54	14.46
34	<i>Rubus apetales</i>	-	-	1.12	1.12
35	<i>Rubus steudneri</i>	-	2.02	-	2.02
36	<i>Schefflera abyssinica</i>	-	-	2.06	2.06
37	<i>Vernonia amygdalina</i>	-	-	0.97	0.97
Total		295.20	140.60	133.36	569.65

### 3.5.2 *Habitat support and protection of soil erosion*

These ecosystem functions were studied within the site designated and being developed as Gullele Botanic Garden.

#### 3.5.2.1 *Floristic composition*

The result showed that Gullele Botanic Garden contained a total of 161 species belongs to 128 genera within 60 families under the three dominant forest categories where 144 species in Juniperus forest, 110 species in Eucalyptus forest and 97 species in mixed forest (Appendix 1). Most of the families (96%) are represented in Juniperus dominated forest (JDF) while the Eucalyptus (EF) and mixed forest (MXF) categories represent 86% and 77% of the families respectively. It is also revealed that 95%, 72% and 66% of the genera has been represented in Juniperus, eucalyptus and mixed forest categories respectively (Figure 28).



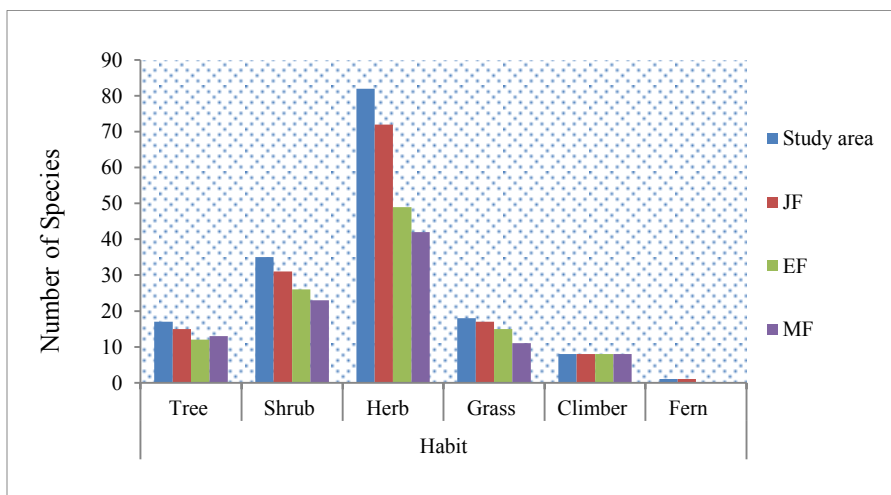
**Figure 28** Number of recorded Families, Genera and Species

The results also showed that all the recorded plant species by growth habit belonged 17 to trees, 35 to shrubs, 81 to herbs, 18 to grasses, 8 to climbers and one to fern which have been distributed in the three forest categories (Table 17).

**Table 17** Number of species recorded by growth habit along forest category

Forest category	Growth habit					
	Tree	Shrub	Herb	Grass	Climber	Fern
JDF	15	31	72	17	8	1
EDF	12	26	49	15	8	0
MXF	13	23	42	11	8	0
Study area	17	35	82	18	8	1

Number of species with tree habit ranged from 12 to 15 in the three forest categories where the highest being in Juniperus dominated forest (JDF) followed by mixed forest (MXF) and eucalyptus dominated forest (EDF) forest categories (Figure 29).



**Figure 29** Graph showing number of species by growth habit and forest category

Comparing the three forest types, Juniperus dominated forest (JDF) exhibited 88% of the trees, 87% of the shrubs, 88% of the herbs and 94% of the grasses while the number of species by growth habit found in the eucalyptus dominated forest (EDF) are 71% trees, 74% shrubs, 61% herbs and 83% grasses. Species distribution by growth habit in the mixed forest category consisted 77% trees, 66% shrubs, 52% herbs and 61% grasses. The climbing species were recorded equally within the three categories.

### 3.5.2.2 Floristic diversity

The Shannon-Wiener information function for the present study showed that the floristic diversity in the Gullele Botanic Garden was 2.76 for Eucalyptus dominated forest, 3.24 for Junipers dominated forest and 2.98 for mixed forest with species richness 113, 143 and 95 respectively. Species equitability was recorded as 0.58 for Eucalyptus dominated forest, 0.65 for Junipers dominated forest and 0.66 for mixed forest (Table 18).

**Table 18** Species diversity among the three forest categories in GBG

Diversity indices	Forest type		
	Eucalyptus forest	Juniperus forest	Mixed forest
Taxa_S	113	143	95
Individuals	2827	5076	2836
Shannon_H'	2.76	3.24	2.98
Evenness_e^H/S	0.14	0.18	0.21
Equitability_J	0.58	0.65	0.66

### 3.5.2.3 Vegetation cover type and soil erosion features

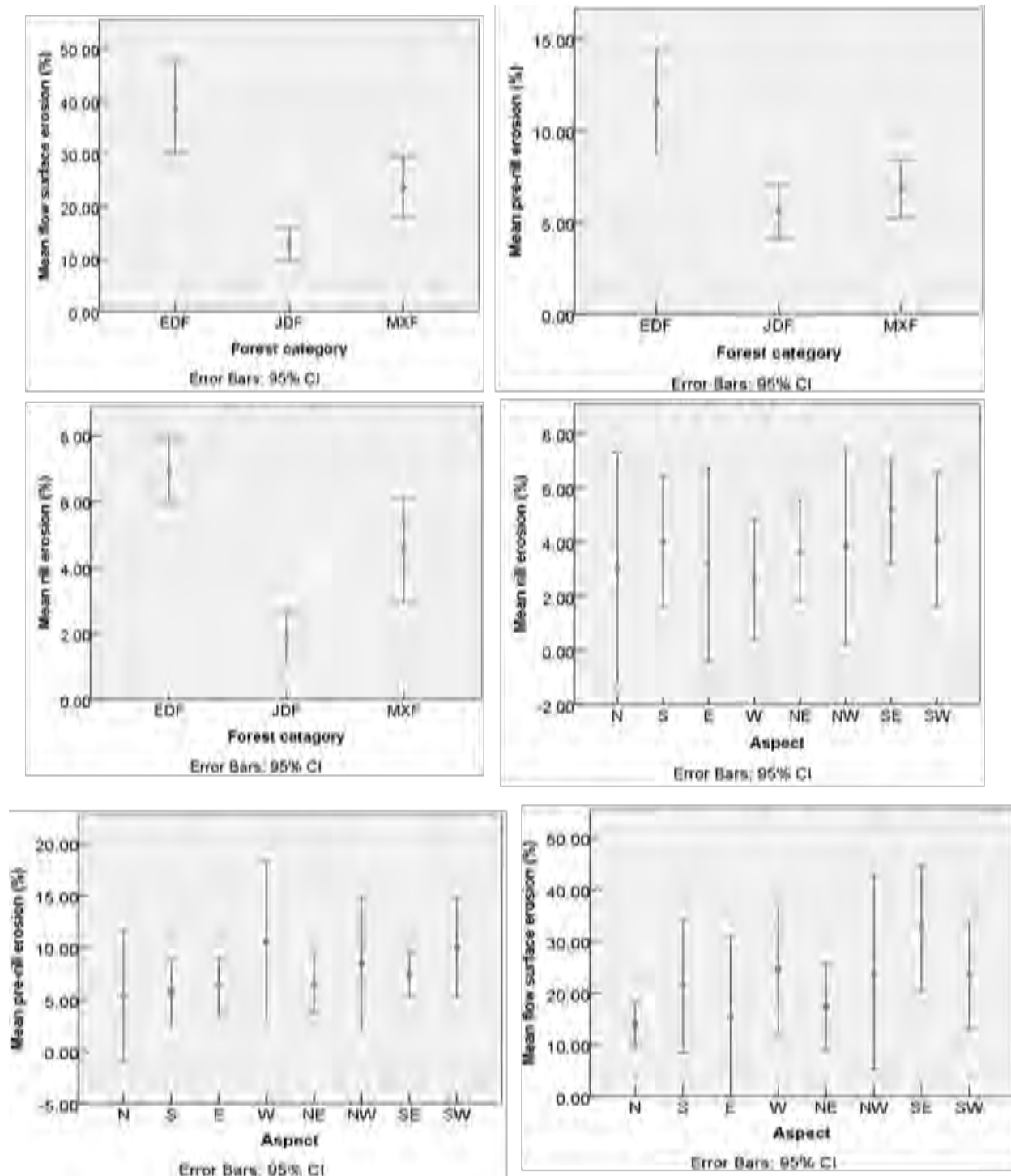
The result showed that the formation of soil erosion features are significant ( $p < 0.001$ ) among the three forest categories including Eucalyptus forest, Juniperus forest and Mixed forest (Table 18).

**Table 19** (Mean  $\pm$ SE) soil erosion features (estimated as percentage of bare ground ) by forest types

Soil erosion features	Forest categories			<i>p-value</i>
	Eucalyptus forest	Juniperus forest	Mixed forest	
Flow surface erosion	38.78 $\pm$ 4.15 <sup>a</sup>	12.81 $\pm$ 1.65 <sup>b</sup>	2.71 $\pm$ 23.65 <sup>c</sup>	<0.001
Pre-rill erosion	11.56 $\pm$ 1.34 <sup>a</sup>	5.66 $\pm$ 0.73 <sup>b</sup>	6.82 $\pm$ 0.76 <sup>c</sup>	<0.001
Rill erosion	6.94 $\pm$ 0.46 <sup>a</sup>	1.88 $\pm$ 0.37 <sup>b</sup>	4.53 $\pm$ 0.76 <sup>c</sup>	<0.001

*Tukey HSD, abc= means along the row followed by the different letters of superscript showed significantly different ( $p < 0.001$ ), SE = standard error*

However, other environmental variables such as aspect, elevation and slope do not show significant difference in the formation of soil erosion features (Figure 30). This could be due to high under growth particularly under Juniperus forest and mixed forest slop, elevation and aspect were not the dominant factor for soil erosion features.



**Figure 30** (Mean  $\pm$ SE) soil erosion features (estimated as percentage area coverage of the bare ground) by forest type

## 4. DISCUSSION

### 4.1 *Urban Morphology Types (UMTs) mapping*

The UMTs analysis revealed that in 2006 the most dominant higher level UMT class was agriculture covering a total area of 19,639 hectares (38%) followed by residential with total area coverage of 16,596 hectares (31.9%). This study is in line with other studies where in Dar es Salaam overall residential UMTs were estimated to contain 50% of the growing stock of urban expansion and residential UMTs account for the largest surface area of the city which are rapidly expanding due to population increase (Cavan *et al.*, 2014)

Accordingly, urban growth with high density of residential development and the loss of green spaces like vegetation and agricultural land are the most important conversions in this study. Similar results were reported for other studies (*e.g.* Fazal, 2000; Yuan *et al.*, 2005) where human activities have been recognized as a major force for shaping the biosphere and known for converting green spaces into built environment. With rapid urbanization and the extension of urban areas, combined with continuing population growth green areas are subjected to continuous loss over time. It has been also noticed that the most profound human alteration of the natural environment in the city of Addis Ababa is through the imposition of structures, buildings, paved surfaces and compacted bare soils on the ground surface which paved the way for increased evapotranspiration from the green surface whereby affect the provision of ecosystem services (Kume *et al* 2010)

The results of UMTs analysis of Addis Ababa provide an initial indication of areas of the city that are likely to be more built or vegetated and used as the thematic and spatial framework for

an assessment of multiple ecosystem functions. Thus, UMTs serve as spatial units linking physical features, human activities and natural processes and indicated that formal open spaces are likely to have more vegetated surfaces whereas town centers have been crowded with built cover (Gills, 2006). The analysis of physical structures at different scales as well as patterns of movement, land use, ownership or control and occupation could be a base for land cover investigation and used for determining the environmental performance of the municipality (Pauleit & Duhme, 2000; Nowak *et al.*, 2001; Whitford *et al.*, 2001; Pauleit *et al.*, 2005). The results presented here in the present study can contribute positively to the ongoing debate around development in city and the relationships between the natural and built environments and provide guidance for those challenged with this environment.

#### ***4.2 Changes in Urban Morphology Types***

Some UMTs in the study area had shown increase in spatial extent between the study period with a notable increase in residential category, which could be linked to increasing human population in the city and the need for high demand for living and business areas. In 2011, residential UMTs stand out with the highest land coverage (33.3%) of the total area indicating rapid conversion of area to residential development from other land uses.

The tremendous increase in the residential area between 2006 and 2011 could be attributed to the accelerated population growth, which is equally demanding on housing and working area. Within the residential UMTs, massive development of condominium with multistory and Villas with single stories had been increased by 170% and 43% respectively between the two periods. However, a decreasing trend was observed in the expansion of mixed residential by 20% during

the same period. Most of the increases in many UMTs were at the cost of agriculture and mineral and quarry areas. The salient characteristics, which emerge by comparing the two UMTs maps of 2006 and 2011, were explained by significant increase in the built-up area mainly due to development in the condominium and multistory, villa & single stories residential units. This growth has been including both the apartment buildings designed for the planned urban expansion and unplanned settlements in the available open spaces. Cavan *et al.* (2014) reported that in Addis Ababa, the current urban renewal strategy to convert high density informal unplanned settlements into formal planned housing needs to explicitly account for green structure provision to avoid adverse effects on future supply of temperature regulation services.

Some urban researchers (*e.g.* Conzen, 1969; White hand, 2004; Cavan *et al.*, 2014) reported that characteristics of urban areas could be conceptualized and subsequently mapped through the idea of urban morphology types (UMTs) classifications that combine parts of urban form and function. Moreover, mapping of UMTs could provide biophysically relevant meso-scale geographical units, which can be used as the basis for understanding environment related impacts. For instance, through the analysis of UMTs one can assess the urban green patterns and the environment regulation services provided by urban green spaces.

An investigation into the urban morphology types (UMTs) of Addis Ababa has shown that the extent to which green space infuses the built matrix. The 2011 UMTs mapping showed an increase of about 20% of the built surface compared to the 2006 mapping. This is demanding for planning strategy to balance the residential area and other built structure with the green space so as to keep the quality of urban life.

Gill *et al.* (2008) has shown that UMT units could be used to link human activities and natural processes. This is because UMT units can be used as a coherent spatial framework through which a series of other indicators can be derived, such as associated with surface cover and population characteristics. UMT based land cover reports are predominantly essential for detailed understanding of the non-built structures within all land use types.

### ***4.3 Land surface cover assessment***

The result showed that almost half of the land cover of Addis Ababa as a whole can be grouped as *'\_evapotranspiring'* (56% in 2006 and 47% in 2011); this included the land cover types of none eucalyptus trees, eucalyptus trees, shrubs/bush vegetation, grassland, field crop, vegetable crop, and the water body. A field crop, which is within the *'\_evapotranspiring'* surfaces category alone, covers 21% of the total area of Addis Ababa. Woody vegetation another important *'\_evapotranspiring'* surface category which includes none eucalyptus trees, eucalyptus trees, bush/shrubs, covers about 18% of the city of Addis Ababa.

The distribution of these land cover types varies considerably between the UMT categories. For example, within the residential UMT categories the proportion of *'\_evapotranspiring'* surfaces ranges from 20% (for condominium and multi-storey) to 26% (for mud / wood construction); whereas in the industry and businesses UMT, the range is from 7% (for storage and distribution) to 61% for palace). Bare ground accounts for 27% in the 2006 surface cover and 35% in 2011 of the area and showed an increasing trend between the two periods; this is split into two categories of dark and light ground. Built surfaces account for 17% in the 2006 surface cover 18% in the

2011 of the area; this includes buildings split into built structure types I and II) as well as other impervious surfaces.

This result agrees well with previous urban morphology and surface cover studies elsewhere (e.g. Gill, 2006) where high proportion of evapotranspiring surfaces in an urban environment was recorded in England which often was thought as consisting primarily built surfaces. The UMT based surface cover analysis was conducted with a combination of UMT mapping provided an effective means to characterize the urban environment including the identification of detailed land uses that are known to contain significant amounts of urban greenspace and it also highlights where greenspace is more likely to occur within the urban matrix itself (Gill, 2006). This type of analysis helps to produce maps at a finer scale relevant for detailed urban planning and district or neighborhood level implementations. For instance, vegetation on private and institutional land, which is not normally shown on city maps, can be clearly mapped with this method and used to plan important environmental management strategies (Pauleit *et al.*, 2005; Whitford *et al.*, 2001).

#### ***4.4 Changes in land surface cover types***

The analysis showed that 4,501 ha (15.5%) of the evapotranspiring surfaces present in 2006 were lost by 2011. The most considerable overall rate of loss has been attributed to field crops (by 2,044 ha, equivalent to 16%), followed by grasses (by 1,639 ha, equivalent to 33%), eucalyptus trees (by 761 ha, equivalent to 31%) and shrubs (by 303 ha, equivalent to 9%). There has been a slight increase in other non-eucalyptus trees (by 122 ha, equivalent to 3%), vegetable farm (by 54 ha, equivalent to 16% ha) and water (by 70 ha equivalent to 33% ha).

At the same time, bare ground increased by 28.6% and built surfaces increased by 484 ha which is a net increase of 5% between 2006 and 2011. The overall increase of bare ground has been explained by expansion of dark bare ground and light bare ground. Similarly, the overall rate of increase of built structure has been totally ascribed to built structure type I (by 1062 ha, equivalent to 145%). The increase in built surfaces was validated by a substantial increase in the road, condominium and garage. There has been a slight decrease in the built structure type II (by 196, equivalent to 3%) and other impervious surfaces by 16%.

There has been also much variation between UMT categories. The biggest loss of evapotranspiring surfaces (in terms of area covered) was in the field crops UMT (4,659 ha lost), followed by mud and wood construction (1,163 ha lost), and plantation (691 ha lost). The biggest gains in evapotranspiring surfaces cover is explained in bare land UMT (1,290 ha gained) followed by the villa and single storey UMT (391 ha gained), condominium multistorey (304 ha gained), garage (253 ha gained) and office (136 ha gained).

#### ***4.5 The contribution of green spaces for ecosystem service functions***

The result showed that the green spaces in the city of Addis Ababa have been contributing different ecosystem service functions among which regulation and supportive functions are specifically highlighted by this study. The existing and potential contribution of green spaces through carbon storage has been given great attention. The forest particularly, in the upper catchment of Addis Ababa has substantial importance in the amelioration of local climate and ensuring healthy life in the urban environment.

#### ***4.5.1 Carbon storage capacity of the urban forest***

Carbon storage and sequestration is one of the dominant regulating functions of ecosystem service. The carbon density in the study area varied with forest categories viz 293t/ha, 142t/ha and 132t/ha in the dense, medium and open forest strata respectively. The average carbon density being 172 t/ha implies that the upper catchment forest of Addis Ababa is providing considerable importance to the Addis Ababa city in reducing greenhouse gas accumulation (CO<sub>2</sub>) and contributing towards the national green economy development strategy of the country. The carbon stock recorded in this study particularly the one within the dense forest which is comparatively a semi natural vegetation is close to the previous researches of afro-montane forest e.g. Tesfaye (2007) reported for afro-montane forest as 403 ton/ ha and Mohammed ( *et al.*, 2014) reported 588.17 ton/ha for Tara Gedam forest.

The carbon storage by the upper catchment forest of Addis Ababa varies among different forest strata and with the species diameter distribution. For instance, the most important parameters in determining carbon stock are tree species have different carbon storage rates where smaller trees have lower carbon storage levels than larger trees (Nowak, 1993). In this study, the differences in biomass and carbon accumulation among different forest stratum could be largely due to differences soil characteristics and anthropogenic disturbances, which greatly affect the growth rates of plants (Redondo, 2007).

Generally, the accumulation of carbon currently stored by urban forest is a strong argument for at least conserving and maintaining the present urban forest structure. This implies that high deforestation rate of urban trees without replacement will act as an increment of net CO<sub>2</sub> to the

atmosphere, both directly and indirectly. Thus, enhancing further afforestation in combination with selecting the right species with higher canopy for maintaining urban trees can make urban forest a larger sink for atmospheric carbon, along with producing other urban forest benefits (e.g. temperature reduction, air pollution mitigation and air quality improvement).

#### **4.5.2 Floristic composition**

The floristic composition, recorded under the three dominant forest categories of Gullele Botanic Garden where 144 species in Juniperus forest, 110 species in Eucalyptus forest and 97 species in mixed forest are comparable with other studies (e.g. Fetene *et al.* (2010) recorded 142 species Menagesha Suba forest and 81 for Dindin forest (Shibru and Balcha, 2004) which both are dry afro-montane vegetation similar to this study area. The reason for the variation in species composition could be attributed to the nature of vegetation type that fosters the growth and regeneration of undergrowth with respect to the forest type under consideration. This could be explained by larger species composition in the Juniperus dominated forest as compared to eucalyptus dominated and mixed forest in that Juniperus is good species in terms of promoting the growth of other species under its lower strata. Having several species in a particular forest would benefit the plants and animals through providing alternative habitats, ameliorating local climates and controlling soil erosion.

#### **4.5.3 Floristic diversity**

The floristic diversity ( $H' = 2.76$  for Eucalyptus dominated forest,  $H' = 3.24$  for Junipers dominated forest and  $H' = 2.98$  for mixed forest) in the present study is essentially comparable with other studies, e.g. Senbeta (2006) has recorded similar diversity indices of 3.17 for Bonga forest, 2.83

for Berhane-Kontirforest, 2.60 for Harena forest and 2.80 for Yayu forest. Higher diversity value in the present study reflects the good management strategies that enable the promotion of indigenous species in the Botanic garden.

Forest with diversified plant species also has an implication in terms of supplying several ecosystem services that could benefit both the peoples' livelihood as well as nature conservation. In this regard, the higher species diversity in the Gullele Botanic Garden will ensure the survival of plants and animals community through providing essential habitat, food and protection of external factors.

#### ***4.5.4 Vegetation cover and protection of soil erosion features***

The result suggests that different vegetation types may have different tendencies in the controlling of rill erosion formation. Aboveground vegetation with intercepting vegetation layer near the soil surface is known to favor water infiltration and to protect soil from erosion. In this study, vegetation categories under Juniperus forest and mixed forest are found to have more diversified species with rich under growth than Eucalyptus forest and have the ability to reduce the intensity of rill erosion. On the other hand, tall trees like Eucalyptus forest without understory can have higher kinetic energy that aggravates runoff generation and erosion initiation (Valentin *et al.*, 2005) which this exactly fit with the result of this study that all the three erosion features were found to be highest as compared to the Juniperus dominated and mixed forest categories. Generally, vegetation with high number of species diversity coupled with interlocking strata could provide the essential ecosystem services. Hence, environment planner particularly at the urban environment should consider the integration of vegetation from

lower level grasses and herbs to the higher plants to be included in the management and conservation of green spaces.

## 5. CONCLUSION

The study has demonstrated that the urban environment consists a complex morphological units evolved through combinations of natural or physiognomic features and continued application of human actions which gradually modify or change the natural elements. Characterizing the urban environment in to detailed disintegrated or simplified units has given paramount importance in bringing the complex units in to working spaces in other words to use as bases for urban planning. UMTs mapping, change detection and analysis has clearly shown which morphological units occupy what proportion of the total land area and which ones and how liable are to be changed between 2006 and 2011 together with possible causes for some of the rapid conversions.

Consequently, rapid conversion of green spaces (agriculture, vegetation.) to impervious surfaces was noticed which increased the built-up area in all directions of Addis Ababa. UMT based surface cover analysis has also provided essential information to understand the environmental performance of the different surface cover types and develop mitigation plans of urban heat island and enabled the detection of green spaces patches which are scattered in smaller proportions along private residential and commercial estates and missed in conventional mapping approaches.

Biomass and carbon estimation of for the upper catchment forest of Addis Ababa indicated that even at the current low level of conservation and management it exhibited a good level of carbon storage potential giving the possibility to be funded through carbon trade with some improvements in its planning and management.

The species diversity and floristic composition assessment also revealed that removal of eucalyptus trees and replacement by indigenous trees favored a high rate of understory growth with more species diversity and floristic composition. Besides forest with no or lower eucalyptus trees showed lower incidence of soil erosion features which also indicate high rate of water infiltration and ground water recharging.

The present study has been limited to the availability of a high resolution aerial photography in 2006 and 2011 making the change detection period relatively shorter. A further investigation is needed on how the UMT approach could be applied in the process of urban renewal to come up with a balance between built-up and open green spaces. Methodological development to harmonize the surface cover assessment to the UMT spatial units would play a crucial role to trace fragmented small greenspace patches in many private holdings enabling to come up with realistic evaluation of the cumulative environmental performance of greenspaces within a city.

## **6. PLANNING RECOMMENDATIONS**

The results have shown that in the city of Addis Ababa there has been rapid conversion of green spaces to impervious surfaces of streets and buildings. The study indicated that impervious surfaces and built-up areas increased substantially while green space development is hampered by various challenges. The riverbanks of Addis Ababa are occupied by settlements and industries, prohibiting its intended ecosystem services, besides opening access to direct release of both solid and liquid wastes to the river body and blocking water ways. Human alterations of the natural area have threatened native plant and wildlife communities as well as associated ecological functions. This has led to loss of natural areas due to direct conversion in to houses, roads and other built environments, fragmentation of natural spaces due to conversion of green space into other land use types is resulted in the formation of smaller and more isolated patches of open space, which greatly alters the way in which natural systems function, degradation of water resources resulted in the overflow of the storm water that reduces the capacity of riparian areas to control floods and it threatens the health of the environment.

Therefore, the priorities for planners and greenspace managers should be to ensure that the functionality of greenspace is properly understood in relation to the built environment and proper conservation strategy should be put in place. In this regard, for maintaining and conserving a clean urban environment for all green spaces in the city should be ecologically networked and the planning of green space should aim at ensuring its multi-functionality.

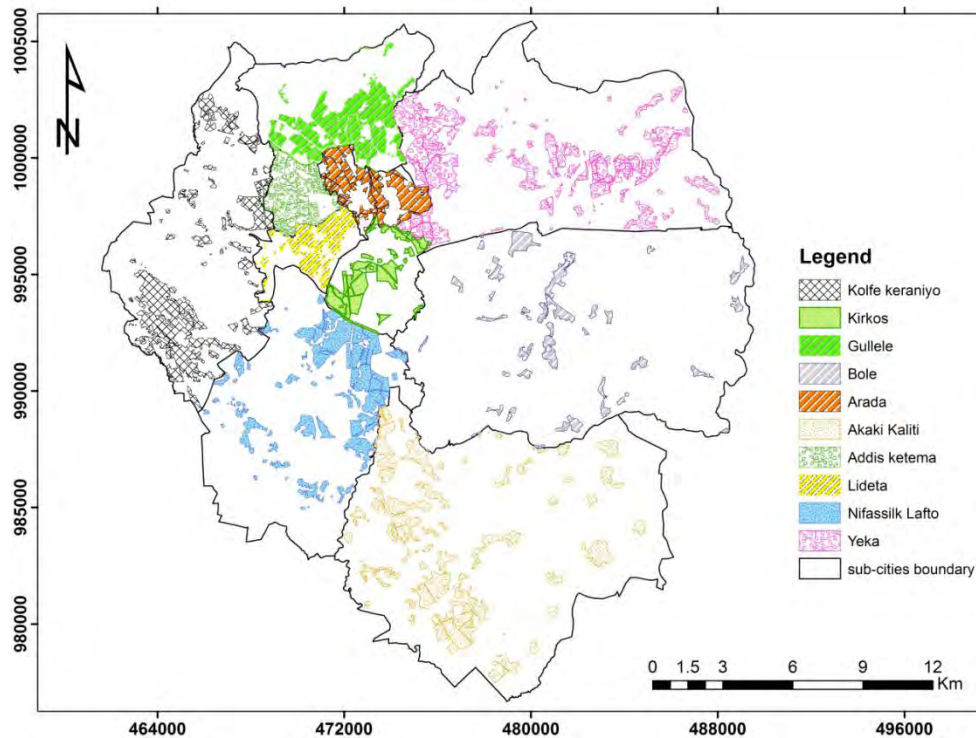
In the newly developing master plan of Addis Ababa, green space planning is one of the main components in which a number of issues had been identified as drawbacks in the last master plan

including; poor classification of green space components, new developments in the upper catchment areas which led to flooding, low levels of accessible green space, encroachment of informal settlements and industries on river banks and loss of urban agricultural lands, the salient results from the analysis of this study are recommended towards improving the urban greenspace planning and management in Addis Ababa.

### **6.1 UMTs based urban green space Planning**

Green space planning should take place at all scales: from the individual parcel, to the district, sub-city and city levels. At the parcel level this could mean designing homes and businesses around green space. At the district level this could mean creating greenways to link existing parks. At the sub-city and city level this could mean protecting broad landscape for recreation, protection and conservation function.

The UMTs mapping and analysis for Addis Ababa showed the discrete components of the urban environment. For planning the greenspace in the urban renewal program, mud and wood constructed houses UMT was analyzed by overlaying this UMT on the sub city map of Addis Ababa (Figure 31). This alternative approach to increase the supply of ecosystem services through the establishment of new green spaces that would be proportional to the renewal of built environment is particularly operational in the process of conversion of the mud and wood constructed houses to villa and multistorey including condominiums. This intervention will directly increase the per capita greenspace, fulfilling the internationally accepted definitions of accessibility and reach of residents.



**Figure 31** Spatial distribution of mud and wood constructed houses by sub-cities

It has been explained that in the structure plan 41% of the total area of Addis Ababa is suggested to be a green space, which includes agriculture and forest in the upper catchment area. But in this study 20% or half of the proposed by the master has been considered to be reserved for the establishment of green space during the conversion of mud and wood constructed houses into modern housing systems including condominiums by which 1668 hectares out of the total 8340 hectares in all the ten sub cities could be developed in to green spaces (Table 20)

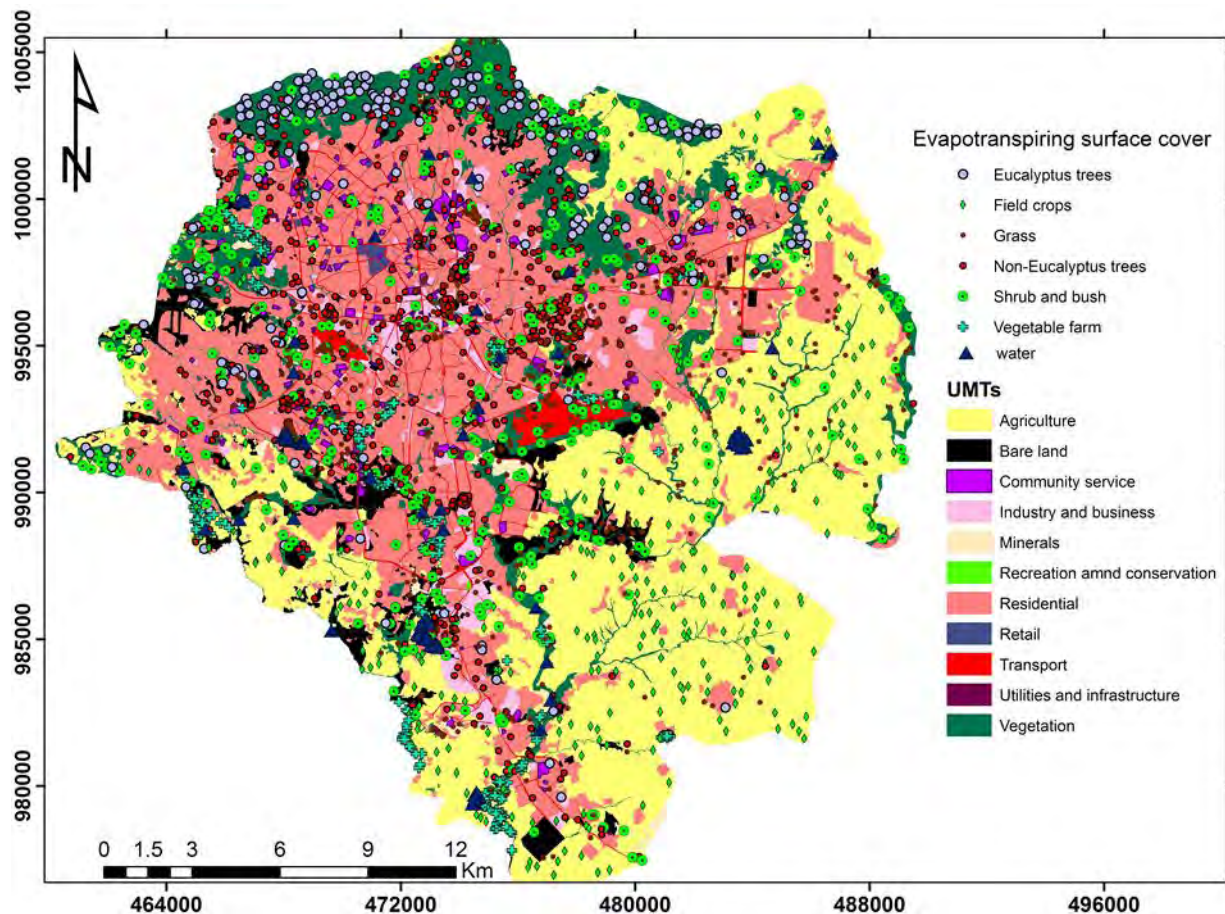
**Table 20** Recommended green spaces in the renewal of mud and wood constructed UMT

No.	Sub-Cities	Area under mud and wood constructed houses (ha)	Proportion At Sub-city Level (%)	20 % of the area under mud wood constructed UMT (ha)
1	kolfe Keraniyo	1168	14	234
2	Kirkos	361	4	72
3	Gulelle	884	11	177
4	Bole	529	6	106
5	Akaki Kaliti	1444	17	289
6	Addis Ketema	429	5	86
7	Arada	507	6	101
8	Lideta	328	4	66
9	Nifas Silk Lafto	1071	13	214
10	Yeka	1619	19	324
Total		8340	100	1668

Therefore, during the urban renewal program it has to be mandatory for the planner to include 1668 ha of land to be reserved for the establishment of new green space for a sustainable, conducive and livable urban environment.

## **6.2 Planning and support non formal greenspaces development**

The UMTs based surface cover assessment showed that there is a considerable vegetation growth over many of the UMTs considered as non-green and impervious. Of course availability of vegetation is not evenly distributed across all the UMTs; rather it is strongly influenced by UMT types. For instance high proportion of green is observed on the forest, crop fields and vegetable farms but low on the peripheries of impervious surfaces (Figure 34).



**Figure 32** Spatial distribution of green space representing land cover types and UMTs

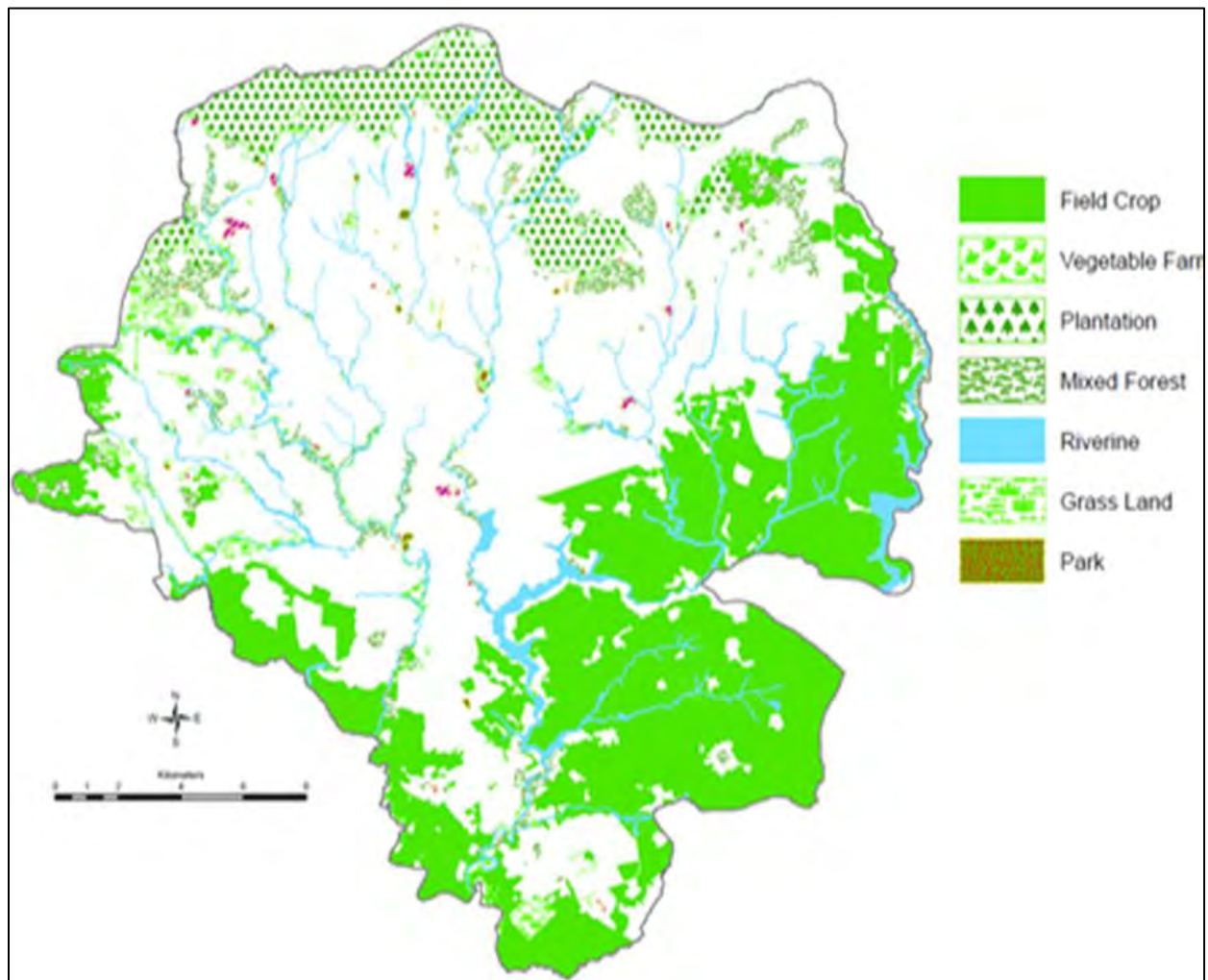
However, despite the uneven distribution of vegetation, growth and development of trees, bushes, grasses and flowers in private residential compounds, commercial buildings, government and none government institutions exhibited substantial green cover which provide ecosystem services like temperature regulating, interception of rainfall splash that reduces rain water flooding as well as aesthetic and recreational values. Hence institutions mandated with development and management of urban greenspace must draw special strategies to deliver an urban green extension system. This is unique from the rural nature conservation programs in that it is carried within a limited area and needs careful selection of species, and the growing media

for plants as well greening the roofs. Only through such concerted efforts and well-structured programs, a city like Singapore has achieved the name of "A City in the Forest".

### **6.3 Landscape based green space planning and management**

Green space is one of the landscape components of urban environment represented as a patch where the built-up area is the dominant share of urban matrix. The structure plan of Addis Ababa (ORAAMP, 2000) sub categorized the green space in to four namely; forest, green along rivers, parks and agriculture while the final draft of the land use plan of Addis Ababa (Addis Ababa Master Plan Development project office 2016) in its land use codes has proposed the open evapotranspiring space under two major categories as green infrastructure which is further sub divided in to six as (i) multifunctional forest, (ii) river buffer, (iii) regional park, (iv) public parks, (v) special parks and (vi) neighborhood parks and urban agriculture. The CLUVA research findings which have contributed partial input for the present research work, have grouped the green spaces in to seven categories (Figure 33) namely: (i) field crops, (ii) vegetable farms, (iii) plantation forest (iv) mixed forest, (v) riverine vegetation (vi) recreational parks and (vii) grassland.

Therefore, planning of green space management based on these broad categories could enable to achieve the provision of comprehensive ecosystem services at landscape level. For instance, multifunctional forest development on the upper catchment of Addis Ababa with a slope greater than 15% to provide fruits, honey, and wood for fuel and construction, carbon sequestration and storage, watershed management, slope stabilization, flood mitigation, habitat for wild animals and indigenous plants, and recreation.



**Figure 33** Green area map of Addis Ababa (Source: CLUVA, 2014)

The interconnectedness of green spaces through river corridors, vegetable and agricultural farms, plantations and mixed forests and street corridors in the entire landscape would enable to generate substantial ecosystem service and can be used to create ecological networks and provide multiple ecosystem services such as shade, regulation of air temperature, air pollution and

improve aesthetics values for the urban communities. Maintaining fertile land along the river corridors can benefit primarily for providing vegetables and fruits.

## **6.4 Approaches and capacity to implement the recommendations**

### **6.4.1 Planning Approaches**

Greenspace management is a framework that provides a strategic approach to nature conservation, in urban planning initiatives as with all other built infrastructure utilities such as: roads, rail trails, water, and other essential community services systems, green space areas should be carefully planned, designed, and invested in advance. The applications of planning, design and financing basis for built infrastructure should be similarly used for green space planning initiatives, which include:

- (i) Designed holistically:** like the transportation networking system, green space should be designed to link diverse green space elements into a system that functions as a whole, rather than as separate that could meet the requirements of end users.
- (ii) Planned comprehensively:** similar to all other urban infrastructures, like power supply and communication systems, the green space systems need to be planned comprehensively to provide ecological, social and economic benefits.
- (iii) Planned and implemented with public participation:** like the development of built infrastructure systems, the green space systems should be planned and implemented with the participation and input from the wider community.
- (iv) Based on multidisciplinary professional involvement** like the design and planning of development infrastructures, green space systems development should involve

professional disciplines such as horticulture, vegetation, landscape architecture, ecology, urban and regional planning.

- (v) **Funded up-front:** Like other infrastructure systems, the design and implementation of green space systems need to be funded as a primary public investment with other essential services, rather than with money that is left over.

Application of the following tools and approaches would improve planning problems and enable to fully integrate the urban greenspaces issues in urban planning.

#### **6.4.2 Ecosystem services based approach**

The Millennium Ecosystem Assessment (MEA) classified ecosystem services in to four main groups (Millennium Ecosystem Assessment, 2005) which include provisioning, regulating, cultural and supporting. Nowadays a high-quality living environment is considered as a living space with green areas suitable for recreation. A greenspace of 1.5 to 2 hectares within a maximum distance of 300m from home is presumably suitable for recreation (Niemela *et al.*, 2010). This is based on the conception that good accessibility is especially important for children, disabled people, and the growing aging population. For instance, Wiik (2005) suggested that a child at primary school level plays only within 300 m from home.

In Addis Ababa, the CLUVA project conducted ecosystem service assessment based on scientific and local evidence, local experience, with the character of the UMTs being considered, including its green structures. The main focus was the extent to which a particular UMT category already supplies the service and that should ideally supply the service with the available potential. Accordingly 14 ecosystem service types were identified that could supply the service

with different level of function (Lindley *et al.*, 2015). The assessment also suggests that the average supply of ecosystem services in Addis Ababa is lower than the need for the services where the mean score for supply of all services was 0.9 compared to a mean of 1.6 in terms of need.

However, the present study suggested that in Addis Ababa there are additional potentials that could offer multiple ecosystem services if proper planning is put in place. This included making accessible the green areas for public use, which is particularly remarkable in many proposed but undeveloped public parks, the green spaces in the upper catchment areas which are essential pools for carbon storage and the floristic unites with diversify plant species serving as a habitat for wildlife and regulating the erosion hazard in the entire urban environment of Addis Ababa.

The biomass and carbon storage estimates presented in this study are an entry points for the conservation of urban forests and could provide basic planning ideas to be considered by international efforts like REDD funding to mitigate the loss of climate change, through reducing the conversion of natural ecosystems. As other studies (*e.g.* Harvey *et al.*, 2009; Gardner *et al.*, 2012) reported, the REDD scheme has the potential to provide significant benefits to biodiversity conservation, through the protection of species diverse forests. In this regard, this study was aiming to analyse ecosystem service from the supportive and regulation point of view and achieved it accordingly through informing that species rich forest is better for controlling erosion than Eucalyptus species dominated forest. But at the end the study identified knowledge gaps and the need for further studies on understanding of the relationship between species diversity and carbon stocks which have not yet been extensively studied in the urban forests and

other vegetation elsewhere in the country. Therefore, greater understanding of the congruence between biodiversity and carbon pools as well as the impact of species composition on ecosystem function should be clearly known in order to inform policy considerations.

### **6.4.3 Link urban green spaces development to policies and strategies**

#### **(i) *National Environmental Policy***

The Federal Environmental Policy of Ethiopia issued in 1997 aims at ensuring sustainable development at different scales and sectors. The policy elements that are pertinent to urban green space development are included in Articles 3.7 and 3.8 which emphasizes ensuring urban development in harmony with the natural environment plan and create urban green spaces. Thus, effective implementation and integration of this policy provides paramount importance for urban greenspace development programs in Addis Ababa and elsewhere in the country.

#### **(ii) *The National Urban Development Policy***

The National Urban Development Policy of Ethiopia that became operational in 2005 indicates the key urban environmental issues and general directions to manage them in Article 4.5.3. Urban greenery has been identified as one of the major issues of concern. Thus, the provision of this guidance or legislation support for the implementation of green space would be beneficial.

#### **(iii) *Forest Development, Conservation and Utilization Policy and Strategy***

The strategy aims at meeting public demand in forest products and fosters the contribution of forest in enhancing the economy of the country through appropriately conserving and developing forest resources. Enforcement of this strategy at national and regional forest conservation

programs would be a welcome addition that would enable delivery of green spaces at urban environment.

*(iv) Urban Green Strategy of Ethiopia*

The strategy was issued in 2012 and has with the following salient aims; green spaces development based on adequate planning with public and stakeholder participation, provision of quality, equitable and accessible green spaces that contribute to environmental protection, biodiversity conservation and climate change adaptation and making urban areas livable. Although, all these issues are indicated in the strategy, the implementation on the ground is not realized which should be a prime concern for cities like Addis Ababa.

**6.4.4 Improve institutional arrangement**

Fundamentally, several institutions in Addis Ababa have put duplicative efforts in managing the green spaces. Therefore different institutions should focus on separate interventions in the urban green space conservation and management with clear none duplicative mandate but additive outcomes such as regulating the city's environment in general and green space management in particular and implementation of greenspace development projects at grass root levels.

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## Appendix 1 List of plant species in the GBG

Species	Vernacular Name	Family	Category recorded
<i>Acacia abyssinica</i> Hochst. ex Benth.	Yabesha grar (Am), Lafto (Or)	Fabaceae	EDF, JDF, MXF
<i>Acacia mearnsii</i> De Wild.	Mimosa (Am)	Fabaceae	MXF
<i>Achyranthes aspera</i> L.	Meret Adrik (Am)	Amaranthaceae	JDF
<i>Achyrocline stenopterum</i> (DC.) Hilliard & Burt	Kurachu (Or)	Asteraceae	JDF
<i>Achyrospermum schimperii</i> Hochst. ex Briq	Yemogn kimem (Am)	Lamiaceae	JDF
<i>Adiantum thalicatroides</i> Schltldl.		Adiantaceae	EDF, JDF, MXF
<i>Agrocharis melanantha</i> Hochst.	Dog (Am)	Apiaceae	JDF, MXF
<i>Agrostis quinqueseta</i> (Hochst. Ex Setud.) Hochst.		Poaceae	EDF, JDF, MXF
<i>Aira caryophyllea</i> L.		Poaceae	EDF, MXF
<i>Alchemilla abyssinica</i> Fresen.	Yemidir Koso (Am)	Rosaceae	EDF, JDF, MXF
<i>Alchemilla pedata</i> Hochst. ex A. Rich.		Rosaceae	EDF, JDF, MXF
<i>Alepidia peduncularis</i> A. Rich.		Apiaceae	EDF, JDF, MXF
<i>Andropogon abyssinicus</i> Fresen	Balemi (Or)	Poaceae	EDF, JDF
<i>Apodytes dimidiata</i> E.Mey. ex Arn.	Donga (Am), Cheleleka (Or)	Icacinaceae	JDF
<i>Argyrolobium ramosissimum</i> Baker		Fabaceae	EDF, JDF, MXF
<i>Argyrolobium rupestre</i> (E. Mey.) Walp.		Fabaceae	EDF, JDF, MXF
<i>Arisaema enneaphyllum</i> Hochst.ex.Rich		Araceae	EDF
<i>Asparagus africanus</i> Lam.	Yeset kest (Am), Seriti (Or)	Asparagaceae	EDF, JDF, MXF
<i>Asplinium aethiopicum</i> (Burm.f.) Bech.	Karole(Or)	Aspliniaceae	EDF, JDF, MXF
<i>Bersama abyssinica</i> Fres.	Azamir (Am),	Meliantaceae	EDF, JDF, MXF
<i>Bidens macroptera</i> (Sch. Bip. ex Chiov.) Mesfin.	Adey Abeba, Kelo(Or)	Asteraceae	JDF, MXF
<i>Bidens prestinaria</i> (Sch. Bip.)	Adey Abeba, Kelo(Or)	Asteraceae	EDF, JDF
<i>Brassica carinata</i> A. Braun	Gomen Zer (Am)	Brassicaceae	JDF
<i>Bromus leptoclados</i> Nees	Wovillo (Or)	Poaceae	EDF, JDF, MXF
<i>Buddleja polystachya</i> Fresen.	Amfar (Am, Or)	Loganiaceae	EDF, JDF
<i>Cardamine trichocarpa</i> Hochst. ex A.Rich.	Yewef gomen (Am)	Brassicaceae	JDF

<i>Carduus leptacanthus</i> Fresen.	Kosheshila (Am)	Asteraceae	EDF, MXF
<i>Carduus schimperi</i> Sch. Bip. ex A. Rich.	Kosheshila (Am)	Asteraceae	EDF, JDF, MXF
<i>Carex spicato-paniculata</i> Bock. ex C.B. Clarke	Merga (Or)	Cyperaceae	EDF, JDF, MXF
<i>Carissa spinarum</i> L.	Agam (Am), Agemsa (Or)	Apocynaceae	EDF, JDF, MXF
<i>Centela asiatica</i> (L.) Urban		Apiaceae	EDF, JDF, MXF
<i>Cheilanthes farinosa</i> (Forssk.) Kaulf.		Sinopteridaceae	JDF
<i>Chenopodium ambrosioides</i> L.	Etse fars(Am), Buchana (Or)	Chenopodiaceae	JDF
<i>Clematis simensis</i> Fresen.	Azo hareg (Am), Hida feti (Or)	Ranunculaceae	EDF, JDF, MXF
<i>Clutia abyssinica</i> Jaub. & Spach	Muka daga (Or)	Euphorbiaceae	EDF, JDF, MXF
<i>Conyza schimperi</i> Sch.Bip. ex A. Rich	Harata hare (Or)	Asteraceae	JDF
<i>Conyza steudelii</i> Sch. Bip.	Yefiyel kitel (Am)	Asteraceae	JDF
<i>Conyza stricta</i> Willd.	Chiro (Am), Hamaresa(Or)	Asteraceae	JDF
<i>Cotula anthemoides</i> L.		Asteraceae	EDF, JDF, MXF
<i>Crassula schimperi</i> Fisch. & C.A.Mey.		Crassulaceae	JDF
<i>Crepis foetida</i> L.	Yebeg gitin(Am), Anano (Or)	Asteraceae	JDF
<i>Crepis rueppellii</i> Sch. Bip	Yefiyel wetet (Am), Dhungo durba(Or)	Asteraceae	EDF, JDF, MXF
<i>Cupressus lusitanica</i> Mill.	Yeferenj tid (Am) ,Gatira (Or)	Cupressaceae	EDF, JDF, MXF
<i>Cyanotis barbata</i> D. Don		Commelinaceae	EDF, JDF, MXF
<i>Cyathula uncinulata</i> (Schrad.) Schinz	Begid zemedede, Dergu, Metene (Or)	Amaranthaceae	JDF
<i>Cynodon dactylon</i> (L.) Pers.	Serdo (Am, Or)	Poaceae	EDF, JDF, MXF
<i>Cynoglossum geometricum</i> Bak. and Wright		Boraginaceae	EDF, JDF, MXF
<i>Dichrocephala integrifolia</i> (L.f.) Kuntze		Asteraceae	EDF, JDF, MXF
<i>Dicrostachys cineria</i> L.		Fabaceae	JDF
<i>Digitaria abyssinica</i> (Hochst. ex A. Rich.) Stapf	Bora, Sari zaba (Or)	Poaceae	JDF
<i>Discopodium penninervium</i> Hochst.	,Ameraro (Am, Or)	Solanaceae	EDF, JDF, MXF
<i>Dovyalis abyssinica</i> (A. Rich.) Warb.	Koshim(Am), Akaku (Or)	Flacortiaceae	EDF, JDF, MXF
<i>Echinops hispidus</i> Fresen.	Kebericho (Am, Or)	Asteraceae	EDF, MXF
<i>Echinops macrochaetus</i> Fresen.		Asteraceae	EDF
<i>Ehrharta erecta</i> Lam.	Gamie (Am) ,Ulaagaa (Or)	Poaceae	EDF, JDF

<i>Ekebergia capensis</i> Sparrm.	Lul (Am), Sembo (Or)	Meliaceae	EDF, JDF, MXF
<i>Eleusine coracana</i> (L.) Gaertn.	Dagusa (Am)	Poaceae	EDF, JDF
<i>Erica arborea</i> L.	Asta (Am), Sato (Or)	Ericaceae	EDF, JDF, MXF
<i>Erythrina brucei</i> Schweinf.	Korch (Am) Welensu (Or)	Fabaceae	EDF, JDF
<i>Eucalyptus globulus</i> Labill.	Nech Bahirzaf, Akaakltii adii (Or)	Myrtaceae	EDF, JDF, MXF
<i>Festuca abyssinica</i> Hochst. ex A. Rich.	Gerbu dade (Or)	Poaceae	EDF, JDF, MXF
<i>Festuca simensis</i> Hochst. ex A. Rich. .		Poaceae	EDF, JDF
<i>Galiniera saxifraga</i> (Hochst.) Bridson	Yeto qula (Am), Adamo (Or)	Rubiaceae	MXF
<i>Galium simense</i> Fresen.	Askit (Am)	Rubiaceae	JDF
<i>Geranium arabicum</i> Forssk.		Rubiaceae	EDF, JDF, MXF
<i>Gerbera piloselloides</i> (L.) Cass.	Ye amora qibe (Am), Balchu (Or)	Asteraceae	EDF, JDF, MXF
<i>Gnaphalium rubriflorum</i> Hilliard.		Asteraceae	EDF, JDF, MXF
<i>Guizotia scabra</i> (Vis.) Chiov	Nug, Mech (Am) Adaaa (Or)	Asteraceae	EDF, JDF, MXF
<i>Hagenia abyssinica</i> (Bruce) G.F. Gmel.	Kosso (Am) Heto (Or)	Rosaceae	JDF
<i>Halleria lucida</i> L.	Misenkero (Am), Kemetea (Or)	Scrophulariaceae	JDF
<i>Haplocarpha schimperi</i> (Sch. Bip.) Beauverd		Asteraceae	JDF
<i>Helichrysum foetidum</i> (L.) Moench.		Asteraceae	EDF, JDF
<i>Helichrysum nudifolium</i> (L.) Less.		Asteraceae	EDF, JDF
<i>Helichrysum rgyranthum</i> O. Hoffm.		Asteraceae	EDF
<i>Helichrysum schimperi</i> (Schultz - Bip.) Moeser	Getin (Or)	Asteraceae	EDF, JDF
<i>Helichrysum stenopterum</i> DC. Prodr		Asteraceae	JDF
<i>Hyparrhenia hirta</i> (L.) Stapf	Sembelet (Am), Chita (Or)	Poaceae	EDF, JDF, MXF
<i>Hyparrhenia tuberculata</i> W.D. Clayton		Poaceae	JDF
<i>Hypericum peplidifolium</i> A. Rich.	Yemidir Koso (Am)	Clusiaceae	JDF
<i>Hypericum revolutum</i> Vahl	Amija (Am),	Clusiaceae	EDF, JDF, MXF
<i>Hypoestes forskalii</i> (Vahl) R.Br	Dhigadhabdu (Or)	Commelinaceae	EDF, JDF, MXF
<i>Hypoestes triflora</i> (Forssk.) Roem. And Schult.	Dergu (Or)	Commelinaceae	EDF, JDF, MXF
<i>Hypoxis villosa</i> (L.) Coville		Hypoxidaceae	EDF
<i>Impatiens rothii</i> Hook.f.	Enshoshila (Am)	Balsaminaceae	JDF

<i>Jasminum abyssinicum</i> Hochst. ex A.Rich.	Enchelbi (Am), Hida Echelbe(Or)	Oleaceae	EDF, JDF, MXF
<i>Jasminum stans</i> Pax.	Kechema arba(Or)	Oleaceae	EDF, JDF, MXF
<i>Juniperus procera</i> L.	Yabesha tid (Am), Gatira (Or)	Cupressaceae	EDF, JDF, MXF
<i>Kalanchoe petitiiana</i> A. Rich.	Andahula (Am), Bosoke (Or)	Crassulaceae	EDF, JDF, MXF
<i>Koeleria capensis</i> (Steud.) Nees		Poaceae	EDF, JDF, MXF
<i>Lactuca inermis</i> Forssk.	Mech argu (Am), Aneno (Or)	Asteraceae	EDF, MXF
<i>Laggera crispata</i> (Vahl) Hepper & J.R.I. Wood	Kes Bedej, Gime (Am), Ajaya	Asteraceae	EDF
<i>Laggera tomentosa</i> (Sch. Bip. ex A. Rich.) Oliv. & Hiern.	Koskoso (Am), Kaskase(Or)	Asteraceae	EDF, JDF, MXF
<i>Leonotis ocymifolia</i> (Burm. f.) Iwarsson	Ras kimir (Am), Bokkollu (Or)	Lamiaceae	JDF
<i>Leucas stachydiformis</i> (Benth.) Hochst. ex Briq		Lamiaceae	EDF, JDF, MXF
<i>Linum trigynum</i> L.		Lamiaceae	JDF, MXF
<i>Lippia adoensis</i> Hochst. ex. Walp.	Kese (Am), Koshonota, Kusaye (Or)	Verbenaceae	EDF, JDF, MXF
<i>Lobelia holstii</i> Engl.		Lobeliaceae	JDF
<i>Maesa lanceolata</i> Forrsk.	Akelawe (Am), Abayi (Or)	Myrsinaceae	EDF, JDF, MXF
<i>Malva parviflora</i> L.	Adgaur, Lut (Am)	Malvaceae	JDF
<i>Maytenus addat</i> (Loes.) Sebsebe	Attat (Am), Kombolsha (Or)	Celastraceae	EDF, JDF, MXF
<i>Maytenus arbutifolia</i> (A.Rich.) Wilczek	Attat (Am), Kombolsha (Or)	Celastraceae	EDF, JDF, MXF
<i>Myrsine africana</i> L.	Kechemo (Am)	Myrsinaceae	EDF, JDF, MXF
<i>Myrsine melanophloeos</i> (L.) R.Br.	Gewra (Am), Algae (Or)	Myrsinaceae	EDF, JDF, MXF
<i>Nuxia congesta</i> R.Br. ex Fresen.	Atquar, (Am), Anfare (Or)	Loganiaceae	EDF, JDF, MXF
<i>Oenanthe palustris</i> (Chiov.) Norman		Apiaceae	EDF, JDF, MXF
<i>Olea europea</i> L. subsp. <i>cuspidata</i> (Wall. ex G.Don) Cif.	Woirra (am), Ejersa (Or)	Oleaceae	EDF, JDF, MXF
<i>Olinia rochetiana</i> A.Juss.	Tfe (Or), Delacho (Or)	Olineaceae	EDF, JDF, MXF
<i>Opuntia ficus-indica</i> (L.) Mill.	Qulqwal, Yeberha qulqwal (Am) Tini (or)	Cactaceae	EDF
<i>Orobanche minor</i> Smith.	Yejib-ras (Or)	Orbanchaceae	JDF
<i>Osyris quadripartita</i> Decne	Kerest (Am), Asaso (Or)	Santalaceae	EDF, JDF, MXF
<i>Oxalis radicata</i> A.Rich.	Soqido (Or)	Oxalidaceae	EDF, JDF, MXF
<i>Pennisetum sphacelatum</i> (Nees) Th.Dur. and Schinz	Sebez(Am), Migira (Or)	Poaceae	EDF, JDF
<i>Pennisetum thunbergii</i> Kunth	Wusha sindedo (Am)o Migira sare (Or)	Poaceae	JDF, MXF

<i>Pennisetum villosum</i> R. Br. ex Fresen	Sar (Am), Sheshu(Or)	Poaceae	EDF, JDF, MXF
<i>Pentas schimperiana</i> (A.Rich.) Vatke		Rubiaceae	EDF, JDF, MXF
<i>Pittosporum viridiflorum</i> Sims	Weyil (Am), Talao (Or)	Pittosporaceae	EDF, JDF, MXF
<i>Plantago lanceolata</i> L.	Yebeq lat (Am), Qortobi (Or)	Plantagnaceae	EDF, JDF, MXF
<i>Plantago major</i> Hook. f		Plantagnaceae	EDF, JDF, MXF
<i>Plectocephalus varians</i> (A.Rich.) C. Jeffrey ex Cufod.	Biliqee(Or)	Lamiaceae	EDF, JDF, MXF
<i>Poa leptoclada</i> Hochst .ex A.Rich		Poaceae	EDF, JDF
<i>Prunus africana</i> (Hook.f.) Kalkm.	Tiqur Enchet (Am)	Rosaceae	EDF, JDF, MXF
<i>Rhamnus prinoides</i> L' Herit	Gesho (Am, Or)	Rhamnaceae	EDF, MXF
<i>Rhamnus staddo</i> A.Rich.	Tsedo (Am), Tado (Or)	Rhamnaceae	EDF, JDF, MXF
<i>Rhus glutinosa</i> A.Rich.	Qimmo (Am), Tatesa (Or)	Anacardiaceae	EDF, JDF, MXF
<i>Rhus vulgaris</i> Meikle	Yahiya Talo (Am), Tatesa (Or)	Anacardiaceae	EDF, MXF
<i>Rosa abyssinica</i> Lindley	Qega (Am), Gora (Or)	Rosaceae	EDF, JDF, MXF
<i>Rubia cordifolia</i> L.		Rubiaceae	EDF, JDF, MXF
<i>Rubus steudneri</i> Schweinf.	Enjori (Am), Gora (Or)	Rosaceae	EDF, JDF, MXF
<i>Rumex nepalensis</i> Spreng.	Embacho (Am), Asure (Or)	Polygonaceae	EDF, JDF
<i>Salvia nilotica</i> Juss. ex Jacq.	Hulgeb (Am) ,Shokoksa(Or)	Lamiaceae	EDF, JDF, MXF
<i>Satureja pseudosimensis</i> Brenan.		Lamiaceae	EDF, JDF, MXF
<i>Satureja paradoxa</i> (Vatke) Engl.	Yewurma kisinks(Am), Kusaye lafa (Or)	Lamiaceae	EDF, MXF
<i>Satureja punctata</i> (Benth.) Briq.	Loimishet sar(Am),Toshinea(Or)	Lamiaceae	EDF, MXF
<i>Scabiosa columbaria</i> L.	Ketetina Sar (Am)	Dipsacaceae	EDF, JDF, MXF
<i>Senecio myriocephalus</i> Sch. Bip. ex. A. Rich	Chare(Or)	Asteraceae	EDF, JDF, MXF
<i>Senecio schimperi</i> Sch. Bip.		Asteraceae	JDF
<i>Sida schimperiana</i> A.Rich.	Chifrig (Am), Kote hare	Malvaceae	EDF, MXF
<i>Sideroxylon oxyacanthum</i> Baill.		Sapotaceae	EDF, JDF, MXF
<i>Smilax aspera</i> L.		Smilacaceae	EDF, JDF, MXF
<i>Solanecio gigas</i> (Vatke) C.Jeffrey	Shokoko gomen (Am), Jilma Jaldessa (Or)	Asteraceae	JDF
<i>Solanum marginatum</i> L.f.	Embuy (Am), Hidi sare (Or)	Solanaceae	JDF
<i>Solanum nigrum</i> L.	Tiqur awit (Am), Mululo (Am)	Solanaceae	JDF

<i>Sonchus bipontnii</i> Asch.		Asteraceae	JDF
<i>Sporobolus africanus</i> (Poir.) Robyns & Tournay	Mure (Am), Loia (Or)	Poaceae	JDF, MXF
<i>Stellaria media</i> Cyrill.		Caryophyllaceae	JDF
<i>Stephania abyssinica</i> (Dillin and A.Rich.) Warp.	Yeayit joro (Am) ,Hida Hantuta (Or)	Menispermaceae	EDF, JDF, MXF
<i>Tagetes minuta</i> L.	Chibo, Gime(Am) Hada (Or)	Asteraceae	JDF
<i>Tephrosia</i> sp.	Doro-seber (Am)	Fabaceae	JDF
<i>Thalictrum rhynchocarpum</i> Dill. and A.Rich.	Sir Bizu (Am)	Ranunculaceae	JDF
<i>Thymus schimperii</i> Ronn.	Tosign(Am)	Lamiaceae	EDF, JDF
<i>Trifolium acaule</i> A.Rich.	Yebeg lat (Am)	Fabaceae	EDF, JDF
<i>Trifolium semiplosum</i> Fresen.	Sidisa (Or)	Fabaceae	JDF
<i>Trifolium simense</i> Fresen.		Fabaceae	JDF
<i>Urtica simensis</i> Steudel	Sama (Am), Dobi (Or)	Urticaceae	JDF
<i>Verbascum sinaiticum</i> Benth.	Yahiya joro(Am), Gura hare (Or)	Scrophulariaceae	JDF
<i>Vernonia amygdalina</i> Del.	Grawa (Am), Ebicha (Or)	Asteraceae	JDF
<i>Vernonia leoploldii</i> (Sch.Bip.) Vatke	Soyoma (Or)	Asteraceae	EDF, JDF, MXF
<i>Veronica abyssinica</i> Fresen.		Scrophulariaceae	EDF, JDF
<i>Vicia hirsuta</i> L. (Gray)		Fabaceae	JDF
<i>Viola abyssinica</i> Steud. ex Oliv.		Violaceae	EDF
<i>Zehneria scabra</i> (L.f.) Sond.	Aregresa (Am),Qorii sinbira (Or)	Cucurbitaceae	EDF, JDF, MXF