USING SATELLITE DATA AS A TOOL TO MONITOR COMPLIANCE AND ENFORCEMENT OF FOREST CONSERVATION REGULATIONS: KARURA FOREST, NAIROBI COUNTY.

BY

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MAY, 2014

DECLARATION

I, **ANTONY GAKOBO MACHARIA,** do hereby declare that this is my original work and the same has not been submitted and is not currently being submitted for a degree award in any other University.

Signature……Date…29/May/2014

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This Research Project has been submitted for examination with our approval as the University Supervisors.

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DEDICATION

I dedicate this work to my mother Mrs. Ruth Wangechi Macharia and my father Johnson Macharia Gakobo

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I extend my most sincere thanks to the many people and institutions for their kind assistance and tolerance without which this study would not have been successful: To my supervisors: Prof. Simon M. Onywere and Mr. Alan Kirui I express my gratitude for their constructive guidance and support which greatly enriched this study. Their advice, support and belief in me and my vision gave me an inner strength that inspired me to perspire to the end.

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ABSTRACT

Forest Conservation is important in maintaining the natural biodiversity fabric of a given ecosystem. Although remote sensing methods and techniques using satellite data have been useful tool in monitoring and mapping Environmental risks and disasters, as well as in environmental protection projects, they are scarcely used in environmental legislation implementation in Kenya. Karura Forest reserve covering 1041.3 hectares and located North of Central Nairobi County is one of the largest gazetted forests in the world that is fully within a City boundary limit. It is rich with flora and fauna considered a national Heritage now under protection but which is under threat from anthropogenic impacts due to encroachment and constant excision by the government itself. This study sought to show the capability of satellite data as a tool that can be used to monitor the losses Karura forest experiences and its potential to assess compliance and enforcement of forest conservation regulations. This was done using satellite data of different time series to map the encroachment in Karura Forest over time. Satellite images of 30 meter resolution from Landsat TM 2000, 10 meter resolution from Alos 2010 and 5 meter resolution from Quick Bird 2013 were used for this study. Detected changes in all the three epochs were mapped out and where applicable field verification was done on site Interview schedules were administered to key institutions to assess the level of awareness on the use of satellite data as a tool to monitor compliance and enforcement of forest regulations. Data obtained from the interview schedules were analyzed and tabulated to give a clear picture of the institutions that have been allocated land inside Karura forest. This was necessary to give a clear direction on how the forest management values the conservation reserve and the weaknesses/strengths of forest legislation in place. Satellite data was used to map the built Environment inside Karura forest and ground truething was done to tell the owners other noticeable changes inside the forest like vegetation clearing noticed during the field survey were photographed and the changes mapped out in the subsequent satellite images where they were equally detected between 2000 and 2014. Analysis of the results revealed that the total area occupied by institutions in 2000 was 138.81 ha (13.31%) and 181.11 ha (17.39%). in 2010, representing a change of 4.08% within 10 years. It also revealed that there is 100% awareness level of the use of satellite data as a tool for monitoring forest regulations. The hypotheses that the forest management is unable to contain forest loss because they lack and/or they do not make use of information based decision making tools, was rejected on the basis of high level of awareness by the management of Karura forest to use satellite data in monitoring compliance and enforcement of forest regulations. The study objectives were met and recommendations made on how to integrate satellite data technology in monitoring compliance and enforcement of forest regulation in Karura forest. A proposed integrated use of Satellite data in Forest management was the climax of this study. The proposal recommended the use of satellite data in all forest management programs and for periodical monitoring of forest activities using high resolution satellite data for non-compliance of enforcement of forest regulations. The proposal also recommended the use of satellite data in environmental studies in institutions of learning to equip the environmental students and planners with the knowledge of using satellite data and Gis to manage the forest and other ecosystems.

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ACRONYMS AND ABBREVIATIONS

CID	Criminal Investigation Department
EIA	Environmental Impact Assessment
FAO	Food and Agricultural Organizations
GIS	Geographic Information System
ICRAF	International Centre for Research in Agro-Forestry
KEFRI	Kenya Forestry Research Institute
KFEEC	Karura Forest Environmental Education Centre
KFS	Kenya Forest Service
RS	Remote Sensing
SPOT	System Probatoired' Observation de la Terre
UNEP	United Nation Environmental Programs
NEMA	National Environmental Management Authority

CHAPTER 1: INTRODUCTION

1.0 Background

Howard (1991) reported that monitoring of forest stand characteristics has its root in the periodic national forest timber inventories in Sweden, used for fiscal purposes. It was not until the advent of continuous forest inventory in the 1960's particularly in Finland, Sweden and the USA, that the importance of monitoring forest change over time was fully recognized. According to Gwynne (1982) the UN Conference on the Environment in Stockholm in 1972, put in plans and mechanisms to coordinate forest monitoring activities throughout the world. This was with co-operation with FAO in global inventories and in the development of methods for future world-wide monitoring of forest covers.

Howard (1991) argues that Satellite Remote sensing can be used to provide quickly information of a more general nature for forest policy at the national level. They provide a permanent visual record of the landscape, and are used in monitoring forest change over long periods at the continental and sub-continental levels. This is being stimulated by the increased interest for regional forest studies provided by frequent coverage and the improvement of low resolution environmental satellites which in the past have been used primarily to provide meteorological data.

MacSiurtain (1989) pointed out that the advantage provided by the much finer spatial resolution of the second generation satellites like Landsat TM and SPOT are now well recognized in their capability to provide more information on forest cover. In favorable circumstance for example, thematic maps can be prepared at a scale of 1:50,000 and revised at a scale of 1:25,000 or lager. The finer resolution data of these second generation satellites provides a record of the surface texture of forests. This in classification of images can be combined with their spectral characteristics to monitor changes in the forest and at what rate.

Macrory & Pudy (2001) observed that environmental regulators across the world face a number of common challenges which hamper their goal of effective and efficient enforcement of forest regulations. One of the challenges is implementing a forest

monitoring system that can report on compliance. Satellite technologies by their nature as documented by Ali (2010) of housing sensors to view the spectral, spatial and radiometric relations of observable objects and materials at a distance are particularly useful at monitoring activities taking place in the forest. Such activities like changes in vegetation cover and density represents a potentially excellent application for satellites by Environmental regulators.

Maina (2005) observed that forests in Kenya, like any other countries, are faced with a lot of challenges and threats ranging from rapid population, expansion of urban areas, need for more agriculture land to produce more food to meet the demand of growing population. Karura forest being one of such protected forests in Kenya according to Wily & Mbaya(2001) has not been spared from internal pressure especially excision of land for institutions. Key to many governments as pointed out by Purdy (2010) was whether satellite monitoring could offer opportunities over and above existing environmental enforcement methods to address vegetation clearance. It appeared that weaknesses in conventional mechanisms of monitoring and enforcing environmental laws, called for an alternative mechanism of monitoring compliance and enforcement of forest regulation in Australia.

This study used satellite data of different time series to map subsequent changes of boundaries in Karura forest and profiled the loss in spatial extent caused by institutions allocated land inside the Karura forest. The researcher assumed that existing mechanism of monitoring compliance and enforcing forest regulations in Kenya are weak. This is because the institutions like the Kenya Forest Service (KFS), mandated to protect and advocate for the conservation of forests are actually located inside Karura forest. Karura forest being a National heritage is a priceless ‘Green Lungs’ for a rapidly growing city of Nairobi where it is located and the neighbouring Kiambu County. It is an important water catchment and fresh air filter. It hosts biodiversity of flora and fauna which if not protected and monitored for future generation, will slowly disappear.

1.1 Statement of the problem

Karura forest, located in Nairobi County and managed by KFS as mandated by Government of Kenya (2005), continues to lose its spatial extent despite the fact that it is a protected heritage. The main internal stressors of Karura forest are actually the government and international institutions that are allocated land inside the Karura forest mainly for its aesthetic value and privacy. It remains then a problem to see that KFS and other government institutions continue to occupy the forest reserve in however much they protect it from further invasion. The institutions that are mandated with the tasks of protecting the forest reserve, monitoring the compliance and enforcement of forest regulations are themselves going contrary to the regulations. This means that the existing forest regulations and monitoring systems are not adequate or are weak and therefore not capable of protecting Karura forest reserve from being allocated to government institutions.

As Wily & Mbaya (2001) reported, there were plans to reduce the Karura forest in favour of housing and other developments under questionable circumstances. The loss of spatial extent of Karura forest according to the findings of Wily &Mbaya(2001) is mainly due to government and other international institutions being allocated land inside Karura forest. The forest management has the knowledge of the importance of Karura forest as a conservation reserve but the political environment does not contextualize the synoptic size of the Karura forest so that they make an assumption that allocating land to these institutions in small portions doesn't affect significantly the size of the forest reserve. The question is how this can be monitored independently in the governance structure where information about the occupation is not made public.

1.2 Research questions

i. Which are the internal stressors of Karura Forest's spatial extent?
ii. How did the institutions manage to acquire land and settle in Karura forest reserve despite the forest being a conservation reserve?
iii. What is the level of awareness, knowledge and attitude toward the use of satellite data as a tool for monitoring compliance and enforcement of forest regulations?

iv. How can satellite data be used in monitoring to ensure that Karura forest is conserved as a National heritage?

1.3 Main objective

The main objective of this study was to show the capability of satellite data as a tool that can be used to monitor the loss of Karura forest cover and to assess compliance and enforcement of forest conservation regulations.

1.3.1 Other objectives

i. Use satellite data to map out internal stressors of Karura forest.
ii. To investigate how institutions managed to acquire land to settle in Karura forest.
iii. To examine the level of awareness and attitude toward the use of satellite data technology as a tool for monitoring compliance and enforcement of forest laws in Karura forest.
iv. To demonstrate the use of satellite data as a tool for monitoring compliance and enforcement of forest regulations in Karura forest.

1.4 Hypothesis

The forest management is unable to contain forest loss because they lack and/or they do not make use of information based decision making tools.

1.5 Justification of the study

Government of Kenya (2012) statement in National Environmental Policy (NEP) that, monitoring compliance which involves collecting and analyzing information on the compliance status of the different stakeholders is important. Monitoring is essential to detect and correct environmental violations, provide evidence to support enforcement actions and evaluate implementation progress by establishing compliance status. Weak enforcement of environmental compliance is attributed to inadequate technical capacities, monitoring infrastructure and trained staff in enforcement institutions. The call is very

timely because protected areas like Karura forest are facing both internal and external pressure to give land for development. Although the call is justified, there are no mechanism in place to monitor compliance and enforcement of forest using satellite data which is readily available to give temporal change over a given time series.

This study was justified as it aimed to demonstrate that the use of satellite data as an alternative tool to the conventional monitoring methods can give timely and updated information about forest cover in Karura reserve. Because satellite data are universally available and archived, same data can be used by many stakeholders without necessarily having physical access to the forest and are able to report the status of forest even when the physical access is prohibited. Using satellite data as a monitoring tool for non-compliance of forest regulation can be used to hold the forest management and other key stakeholders to account for the loss of forest cover in Karura forest due to excision of land to settle institutions in a protected forest. The issues related to weak policies and regulations were brought to the lime light.

1.6 Significance of the study

The outcomes of this study were maps from satellite data and site photos showing forest cover change. Their analysis showing the internal stressor of Karura forest over time is instrumental to inform the forest management to understand the shrinkage rate of Karura forest and thus the remaining spatial area. It enables the forest management make prediction of the future in case the tread continues and thus make informed decision on how to conserve the remaining Karura forest. The findings of the study will be made available to the relevant Ministries, Counties, development agencies, international community and agencies, research, teaching and learning institutions. The expectation is that such information can be of importance in decision making on matters pertaining development of sensitive ecosystems like Karura forest. To policy makers, the findings will inform on policy and regulation gaps which might have influenced the encroachment of the protected forest. This will inform the policy makers to include satellite data: (i) as an alternative tool to monitor compliance and enforcement of forests in their management plans. (ii) As an important decision making tool where physical monitoring can be a

challenge or compromised. It will contribute to the body of knowledge for future researchers in the thematic area.

1.7 Research assumptions

This research assumed:
That policy, legal and institutional frameworks offering management tools in Karura forest are weak. That Karura forest continues losing spatial extent because forest management lacks information to understand the dynamics going on in Karura forest. The outcome of this study will inform the forest management that satellite data can be used as a source of information to monitor compliance and enforcement of forest regulations.

1.8 Scope and limitation of the study

Karura forest being a protected and gazetted area has a fixed boundary. This study was limited to the protected area. The use of satellite data was limited to passive medium and higher resolution imagery covering the Karura forest area. Maps generated from the available document and satellite data were limited to analysis of spatial information of the Karura forest. Institutions that have settled inside Karura forest like KFS formed the target population for interview schedule. This gave a bearing on how they managed to acquire land inside a protected forest and which criteria were used to allow them to do so. Documented Policies and legal frameworks touching forest management, compliance and enforcement of forest regulations were perused to give more secondary information on the actual requirement of a protected area. Access to crucial documents like the title deeds was a challenge due to their sensitive information of the actual owners of the parcels in question. This necessitated the researcher to limit the study to the answers given during the interview schedules and other observation on site. Time constraint did not allow the fully utilization of satellite information available on the imagery due to technicality of classification for every epoch.

1.9 Conceptual Framework

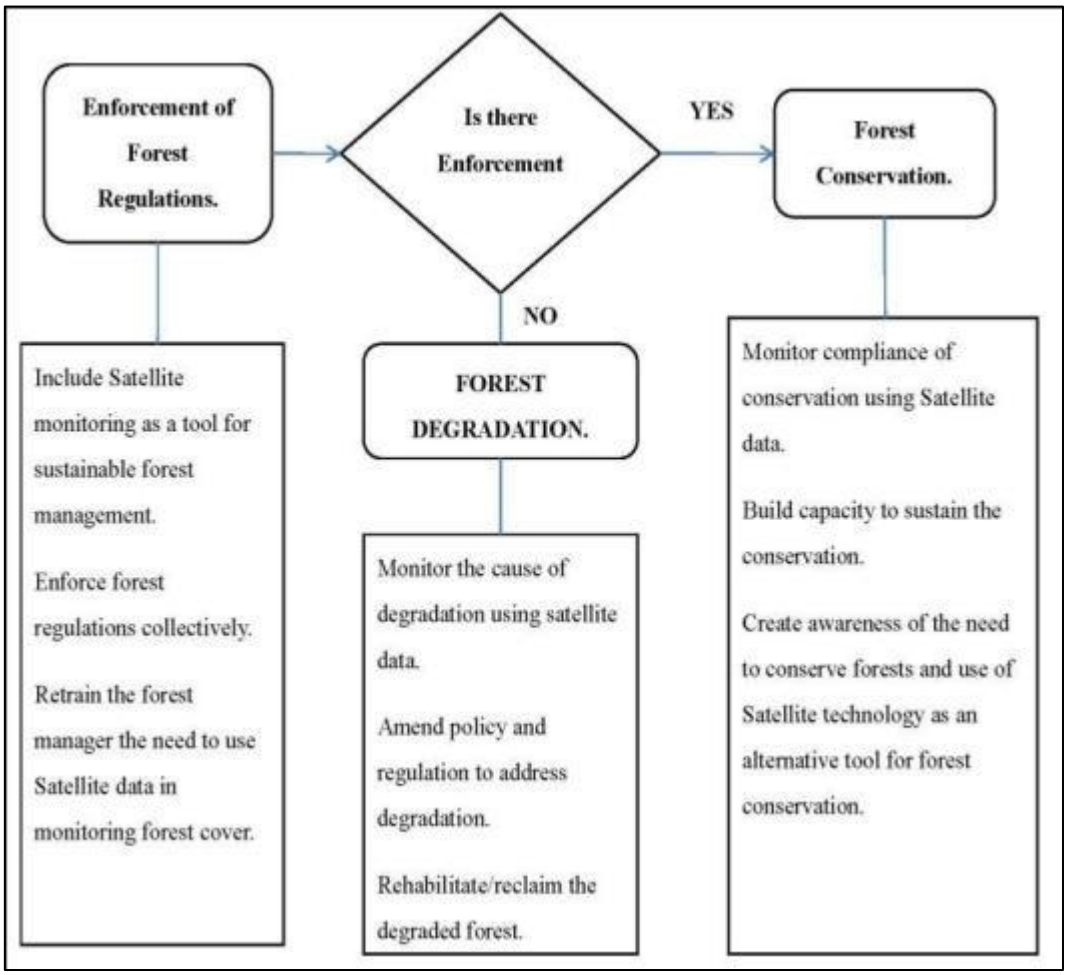


Figure 1.1: Conceptual Framework.

(Source: The Researcher, 2014.)

The above Figure 1.1 conceptual framework is based on Compliance Theory of Rule of Law. As explained by Zaelke (2005), all forces that can influence human behavior are potential tools of governance and the Sustainable Forest Management (SFM) Theory, which according to MCPFE (2011) is the management of forests according to the principles of sustainable development.

CHAPTER 2: LITERATURE REVIEW

Howard (1991) documented that historically, forestry has been concerned mainly with the assessment of timber resources management and utilization of closed forests for the production of wood. Loetch & Haller (1964) adds that forest have become widely recognised as; all lands bearing a vegetation association dominated by trees of any size, exploited or not, capable of producing wood or other products, of exerting an influence on climate or on the water regime or providing shelter for livestock and wildlife. Karura forest provides home to flora and fauna and offers a cool environment to the neighbouring community of Muthaiga, Gigiri, Runda, Ridgeways, Mathare North, Highridge and Spring Valley.

UNEP (2013) reports that forests play a key role in our war against climate change. Forests feed our rivers and are essential to supplying water for nearly 50% of our largest cities. They help to regulate the very often devastating impact of storms and floods. Forests are the most biologically-diverse ecosystems on land, home to more than half of the terrestrial species of animals, plants and insects. Forests also provide shelter, jobs and security for forest-dependent populations. Despite all of these priceless ecological, economic, social and health benefits, we are destroying the very forests we need to survive. Maryanne (2011) documents that global deforestation continues at an alarming rate of 13 million hectares of forest destroyed annually, which is equal to the size of Portugal.

According to FAO (2009), the forest industry is extremely important for some developing countries. A figure of 6 % contribution to GDP as often quoted for the entire Sub-Sahara Africa (SSA), such a figure masks the disparities between tropical and non-tropical countries. For example, forests play a major role in the economies of Cameroon, the Central African Republic, Congo, the Democratic Republic of the Congo, Equatorial Guinea and Gabon, and in the livelihoods of local people. The forest sector contributes, on average, between 5 and 13 % of the gross domestic product (GDP) of these countries. Up to 60 per cent of export earnings for Gabon are from timber products, while for the Central African Republic it is about 50 per cent. Gabon is the biggest exporter of industrial roundwood, exporting nearly 97 per cent of its total production. Export of medicinal plants

is a significant foreign exchange earner for Cameroon, amounting to around US$ 2.9 million a year.

Government of Kenya (2012) pointed that conservation and sustainable development of forest ecosystems and their associated resources are essential for lasting poverty reduction and sustainable development. Forest ecosystems like Karura forest are important in conservation of soil, water and biodiversity as well as in moderation of climate. They are the richest terrestrial habitats for biodiversity. Maintaining forest biodiversity protects the economic potential of future opportunities for new non-timber products, such as foods and medicines, as well as social sustainability by offering aesthetic, spiritual and recreational settings for people. The concern of this study was the call for measures to monitor how such forest ecosystem like Karura is conserved to sustain its existence.

The global problem of monitoring the activities that degrade the environment and more so deforestation, has necessitated most of the developed and some developing countries to adapt satellite data technology to supplement forests manual inspection, protection and management. Use of satellite data technology as a supplementary tool to monitor forest activities and compliance of enforcement of forest law is barely new and being tried by some countries such as Australia, Myanmar, Brazil to name but a few. Lillesand & Kiefer (1994) defined remote sensing as being a science and an art of obtaining information about an object, area or phenomenon through analysis of data acquired by a device that is not in contact with the object, area or phenomena under investigation. The advantage of using remote sensing is its unlimited access to protected areas to get information without necessary going through the official procedure of physical access which more often than not is a problem.

Purdy (2010) documented that the use of satellite data technologies by Australian regulators to combat illegal vegetation clearance is the first international example where satellite data have been used systematically to monitor compliance with a specific environmental law. Australian regulators used satellite imagery to check legislative compliance, by analyzing satellite data to determine whether and when vegetation was cleared. They looked for relative changes in vegetation response between two satellite images of the same location with different time series. Comparative images showed that

vegetation clearing took place between the first image date and the second. According to Purdy (2010) if the satellite image shows that an offence might have occurred, regulators take a decision as to whether to direct resources for further investigations. Australian regulators observed that Satellite monitoring can be a very pro-active method of enforcement. Before satellite monitoring, Governments of Australia mainly relied on detecting offences through tip-offs. Satellite monitoring made them aware of a lot more possible offences. Meaning they had to substantially increase numbers of staff if they wanted to conduct inspections and make compliance decisions.

Swe (2002) documented that in Myanmar, over 70% of the total population is rural people and dependent on forest resources for basic needs such as food, fodder, fuel and shelter. The Myanmar Forest Department has put in efforts to check further depletion and degradation of the natural forests through law enforcement and increased natural and artificial planting programmes while periodically appraising their status. Myanmar started a programme for monitoring and assessing of anti-narcotic activities with her own resources. Swe (2002) point out that the GIS and Remote Sensing Section of the Forest Department is carrying out the interpretation of satellite scenes and ground checking for the survey of illegal poppy plantations.

According to Wolf (1974), the use of artificial satellites as sensor platforms has made possible the acquisition of high-resolution multispectral data of the earth's surface on a global basis. Satellite images not only cover very large areas, but they are also virtually free of image distortions due to relief because of the typically high flying heights. The reasonably good resolution, broad area coverage and synoptic character of satellite imagery are becoming increasingly useful in a number of applications. The continual updating of regional resources and land-use inventories is one of its most important applications. This study demonstrated that such important application can be used to monitor compliance and enforcement of forest regulations in Kenya and specifically in Karura forest.

Michael Meitner (2009) documented that the three biomass of Brazil; the Amazon, the Savanna Woodland and the Atlantic forest are threatened by degradation. The survival of these forests rests with Brazil's ability to enforce the laws that are already in place to protect these forests. Environmental scientists are using GIS technology to study the extent

that deforestation is continuing in Brazil's designated protected areas. Historically, the delineation of protected areas and subsequent enforcement of land-use restrictions within them has been hampered by the difficulty in determining the physical boundaries of these areas currently expressed only in policy.

Assunção, Gandour, & Rocha (2013) documented that the analysis, conducted by the Climate Policy Initiative (CPI), assessed the influence of policy changes on the sharp decline in deforestation in the Brazilian Amazon since 2004. In 2007, the Brazilian government introduced DETER, a satellite-based monitoring system that can detect changes in forest cover on a monthly basis. The technology enabled law enforcement officials from Brazil's environmental protection agency, IBAMA, to take quick action against illegal forest clearing.

2.1 Conservation Theory of Natural Ecosystem.

Cronon (1995) defines Conservation reserves as generally large areas in which maintenance of native biota and natural ecosystem processes are the primary management objectives. The Reserve approach to preserving biota has a long history and deep philosophical roots going back at least several centuries to the royal game preserves. According to Noss & Cooperrider(1994) reserves are the dominant paradigm of modern conservation biology, the objective being to fully protect existing habitat and populations from direct human modification.

As Lindenmayer & Franklin (2002) have written, reserves have major limitations as the sole or even the primary tool for conserving biological diversity. Major problems with a reserve-based strategy include: Insufficient total area, inadequate representation of natural ecosystems and pervasive influences of human society, even in the largest of reserves. Karura forest seemed to suffer from all the above three and without a monitoring system that is independent of human bias, then it is hypothetical to conclude that the forest will be consumed by human development.

2.2 Compliance Theory of Rule of Law.

As noticed by Zaelke (2005), all forces that can influence human behavior are potential tools of governance. Good governance depends on rule of law which refers to a set of rules applied fairly, efficiently and predictably by independent institutions in a framework of public-private interaction process. Thus, a set of social norms comprising, rule of law, anti-corruption, and accountability have been put forward to enhance governance. In this context, compliance is a substantial element of good governance. Compliance with the law is related to the respect and the enforcement of legal system. As a result, compliance may be treated as an indivisible part of rule of law and thus rule of law cannot have meaning without compliance. Diarra & Marchand (2011)argued that growing focus on compliance seems to be important to enhance the success of efforts to strengthen rule of law, which in return will improve the achievement of efforts to promote good governance, and there by allow the society to reach sustainable development.

2.3 Sustainable Forest Management (SFM) Theory.

SFM theory is the management of forests according to the principles of sustainable development. Sustainable forest management uses very broad social, economic and environmental goals. A definition of SFM was developed by the Ministerial Conference on the Protection of Forests in Europe (MCPFE), and has since been adopted by the Food and Agriculture Organization (FAO). According to MCPFE (2011), Sustainable Forest Management is the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems.

Karura forest, a National Heritage that was supposed to be protected from any human activity has failed to enjoy the full protection it deserves from the forest management. In the context of sustainable forest management, Karura forest cannot be sustained if nothing is done to stop the tread. The rate, at which the forest continues hosting infrastructure development by government institution, is damaging forest ecosystem, which is contrary to

the conservation theory and the sustainable forest management theory where the native biota of the Karura forest should be sustained

2.4 Information System Theory

Davis (1989) defined Technology Acceptance Model (TAM) as an information systems theory that models how users come to accept and use a technology. The model suggests that when users are presented with a new technology, a number of factors influence their decision about how and when they will use it. Perceived usefulness is the degree to which a person believes that using a particular system would enhance his or her job performance. Perceived ease-of-use is the degree to which a person believes that using a particular system would be free from effort.

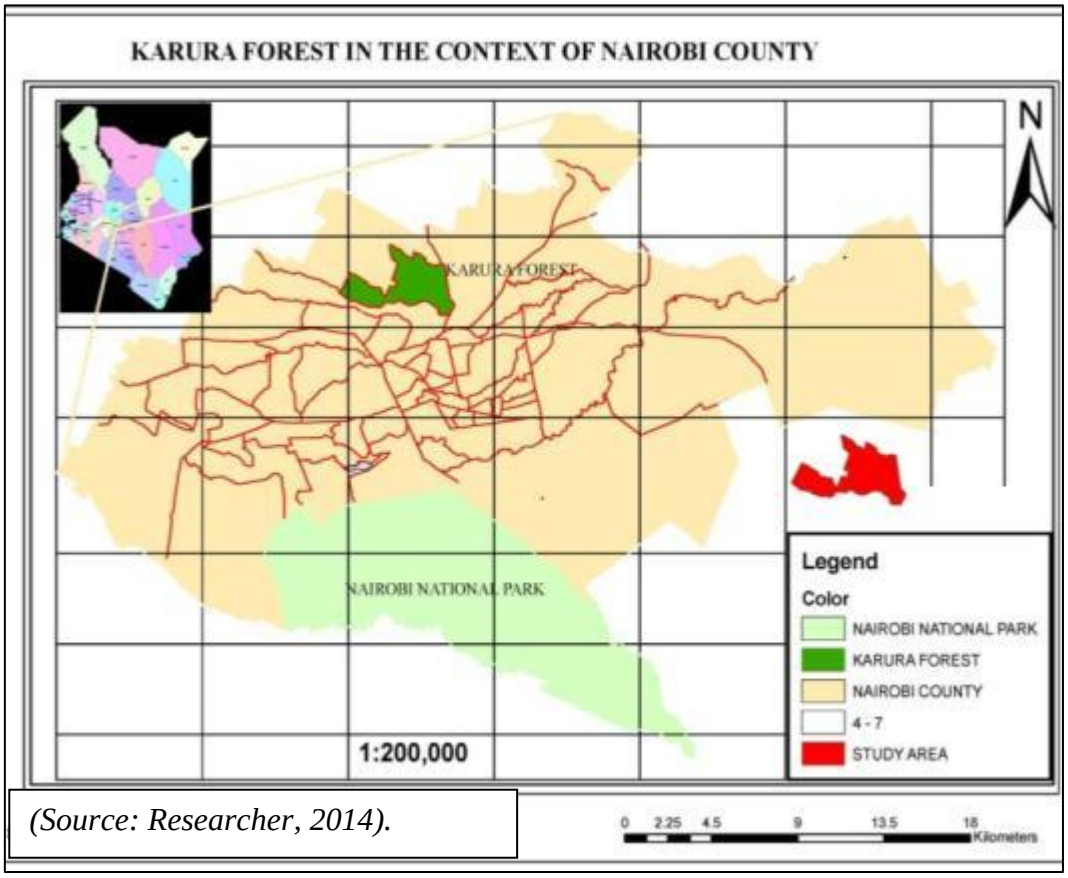
Because new technologies such as the use of computers to analysing forest cover using satellite data are complex. An element of uncertainty exists in the minds of decision makers with respect to the successful adoption of such technologies. Davis (1989) further observed that people form attitudes and intentions toward trying to learn to use the new technology prior to initiating efforts directed at using the technology. Attitudes towards usage and intentions to use may be ill-formed or lacking in conviction or else may occur only after preliminary strivings to learn to use the technology.

The assumption of this study was that there is an attitude toward the use of satellite data as a tool to monitor compliance and enforcement of forest regulations in Kenya. Thus, actual usage may not be a direct or immediate consequence of such attitudes and intentions as reported by Bagozzi, Davis, & Warshaw (1992). That forest management of Karura forest may or may not have the knowledge that using satellite data as a monitoring tool can offer them a tool to monitor compliance and enforcement of forest regulation. Objective number (iii) of this study was to examine the level of awareness and attitude toward adopting the use of satellite data as a source of information to inform the forest management what is happening inside the protected Karura forest. How do they perceive the new technology? Is it difficult to utilize or is it in anyway useful to their management system?

CHAPTER 3: STUDY AREA

3.1 Location and Extent

According to Orwa (2014), Karura Forest reserve covers 1041.3 hectares and is located North of Central Nairobi County bordering the suburbs of Muthaiga, Gigiri, Runda, Ridgeways, Mathare North, Highridge and Spring Valley (Figure 3.1). The reserve has two blocks namely Karura block covering 765.9 ha and the western part of the forest also known as Sigiri Forest block covering 275.4 ha. Karura forest (Figure 3.2) is one of the largest gazetted forests in the world fully within a city limits. (Wily & Mbaya, 2001) reported that the forest was gazetted in 1932 and is managed by the Friends of Karura Forest (FKF) in conjunction with Kenya Forest Service (KFS). It's the largest of three main gazetted forests in Nairobi. The other two gazetted forests being Ngong Forest and Ororua Forest.



(Source: Researcher, 2014).

Figure 3.1: Karura Forest in the Context of Nairobi County.

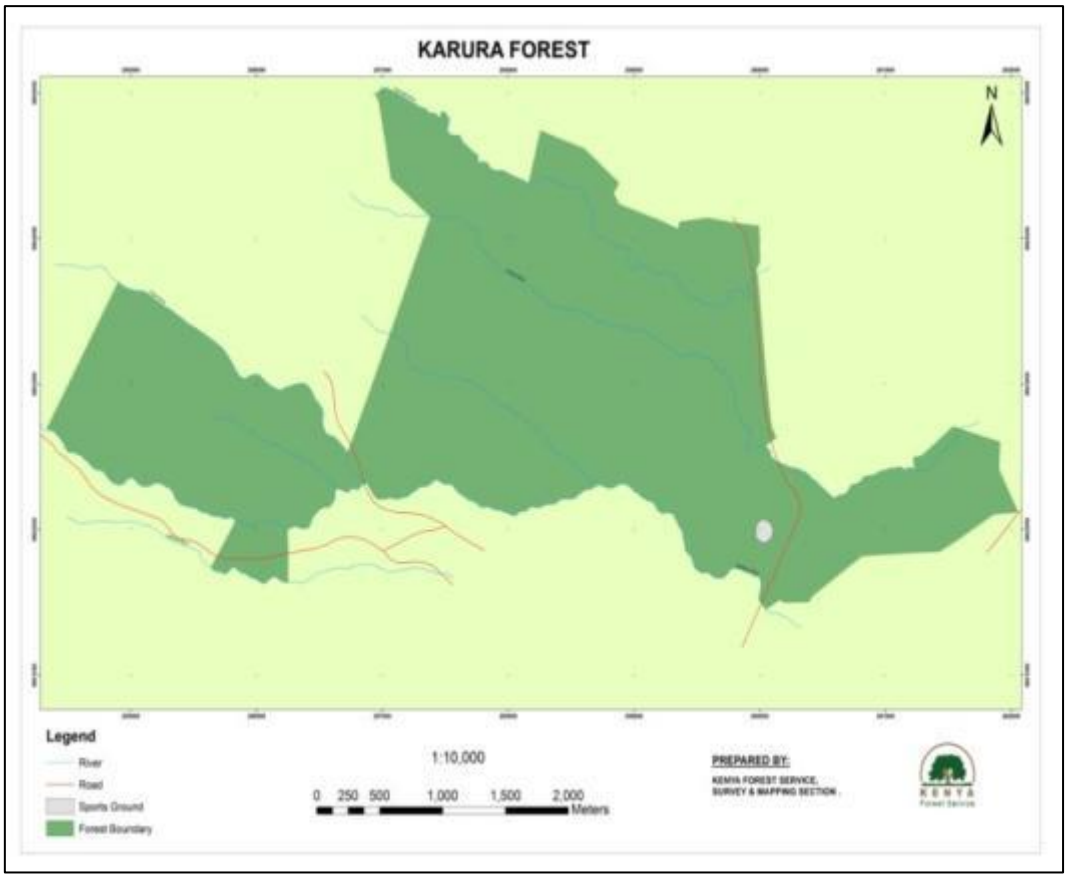


Figure 3.2: Karura Forest.

(Source: KFS Survey & Mapping, 2014).

3.2 History

Karura is a remnant of the so called montane sclerophyllous (small leaves) forest that covered all of the Kenya highlands from Nairobi to the Aberdare moorlands in pre-colonial times. It has always been a place of bounty for the Gikuyu people who traditionally used the forest for food, fuel and fiber, as a sacred burial place and source of herbal remedies.
Scientist from the National Museums of Kenya has carried out archeological excavation work in the Mau-Mau caves along the Karura River as (Figure 3.3). Study of rare artifacts like the obsidian Stone Age knife found in the caves indicates human occupation of the forest in the distant past.

Figure 3.3: Mau-Mau Caves.

(Source: Researcher Field Survey, 2014).

(Orwa, 2014) in his interview schedule, supported by publications in "Karura Forest-A green haven within Nairobi City limit", Karura became a forest reserve in April 1932. This is when the colonial government set it aside as a source of fuel wood for the new Uganda Railway. Due to this, three quarters of the forest was felled and replanted with exotic species (Cyprus, Eucalyptus and Araucaria). Figure 3.4 shows the type of exotic trees in Karura forest.

Figure 3.4: Eucalyptus and Cyprus trees in Karura forest.

(Source: Researcher Field Survey, 2014).

In 1999, the late Noble Laureate Prof. Wangari Maathai led a group of stakeholder to confront and rid the forest of developers trying to grab the Northern portion of Karura forest shown in Figure 3.5.

Figure 3.5: Wangari's Corner and Cleared Vegetation.

(Source: Researcher Field Survey, 2014).

3.3 Significance of Karura Forest

The forest has been used sporadically over the years by central bank to burn old notes in the odd-looking Chimney just north of the KFS nursery. This now provides a fascinating resting point along a stroll through the forest. Other interesting sites which form attraction for eco-tourism both for Kenyans and visitors from abroad are: a 20-metre waterfall edaphic marshlands (Figure 3.6) and grassy glades, 50 km of trails to walk or jog under trees (Figure 3.7) among others. Karura is a priceless 'green lung' for a rapidly growing city; it is an important water catchment and fresh air filter.

Figure 3.6: Water fall and edaphic Marshland.

(Source: Researcher Field Survey, 2014)

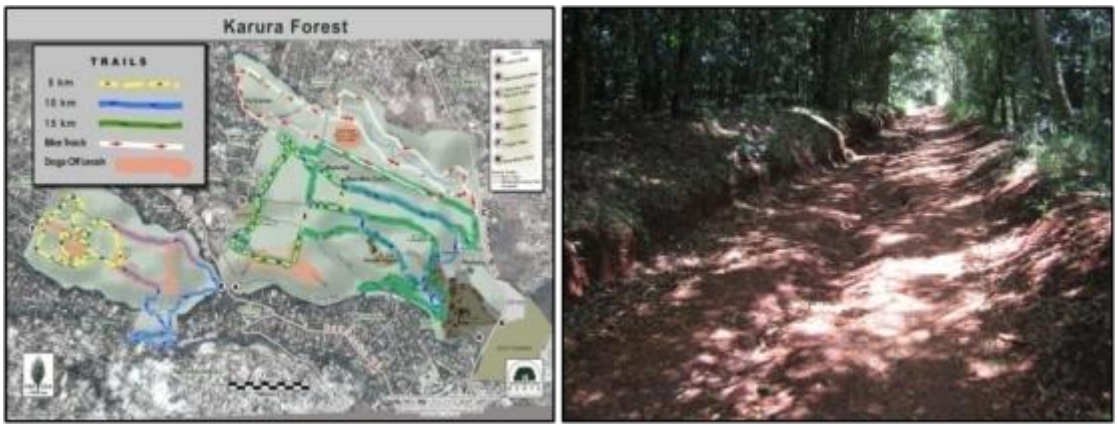


Figure 3.7: 50 km of trails and Jogging tracks under trees.

(Source: Researcher Field Survey).

3.1 Environmental Data

Table 3.1: Average Temperature and Precipitation of Nairobi County.

Month	January	February	March	April	May	June	July	August	September	October	November	December	**year**
Avg. H temp. ^{o}C	24.5	25.5	25.6	24.1	22.6	21.5	20.6	21.4	23.7	24.7	23.1	23.4	**23.4**
Avg. L temp. ^{o}C	11.5	11.6	13.1	14.0	13.2	11.0	10.1	10.2	10.5	12.5	13.1	10.1	**13.1**
PTT(mm)	64.1	50.5	92.8	219.4	176.6	35.0	17.5	23.5	28.3	55.3	154.2	101.0	**1024.2**

(Source: EPM 571, Site and Neighbourhood Planning, 2012 report).

3.2 Climatic and Temperature

The climate is generally a temperate tropical climate with cool evenings and mornings becoming distinctly cold during the rainy seasons. Temperatures fluctuate between 11^{o}C and 32^{o}C and on average is 24^{o}C with a constant of 12 hours of daylight. Generally the climatic conditions in the area under study are moderate and pleasant most of the year (EPM 571, 2012).

3.3 Rainfall

Nairobi County experiences a bimodal seasonal rainfall pattern where there are long rainy periods between April and June while the short rains in November and early December, as shown in Table 3.1. The Mean annual rainfall ranges between 500-1024mm/year.

3.4 Geology

Nairobi has an underlying rock of tuff and trachytes with no significant characteristics of unsuitable fault lines. The forest sits on Tertiary volcanic rocks forming volcanic tuffs with intercalated flows of basaltic larva. Both types are occasionally exposed in Karura's deeper river valleys, and the tuffs yield the familiar grey building stone of Nairobi. "Chimneys" of larva are occasionally found exposed on ridges in the western and middle sections of the Forest (Friends of Karura Forest, 2014).

3.5 Topography and Soils

The Karura landscape rolls gently between and through shallow valleys. Drainage is generally southeasterly. Depressions throughout the forest impede drainage and cause formation of small edaphic grassy swards and swamps, some of which are under threat from thirsty Eucalyptus trees. Karura forest soil is usually very heavy, dark grey clay which stained black with un-decomposed humus, so-called 'black cotton' soil. Between 5 cm to 1 meter below the clay layer, a red-brown laterite occurs, a product of re-cementation that is rich in iron compounds and associated with swampy areas and a shifting water table. The forest soils are eminently suited to tree growth, except in the

impeded drainage of swampy sites that provide natural edaphic grassy glades characteristic of Kenya's upland forests, (Friends of Karura Forest, 2014).

3.6 Hydrology

Five perennial tributaries of the Nairobi River pass through the forest running roughly west to east and cutting through gently undulating landscape. These are: Ruaka, Karura, Gitathuru, Thigiri and Mathare River (Figure 3.8). Karura River valley offers a precarious and stunning descent through indigenous forest to the large waterfall and the Mau-Mau caves,(Friends of Karura Forest, 2014).

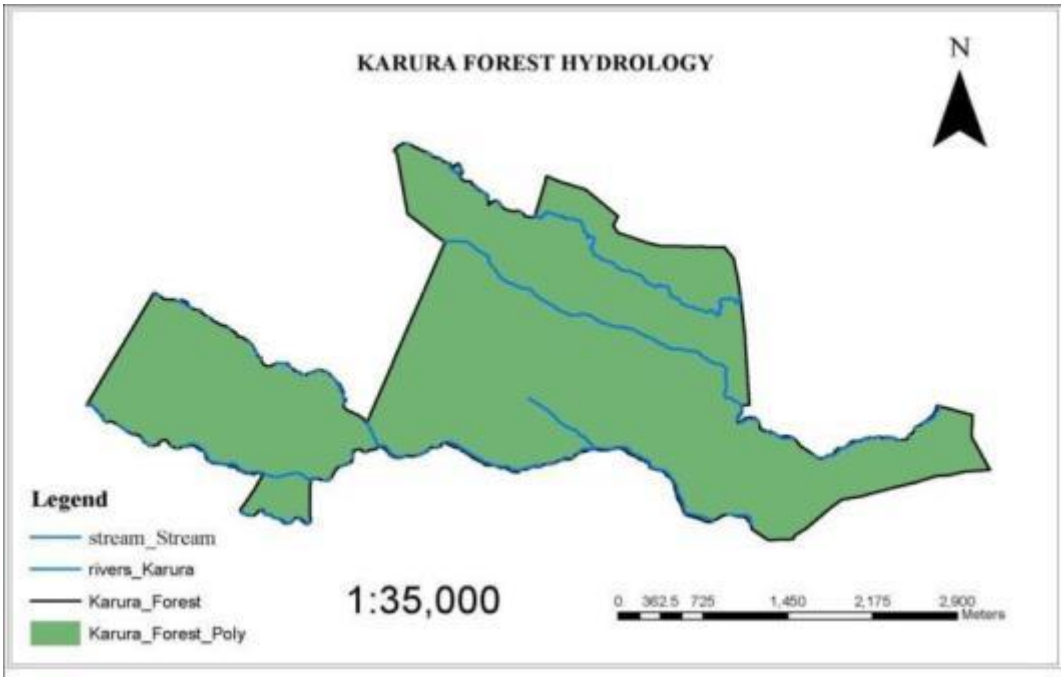


Figure 3.8: Karura Forest Hydrology.

(*Source: Researcher, 2014).*

CHAPTER 4: RESEARCH METHODOLOGY

4.0 Introduction

This chapter outlines the research design and the methodology that was used in this study to demonstrate the use of satellite data as a monitoring tool for compliance and enforcement of forest regulations. This included research design, target population of the study area, data collection, data analysis procedure and presentation of data.

4.1 Research Design

Kothari, (2004) defines a research design as the arrangement of conditions for collection and analysis of data in a manner that aims to combine relevance to the research purpose with economy in procedure. It is the conceptual structure within which research is conducted; it constitutes the blueprint for the collection, measurement and analysis of data. This research adopted the case study approach. Kothari, (2004) explains that the object of the case study method is to locate the factors that account for the behaviour-patterns of the given unit as an integrated totality.

Mugenda & Mugenda, (1999) argued that, although interviews, especially unstructured, have a potential for getting into the richer aspect of the phenomenon, they are not purely objective ways for collecting information. They should however be continuously transformed to fit the research and themes as they emerge during field encounter.

4.2 Sources of Data

Both primary and secondary data were sourced to from relevant key institutions.

4.2.1 Primary Data Sources

Primary sources of data was obtained from structured interview schedules with KFS, NEMA, resource persons from relevant institutions including Ministry of Environment, Water and Natural resources and from Satellite Imageries.

4.2.2 Secondary Sources

All the information that was retrieved from already existing literature for the purposes of this study was treated as secondary data. This information was contained in publications, books, annual/quarterly reports, journals, Development plans, periodicals and existing spatial information like maps of the study area.

4.3 Methods and Instruments for Data Collection

Various methods and instruments of data collection were used. Available Map of Karura forest was scanned and digitized using ArcGis 10.1 and used for base map preparation as a background image. Satellite Images were then superimposed on the digitized georeferenced boundary. Interview schedules were administered to key institutions to collect primary data to shed more light on the use of satellite data in their institutions. Digital camera was used to capture scenes during field survey. Literature available about Karura forest were perused to shed more information and as a source of secondary data.

4.3.1 Base Map Preparation

Existing Karura forest map of 1923 from Survey of Kenya was scanned, georeferenced to the existing Cadastral data of Nairobi and digitized in ArcMap 10.1 to form the base map. The digitized map gave the spatial Area information about Karura forest extent and was used to compare with the other extent Area given during the interview and from other secondary data.

4.3.2 Satellite Imageries

Available Landsat TM (Thematic Mapper) 30 meters resolution satellite images of the year 2000 and ALOS 10 meter resolution of the year 2010, were used for Digital image analysis using 10 years time series. Sourcing of 1990 Images which would have give a good over view of the changes that have taken place before the 1999 invasion of the forest did not materialize. High resolution image map of 2010 obtained from KFS was Georeferenced and used together with 0.5m high resolution satellite data from Quick bird, 2013 obtained

from Regional Centre for Mapping and Remote Sensing, courtesy of Professor Onywere. The images were digitized to give the extent of area occupied by the institutions. This gave evidence of changes that have taken place and confirmed the existence of institutions inside the Karura Forest.

4.3.3 Interview Schedules

This method involved collection of data through face to face interaction with the key Institutions interviewed; the Kenya Forest Service (KFS), National Environment Management Authority (NEMA), Kenya Forest Research Institution (KEFRI) and the Ministry of Environment, Water and Natural Resources. Data collected using this method included: mandate of stakeholders in forest protection and management, the legal legislation, and policy framework that guide the institutions in enforcement of forest regulations, the strategies they employ to monitor compliance and enforcement of forest regulation, the capacity to execute these tasks and the awareness of satellite data technology as a tool to monitor compliance and enforcement of forest regulations.

4.3.4 Observation

Kothari, (2004) outlines that under the observation method the information is sought by way of investigator's own direct observation without asking from the respondent. Physical aspects that were relevant to the study were obtained through observation to verify verbal claims by respondents. An observation guide as an instrument was used to capture such elements. This was used in verifying information, as data collection using the interview schedules preceded observations as a method of data collection. It also served to increase the range of relevance and reliability of data. Checklists were used to gather data based on the study's premises, assumptions made on various aspects of the research. Variables were confirmed or disapproved by use of the above method. This method provided evidence of use of satellite data technology in monitoring forest in Kenya and specifically in Karura. It also provided evidence of some section of Forest clearing among other activities inside the Forest.

4.3.5 Photography

Photographs were used to capture information such as Institutions existing inside the forest, Forest clearing, Tourist attraction sites, existing electric fencing and any evidence of the use of satellite data technology in the institutions offices. Digital camera was used to record on-site observations made inside the Karura forest especially where activities have taken place and were noticeable by the researcher from the satellite images.

4.3.6 Literature Review

Documents such as departmental reports, projects reports, books and referred publications were reviewed and relevant information regarding Satellite data as a tool to Monitoring Compliance and Enforcement of Forest Conservation gathered. This allowed for comparison between primary data collected and existing information.

4.4 Data Analysis

Descriptive statistics was used to analyze both qualitative and quantitative data in respect of use or non-use of the use of satellite data as a tool to monitor compliance and enforcement of forest regulations in Karura forest. In analyzing data, both quantitative and qualitative methods were used. Kothari, (2004) recommend it as important not only to establish the data trends and patterns but also the relationships existing between various aspects from the gathered information. Interviews schedules provided qualitative form of data.

4.4.1 Image Analysis

Different thematic layers mapped with ArcGis 10.1 were used to show the major consumers of Karura forest spatial Area. The generated tables from different layers for different time series were compared to show the change in Area. The results were tabulated in tables and thematic maps used for presentation in each time frame. This showed why the forest is changing by comparing the different consumer and activities. This approach was recommended by Lung in Mitchell & Lung, (2004), where forest cover change for

Kakamega forest was revealed for a period of almost 90 years. Lung demonstrated the value of combining satellite imagery, aerial photographs and old topographical maps in order to derive figures on forest losses from the early 20th century to the start of 21st century.

Comparing images from different Time series of 2000 from Landsat TM, 2010 from Alos and 2013 Quick Bird also showed that using Satellite data can monitor different activities inside the forest which might not be reported during the interviews. Noticeable in this study is the clearing of the Eucalyptus trees which was not mentioned all through the interviews. Institutions allocated land inside the forest like the CID headquarters, and the Survey of Kenya are putting up new structure development among others as.

4.4.2 Image Classification

Supervised Classification was used to classify features using 30m resolution 2000 Landsat TM, 10m resolution 2010 Alos and 5m high resolution image 2013 from Quick Bird. Training samples were created by digitizing features that were noticeable to the researcher. Where conspicuous characteristic of data pattern were recognized, the training sample were created to give more information for signature creation. Maximum likelihood classification was used during the supervised classification process. The resulting classified images were used for analyses and presentation.

CHAPTER 5: DATA PRESENTATION, ANALYSIS AND DISCUSSION

5.0 Introduction

This chapter presents the analysis of the data, and interpretations from the mapping and interview schedules. The approach of the presentation is per objective. ArcGis 10.1 was used for the mapping of the scanned images and satellite data. The resulting maps Areas were computed and compared for change analysis from the recorded and digitized. Interview schedule and observed data information was used to support the findings.

5.2 Use of satellite data to map internal stressors of Karura Forest.

Existing map of 1923 from Survey of Kenya was scanned, georeferenced on Cadastral data and digitized in ArcMap 10.1 to form the base map. Figure 5.1 shows the scanned and Georeferenced map at a scale of 1:40,000 ready for digitization.

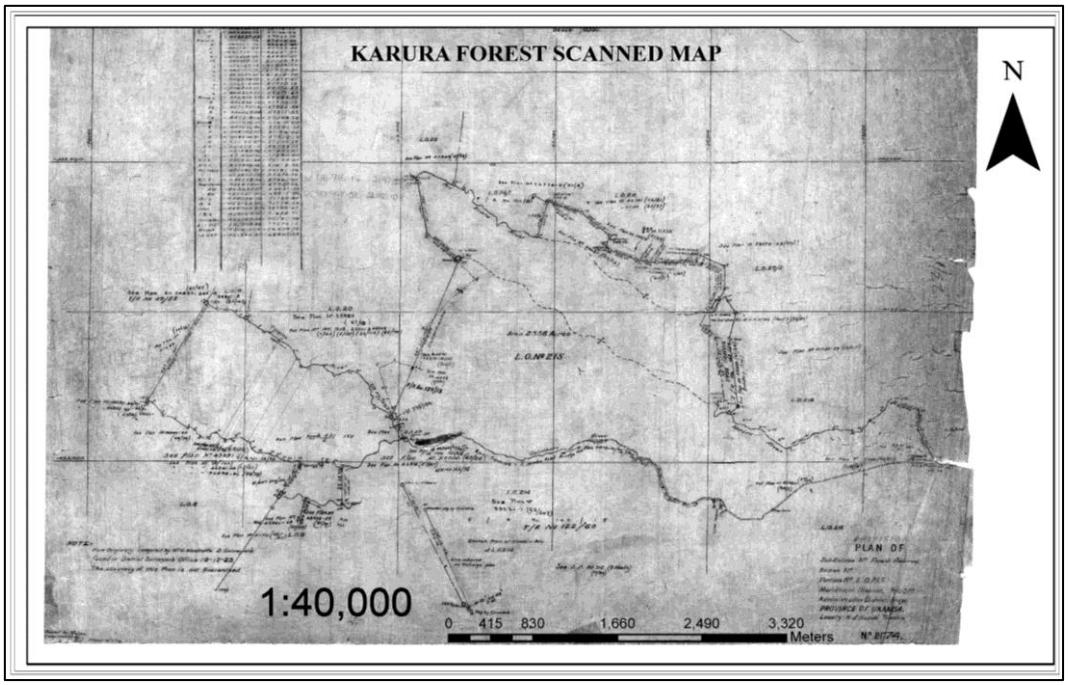


Figure 5.1: Scanned hard copy Map of Karura.

(Source: Survey of Kenya, 2014).

5.2.1 Base Map Digitization

Table 5.1 shows control points that were used to Georeference the scanned map using 1st Order Polynomial Affine Transformation. The cadastral data used was projected to UTM Clarke 1880 Arc 1960Zone 37 South.

Table 5.1: Reference Points for Georeferencing

NO.	MAP COORDINATES (M)		UTM COORDINATES (M)	
1	4234.094666	-2634.256987	260001.270000	9862687.630000
2	630.838576	-2636.878800	254332.300000	9862687.510000
3	3328.258358	-1424.282887	258594.720228	9864608.567471

(Source: Researcher, 2014).

After Georeferencing the scanned map, it was set as a background image and boundaries digitized as shown in Figure 5.2.

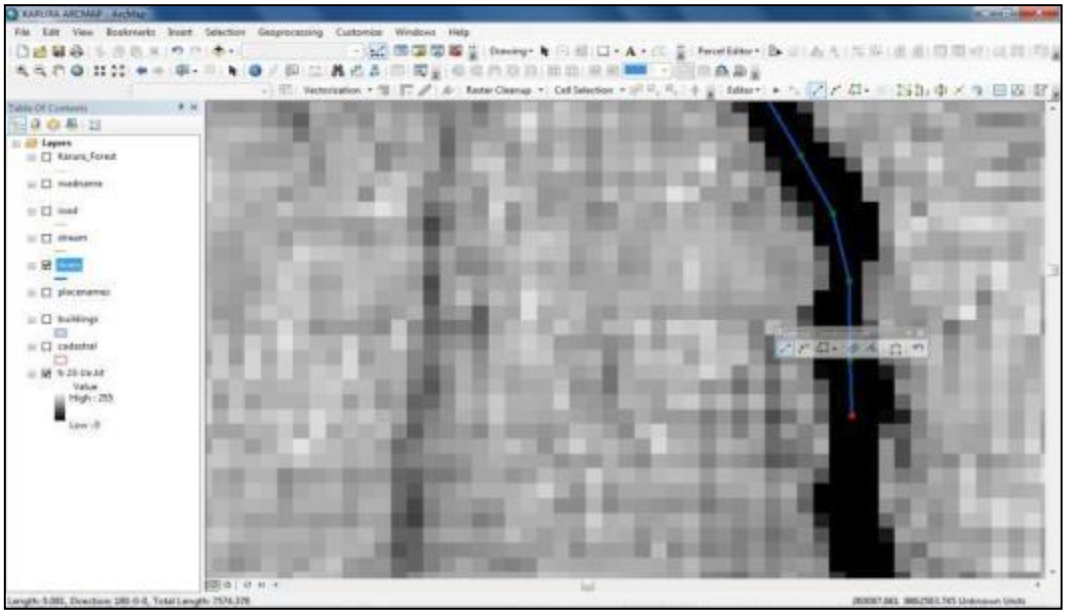


Figure 5.2: Digitization Process of Georeferenced Map.

(*Source: Researcher, 2014).*

In Figure 5.2, ArcGis 10.1 ArcMap tools digitizing the boundary from highly zoomed in scanned image. The process of digitization for all the features in this study followed this process.

Figure 5.3 upper image shows the resulting digitization polygon of Karura forest boundary of 1923 on scanned map and lower image without the scanned map.

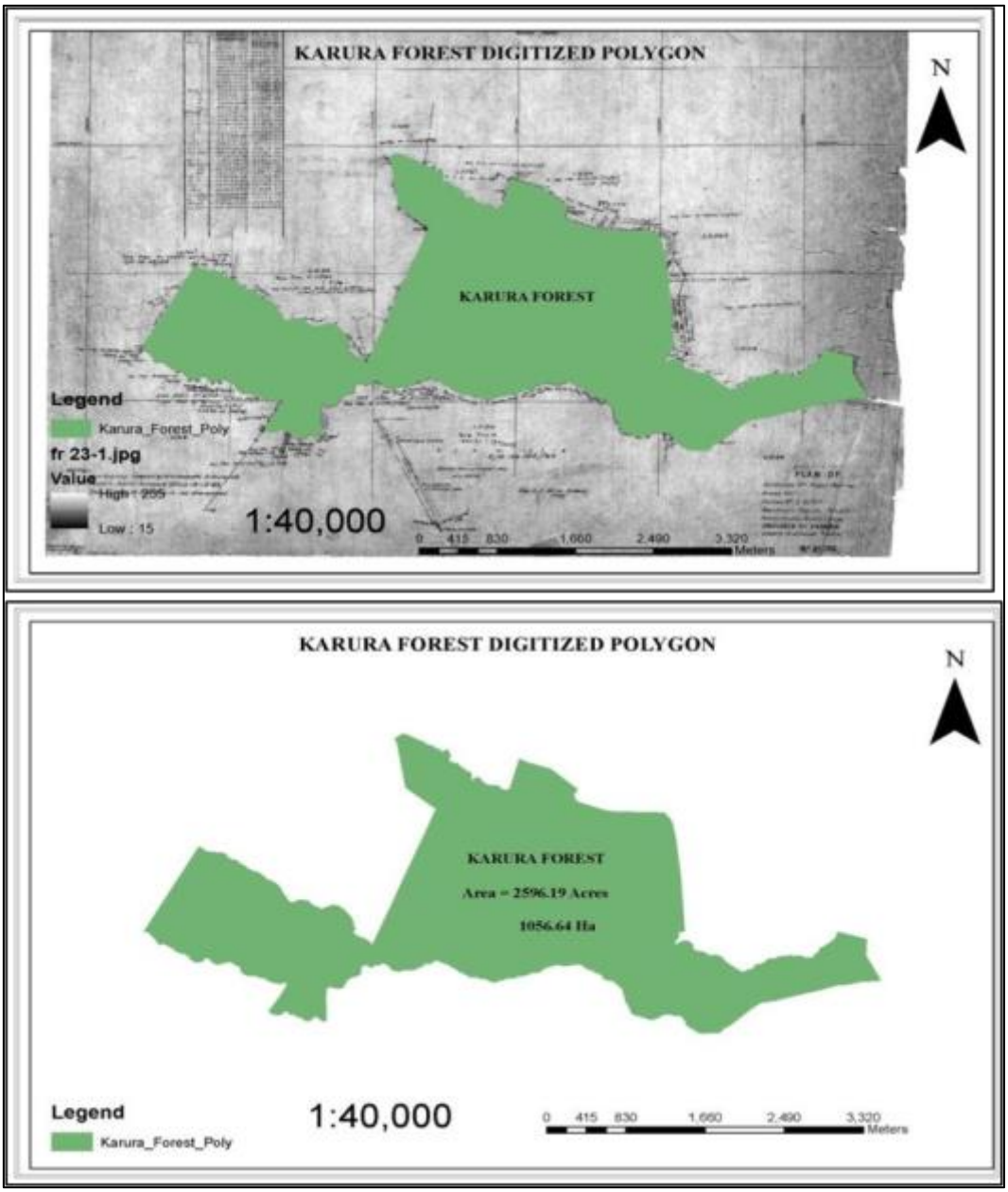


Figure 5.3: Karura Forest Digitized Map.

(Source: Researcher, 2014).

The digitized polygon was then checked with the existing cadastral data to ascertain the reliability of the digitization process (Figure 5.4). The process was satisfactory to the researcher after overlying the digitized map on the satellite data of 2000, 2010 and 2013.

5.2.2 Base Map on Cadastral data

Cadastral data of Nairobi County obtained independently from the researcher's archive, was then superimposed on the digitized Karura Forest to show the extent of development that are part of the pressure to Karura forest to give-up land for urban development. The parcels in red that overlaps the Karura Forest (Figure 5.4) shows the extent of Forest land that was grabbed in the late 1990s. However according to Orwa, (2014) after the protest of the late professor Wangari Maathai and other stakeholders, the Forest was secured and is now fence to keep off any unauthorized intruders. The Satellite image from Google map 2011 that was used by KFS Survey and Mapping department to prepare the Karura Forest map and the high resolution image from Quick Bird 2013, however showed that some institutions like CID, NIS,KISM, and ICRAF still occupies the Karura forest as revealed by the cadastral data.

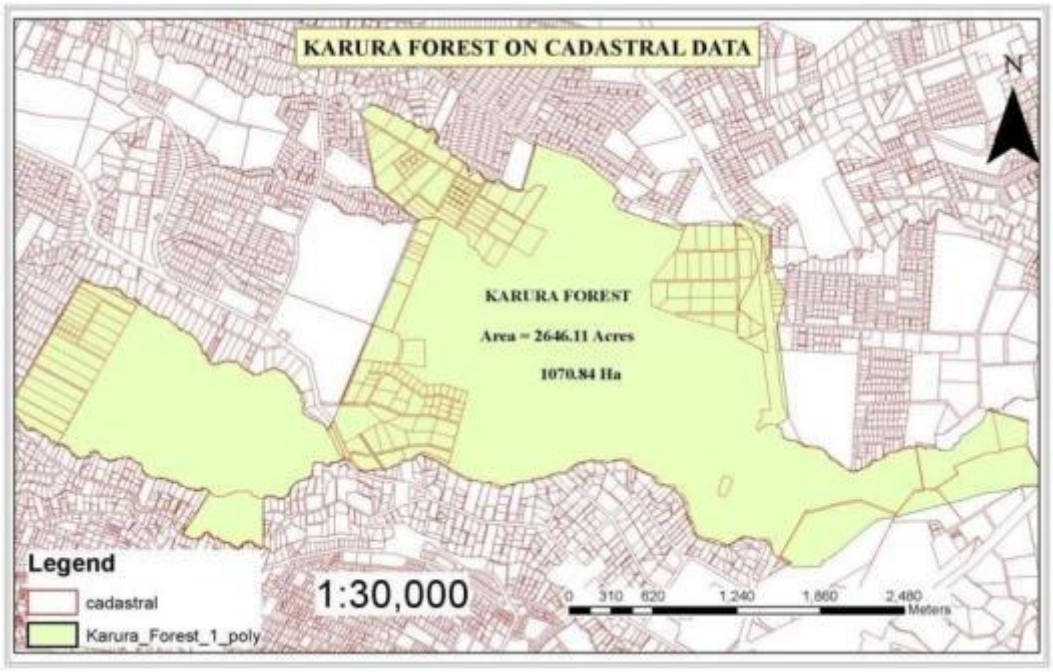


Figure 5.4: Karura Forest Superimposed on Nairobi Cadastral data.

(Source: Researcher, 2014).

5.2.3 Satellite Images and Digitized Data Overlay

The 1923 digitized boundary of Karura Forest was overlaid on the 2000 upper image and 2010lower Satellite Images (Figure 5.5).The boundary was adjusted using the cadastral data and the map from KFS to give current Forest Coverage (Figure 5.4).

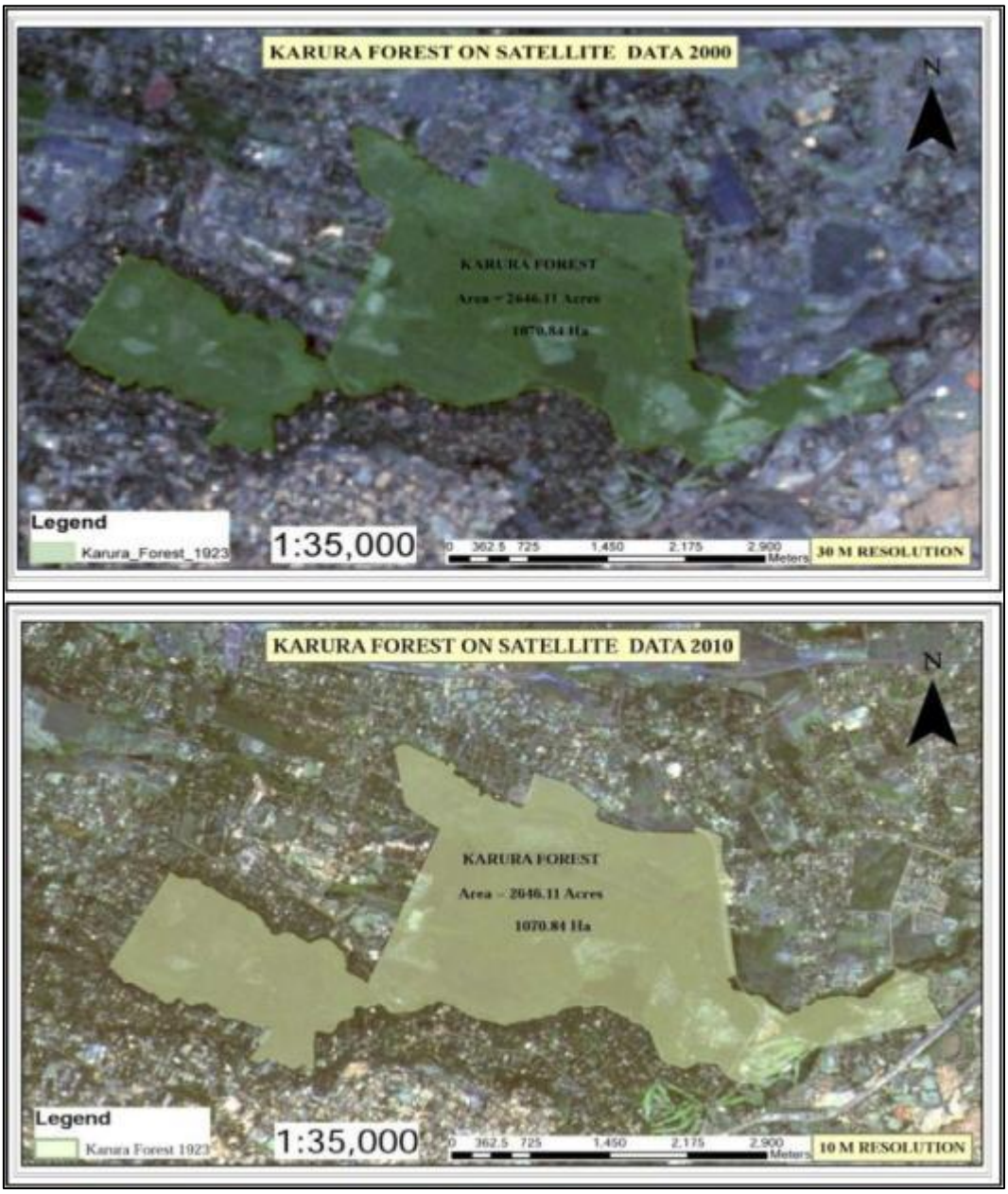


Figure 5.5: Karura Forest overlaid on 2000 and 2010 Satellite Images.

(Source: Researcher, 2014).

As noticed in the lower image of Figure 5.5, 10m resolution image is more visible.

The three polygons (Figure 5.6) were analyzed to give the changes in Area due to infrastructure development particularly the Kiambu and Limuru road which were originally part of the forest.

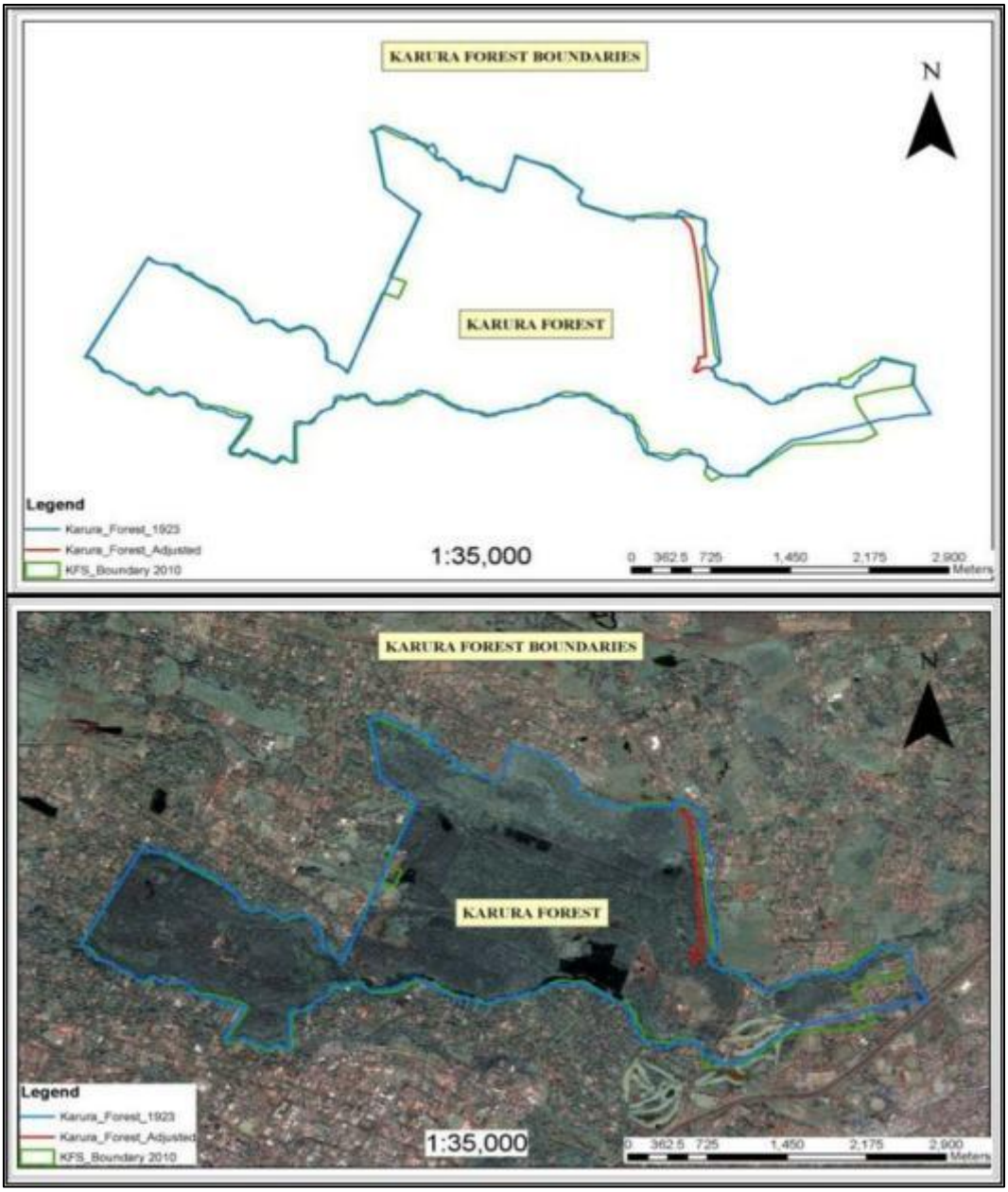


Figure 5.6: Karura Digitized Boundaries.

(Source: Researcher, 2014).

The Area of the digitized polygon measured 2646.11 Acres (1070.84 ha.) while the recorded Area on the Map was 2556 Acres (1043.27ha.). As can be seen in Figure 5.6,

lower image, the Forest boundary extends to include a section of Kiambu and Limuru road meaning that the road corridors were excised from the original Karura Forest. There seemed to be a difference of approximately 50 Acres in Area when the digitized and the Cadastral adjusted polygons were overlaid. Table 5.2 shows the differences.

Table 5.2: Differences in Polygon Area in Acres.

POLYGON	RECORDED	DIGITIZED	**DIFFERENCE**
DIGITIZED 1923	2556.00	2646.11	**90.11 (ACRES)**
ADJUSTED CAD	2551.19	2596.19	**45.00 (ACRES)**
KFS DIGITIZED	2551.19	2601.22	**50.03 (ACRES)**
DIFFERENCE 1 **DIFFERENCE 2**	**4.81 (ACRES)** **4.81 (ACRES)**	**49.92(ACRES)** **44.89 (ACRES)**	

(Source: Researcher, 2014).

Adding adjusted cadastral boundary to digitized boundary from KFS gives a total area of 90.03 Acres which compare closely with digitized 1923 boundary. There is a difference of 4.81Acres between KFS digitized and 1923 digitized boundary.

5.2.4 Mapping the Encroachments

After the boundary alignment for the three epochs were satisfactory to the researcher, encroachments inside the Karura Forest that could be detected by observation from the three sets of satellite data were mapped. Each set of image was mapped starting with the year 2000, 2010 and2013. The 0.5m high resolution of 2013 was used to counter check the same and to map out changes. The resulting features were overlaid for change detection. It was observed in Figure 5.7that by the year 2000 apart from the 1999 invasion that was stopped by the late Professor Wangari Maathai, the following institutions were inside the Karura Forest: ICRAF, KFS Rangers, KEFRI, KFS Head Quarters, CID, NIS, Muthaiga Golf Club, KISM, Survey of Kenya and Utali Staff Housing.

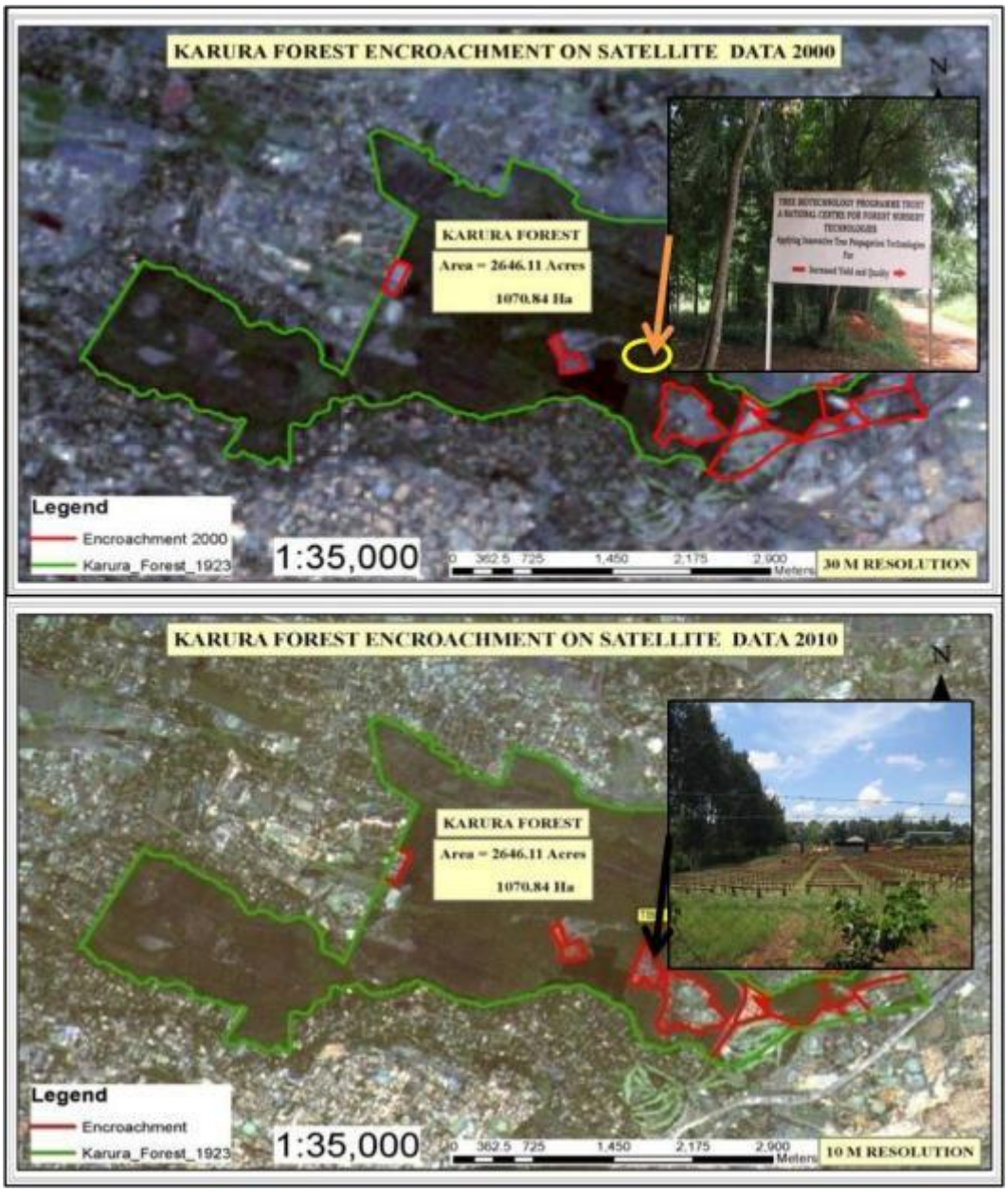


Figure 5.7: Mapped visible Encroachment 2000-2010.

(Source: Researcher, 2014).

Between 2000 and 2010 (Figure 5.7), there was an addition of the Tree Biotechnology Program Trust (TBPT) Centre in the list of internal stressors. This is a National centre for forest Nursery Biotechnology to increase yield and quantity in the country forest cover under KFS. The mapped polygon is highlighted in yellow box (Figure 5.7) 2010 lower satellite image which was not visible in 2000 upper image highlighted with yellow oval. Inserted is a photo of the TBPT centre adjacent to the KFS Headquarters.

Purdy, (2010) reported that high-resolution imagery is more photograph-like in image quality, and can be more easily understood by lay people. To give more accurate and detailed information concerning the encroachments, it was necessary to get high resolution images which would allow the researcher to digitize more meaningful features. This was one of the biggest challenges due to their cost and procurement process. Figure 5.8 shows the TBPT on 0.5m resolution Quick bird, 2013 and site photos inserted to give more ground information.

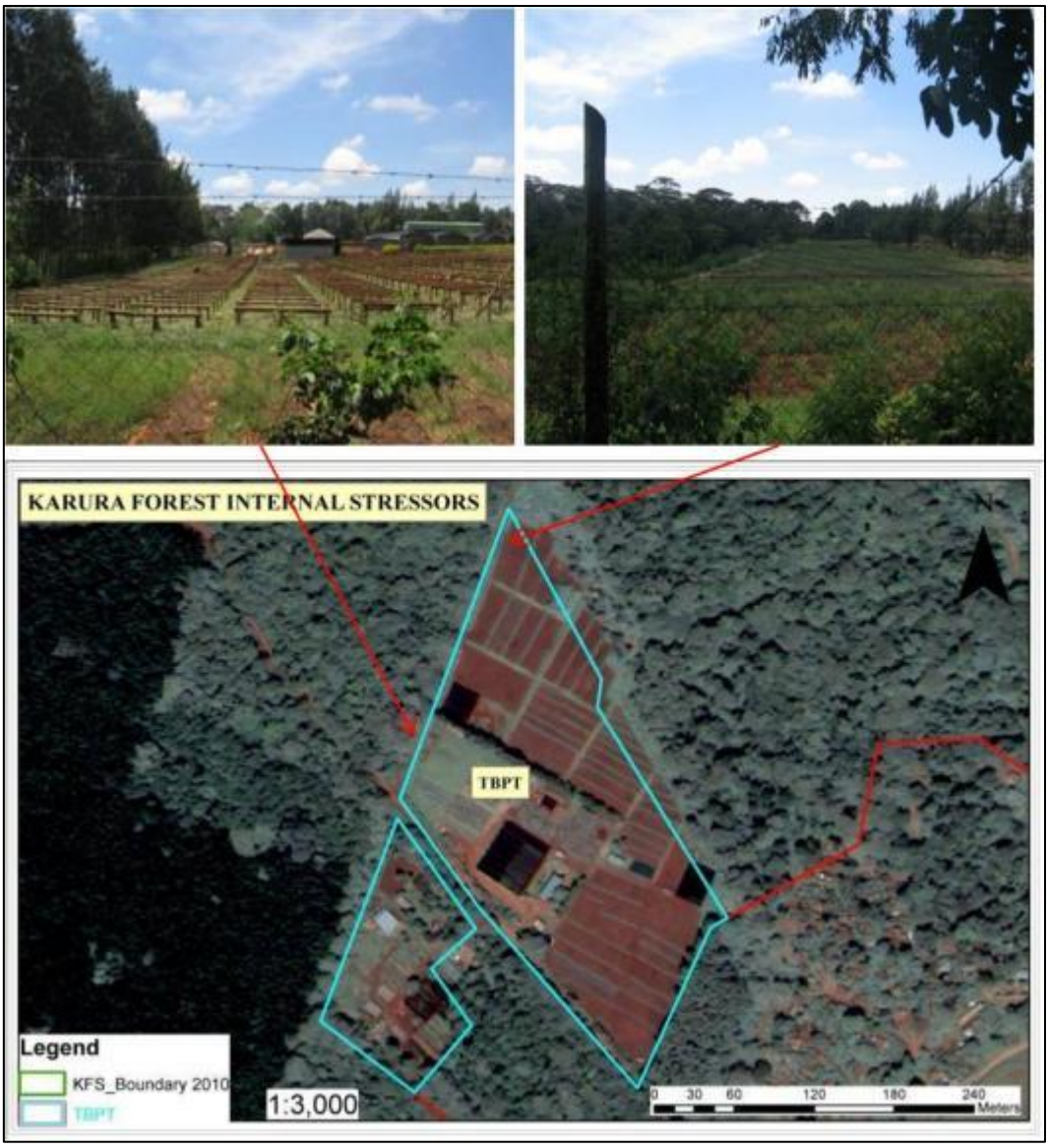


Figure 5.8: KFS TBPT on 0.5m Resolution Quick Bird Image.
(Source: Researcher, 2014).

During the interview session with the KFS head Surveyor, he pointed out that they have used high resolution images to prepare the map of Karura Forest which was evident on the wall map in the Gis unit The researcher requested to get the digital copy of the image but only the map could be provided free for academic purposes. This formed one source of high resolution image from which to digitize the encroachments. The other source was from Kenyatta University geo-database, which provided a 0.5m resolution satellite image of Quick Bird 2013, which revealed a lot of changes that have taken place since 2010 (Figure 5.8).

5.2.5 Preparing and Mapping from high resolution digital image.

The digital map image obtained from KFS was Georeferenced to the cadastral data as was done with the forest boundary map of 1923.Processing data used for the 1st Polynomial Affine Transformation are tabulated in Table 5.3. This image was preferred over the other 10m resolution of 2010 satellite data available because it gave the researcher a clear image to discern where to digitize and the existing boundary lines gave more details. Boundaries that were previously overlaid by the KFS Survey department were re-digitized and cadastral data overlaid to confirm the boundaries and check the accuracy of digitization process.

Table 5.3: Georeferencing data for 2010 High Resolution Image.

NO.	**MAP COORDINATES (M)**		**UTM COORDINATES (M)**	
1	4035.062653	-1786.702311	257384.707417	9864135.197693
2	7064.966147	-1848.715967	259937.052500	9864030.405800
3	9302.484835	-3576.179735	261908.700000	9862608.110000
4	9271.781577	-3780.162525	261898.390000	9862415.800000
5	2718.858594	-4689.920771	256245.670200	9861631.347600
6	5486.639128	-3467.567090	254336.599300	9862664.151000
7	1147.745777	-2313.660390	254903.929200	9863689.771300
8	5072.175397	-1135.004313	258259.036300	9864726.950900
9	5436.933178	-1256.037465	258598.647705	9864609.054688
10	5758.179333	-1509.322227	258876.061800	9864375.597900

(Source: Researcher, 2014).

Internal stressors on Georeferenced image of 2010 (Figure 5.9) upper image digitized on the KFS mapped boundary of 2010.

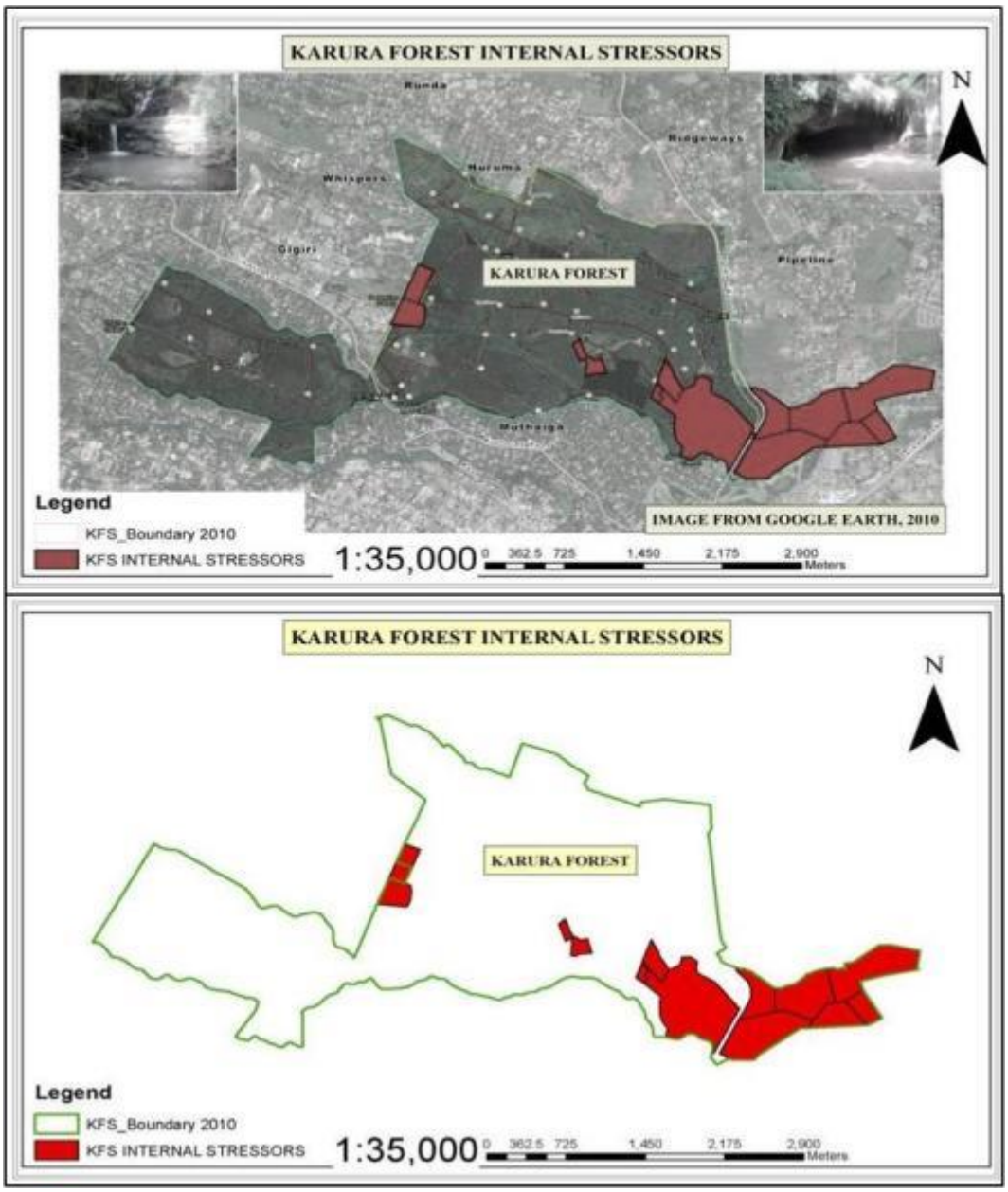


Figure 5.9: Karura Forest Internal Stressors 2010.

(Source: researcher, 2014).

From the 2010 boundary (Figure 5.9), it is evidence that Survey of Kenya with an Area of 24.22 ha has been curved out of the Karura Forest. Details about Survey of Kenya were left for further investigations. For ICRAFT, the information given was that 3.0 ha is allocation and 2.78 ha according to the Chief Surveyor KFS have been excised.

The Areas of digitized polygons for the 2000 and 2010 epochs, tabulated in Table 5.4 were sourced from the Chief Forester Karura station. From the tabulated data (Table 5.4), it is

clear that those government institutions that were inside Karura Forest by 2000 continues to get more land allocation. For example N.I.S from 5.8 ha to 23.68 ha (Figure 5.10) and C.I.D Head quarters from 9.0 ha to 28.21 ha being the biggest beneficiaries.

Table 5.4: List of Internal Stressors of Karura Forest.

NO.	INSTITUTION	AREA (Ha) 2000	AREA (Ha) 2010	GIVEN AREA(Ha)
1	C.I.D	9.78	28.21	9
2	I.C.R.A.F	5.78	5.78	5.78
3	K.I.S.M.	5.59	5.59	
4	KFEEC	6.46	6.46	
5	KFS HQ.	44.45	44.45	50
6	KFS RANGERS	4.17	4.17	
7	MUTHAIGA GOLF	23.59	23.59	21.8
8	N.I.S	5.78	23.68	5.8
9	SURVEY OF KENYA	24.22	24.22	
10	TBPT		6.17	
11	UTALI HOUSES	8.79	8.79	
	TOTAL AREA (Ha.)	**138.61**	**181.11**	**92.38**

(Source: Researcher, 2014).

Figure 5.10: NIS allocation between 2000 and 2010.

(Source: Researcher, 2014).

The total Area of allocation according to the Chief Forester Karura station was 92.38 ha. This research assumed that the total Area of Karura Forest to be the one given by the Chief Forester Karura station of 1041.3 ha. The total occupied Area in 2000 was 138.81 ha (13.31%) and181.11 ha (17.39%). in 2010, representing a change of 4.08% within 10years

Figure 5.11 shows the tread in Area change between 2000 red color and 2010 blue color. It also reveal that KFS headquarter has the biggest Acreage of 50 Ha which has been maintained between 2000 and 2010.

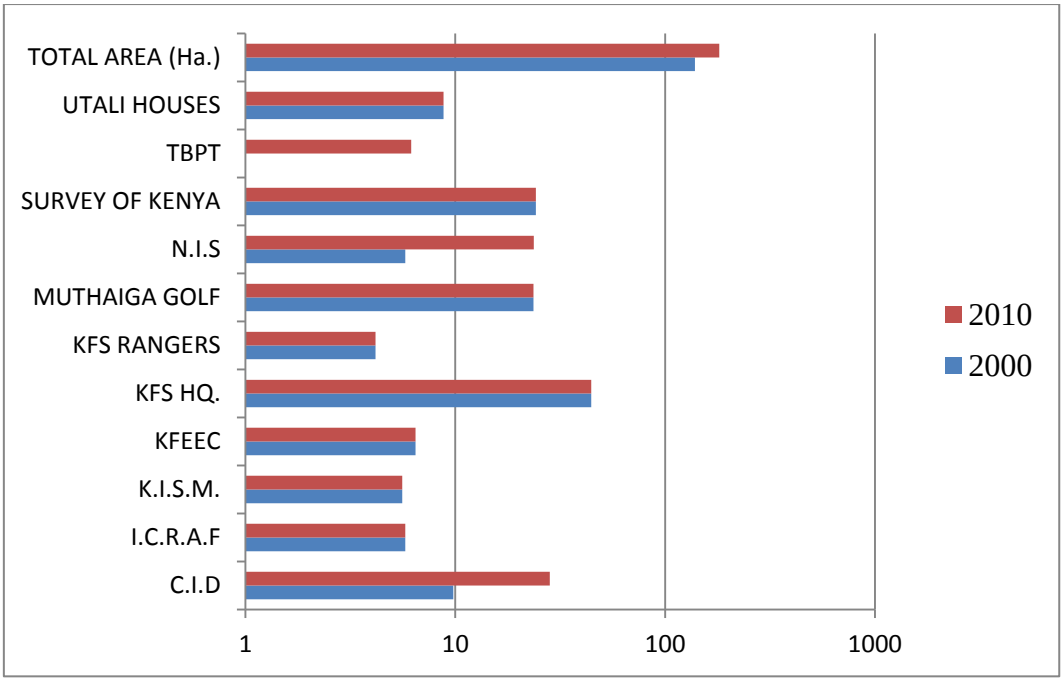


Figure 5.11: Karura Forest Internal Stressors between 2000 and 2010.

(Source: Researcher, 2014).

Figure 5.12 year 2000 and Figure 5.13 year 2010 shows the same tread in pie charts.

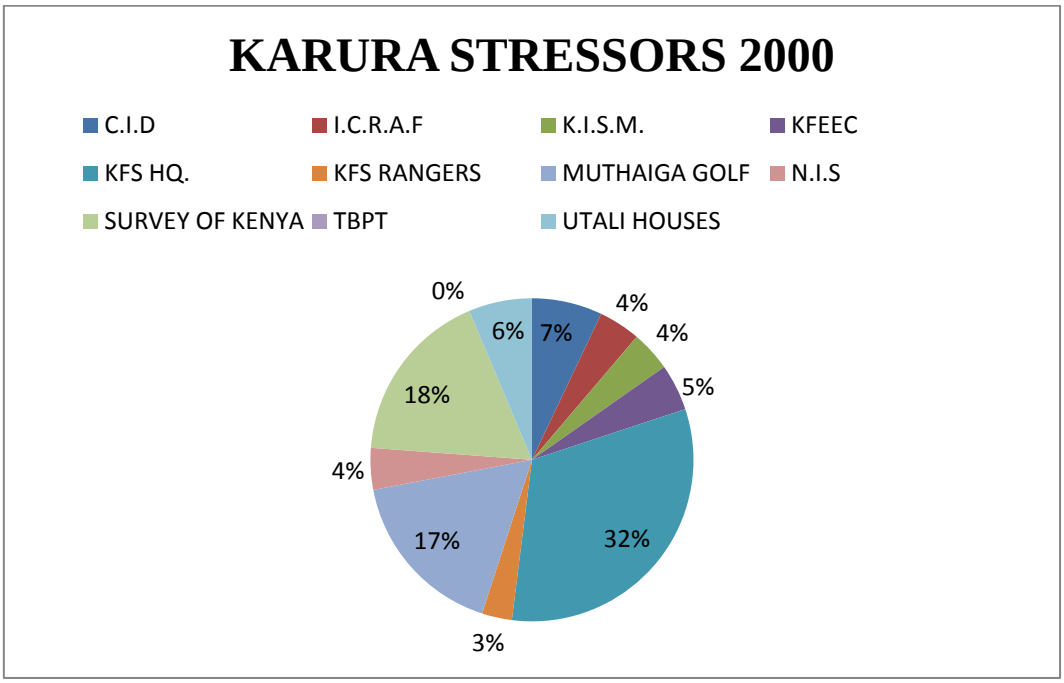


Figure 5.12: Karura Forest Internal Stressors 2000.

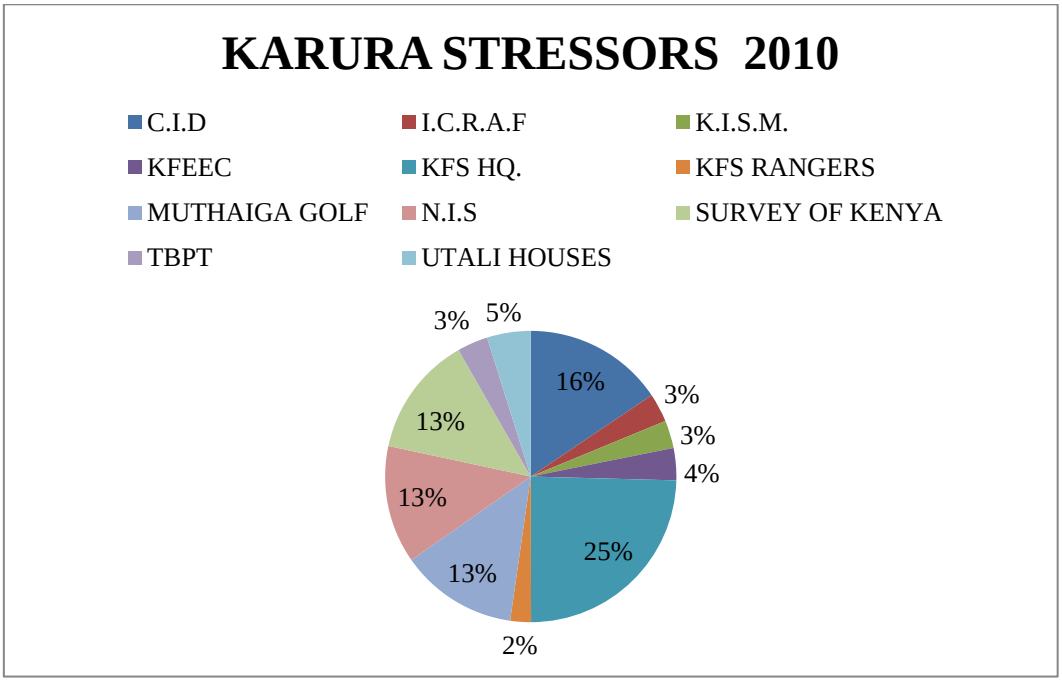


Figure 5.13: Karura Forest Internal Stressors 2010.

(Source: Researcher, 2014).

5.3 How Institutions managed to acquire land and settle in Karura Forest.

This was aimed at bringing forth information of how protected reserve is allocated to institutions.

5.3.1 Interview Schedules for institution

To investigate how the institutions managed to get land allocation inside Karura Forest, interview schedule for institutions were administered to the Institutions that were identified to be inside the Karura forest. Some didn't respond at all, other gave scanty information. The KFS Chief Forester shed more light on how the other institutions which dint respond to interview got allocation inside Karura forest.KFS (Figure 5.14) has its head quarter inside Karura forest. The Mazingila Buildings shown on the right of Figure 5.14 is now the C.I.D headquarters. It was actually constructed by KFS to be its Headquarters. How it ended up being the C.I.D is beyond the scope of this study.

Figure 5.14: KFS Headquarters.

(Source: Researcher, 2014).

This pointed the discussion to the regime of KANU which had all the powers to do anything regardless of the impact caused by their actions. Table 5.5 gives an idea of how the institutions are allocated Land.

Table 5.5: Institutions Allocated Land inside Karura Forest.

NO.	NAME OF INSTITUTION	GIVEN AREA(Ha)
1	C.I.D	9
2	I.C.R.A.F	5.78
5	KFS HQ.	50
7	MUTHAIGA GOLF	21.8
8	N.I.S	5.8
	TOTAL AREA (Ha.)	**92.38**

(Source: Researcher, 2014).

The list in Table 5.5 is shorter contrary to the institution listed in Table 5.4.However it formed the basis of investigation as the Chief Forester answered the question of how they ended up being inside Karura forest. Muthaiga golf's club has a long lease of 21.8 Ha so it is not excised, ICRAF is allocated 3ha and 2.78ha excised as mentioned earlier and shown in (Figure 5.15). According to Orwa, (2014), KFS itself had to have a home on which to operate so justifying their 50 ha occupation inside the Karura Forest.

Figure 5.15: ICRAF on 5.78 Ha.

(*Source: Researcher, 2014).*

All other Institutions are allocated land by the government in consultation with KFS but further information on this process seemed to touch on the wrong nerves. Table 5.6 shows 8 out of the 11 institutions (72.73%) were allocated land by the government while 3 out of the 11 (27.27%) were allocated by KFS.

Table 5.6: Mapped Institutions and their allocations.

NO.	NAME OF INSTITUTION	MAPPED AREA (Ha) 2010	ALLOCATED BY	GOK	KFS
1	C.I.D	28.21	Government	1	
2	I.C.R.A.F	5.78	Government	1	
3	K.I.S.M.	5.59	Government	1	
4	KFEEC	6.46	KFS		1
5	KFS HQ.	44.45	Government	1	
6	KFS RANGERS	4.17	KFS		1
7	MUTHAIGA GOLF	23.59	Government	1	
8	N.I.S	23.68	Government	1	
9	SURVEY OF KENYA	24.22	Government	1	

10	TBPT	6.17	KFS		1
11	UTALI HOUSES	8.79	Government	1	
	TOTAL AREA (Ha.)	**181.11**	**0**	**8**	**3**

(Source: Researcher, 2014).

KFS allocations are through high consultation with the key stakeholders like the Friends of Karura Forest. The objective of such consultation is to help KFS in protecting and managing the Karura forest. KEFRI (Figure 5.16), which is located inside the 50 ha occupied by KFS headquarters, only does forest product research. Oral interview with one of the official working there revealed that their mission is to do research on forest products. These products are not from Karura Forest, but from other forests. Individuals can bring in their forest product to get more information on the use of the product. TBPT as shown in Figure 5.8 occupy 6.17 ha (3%) of the allocations.

Figure 5.16: KEFRI Karura Forest Workshop.

(Source: Researcher Field Survey, 2014).

Karura Forest Environmental Education Training Centre occupying 6.46 ha (4%) of the allocated land is mainly managed by KFS and other stake holders. This forms one source of revenue for KFS to supplement some of its financial demand to maintain the Karura forest reserve. Other sources of revenue according to Chief Forester Karura station are eco-Tourism netting KFS ksh.1.5 million per month. Karura Forest Environmental Education Training Centre (KFEET) generates revenue by renting wedding ceremonies and such like activities to members of the public (Figure 5.17).

Figure 5.17: KFEET Centre showing the open field.

(Source: Researcher Field Survey, 2014).

Figure 5.18 give an over view of how the KFS headquarter is located in relation to the neighbouring institutions. The CID HQ is seen with the blue roofing above the Muthaiga Golf's Club at the lower right corner. The Red roof is the KEFRI workshop shown in Figure 5.16 above.

Figure 5.18: KFS in relation to Neighbouring Institutions.

(Source: Researcher, 2014).

5.4 The level of awareness and attitude toward the use of satellite data

Key Institutions namely: KFS,NEMA and the Ministry of Environment, Water and Natural Resources were interviewed to examine their level of awareness and attitude toward the use of Satellite data as a tool to monitor compliance and Enforcement of forest regulations in Karura Forest.

5.4.1 Level of awareness toward use of Satellite data Technology.

This was to evaluate the level at which the key institutions use or may have used the satellite technology. The information given showed that all the institutions are aware of the use of satellite data in monitoring compliance of forest regulations.

5.4.1.1 Kenya Forest Service (KFS)

Kahuri, (2014), when the head of FIS was asked about the KFS awareness of the use of satellite data technology as a tool to monitor compliance and enforcement of forest regulations, she said KFS is using satellite images to update its Forest boundaries all over the country. The satellite data help the KFS to monitor compliance of forest regulations especially where encroachment into the public forest is concerned. Medium resolution data from Landsat and Alos of 1990, 2000, 2005 and 2010 are being used for such activities.
Plate 18 is a photo showing evidence of awareness level of using satellite data as a tool to monitor compliance and enforcement of forest regulations in Kenya.

Figure 5.19: Satellite Imageries being used to produce Forest boundaries maps.

(Source: Researcher Field Survey, 2014).

5.4.1.2 NEMA

Ngolo, (2014), the head of GIS unit said NEMA is aware of satellite data technology as a tool to monitor forest management and compliance of forest regulations. Satellite data of Medium resolution used by NEMA according to the head of GIS unit are from ESRI. The details of the procurement or how NEMA gets access to ESRI portal was outside the scope of this study.

5.4.1.3 Ministry of Environment, Water and Natural Resources.

Kabugi, (2014), the Director of Forest Conservation (DFC), accepted that the Ministry is aware of satellite data as a tool for monitoring forest management and compliance of enforcement of forest regulations. The satellite data that the ministry once used were high resolution from Quick bird to monitor fire at the moorlands of Mt. Kenya and the Aberdare and in Karura when it was invaded in 1999.

5.4.2 Attitude toward the use of Satellite data Technology.

This was to assess positive or negative attitude toward the use of satellite data technology. It aimed at getting the feeling of various stakeholders on the way forward in adopting the satellite data in their monitoring activities of forest ecosystems.

5.4.2.1 Kenya Forest Service (KFS)

The head of remote sensing unit added that satellite data technology can be used to monitor encroachment of the forest, mapping boundary alignment especially where old survey map exists alone. The satellite data can be retrieved for as far as 1972 to try and get the actual forest boundary alignment. This according to Kamwara, (2014) the Head of Survey and Mapping is a good source of evidence in the Court of law where the satellite images support existing Registry Index Maps (RIM) and where the Riverine has changed course. Figure 5.20 shows the positive attitude adopted by KFS to use satellite data to update their maps.

The challenge of adopting this technology according to Head FIS will be the number of expertise needed to match the task. Currently the number of personnel employed by KFS cannot match the task required to map all the forest say within 1 year and keep the records updated. Although high resolution satellite images will be very good for forest monitoring, the financial allocation for such activities may not be a priority to the KFS. This has necessitated the Remote Sensing and GIS units to use what is available for free download on the internet.

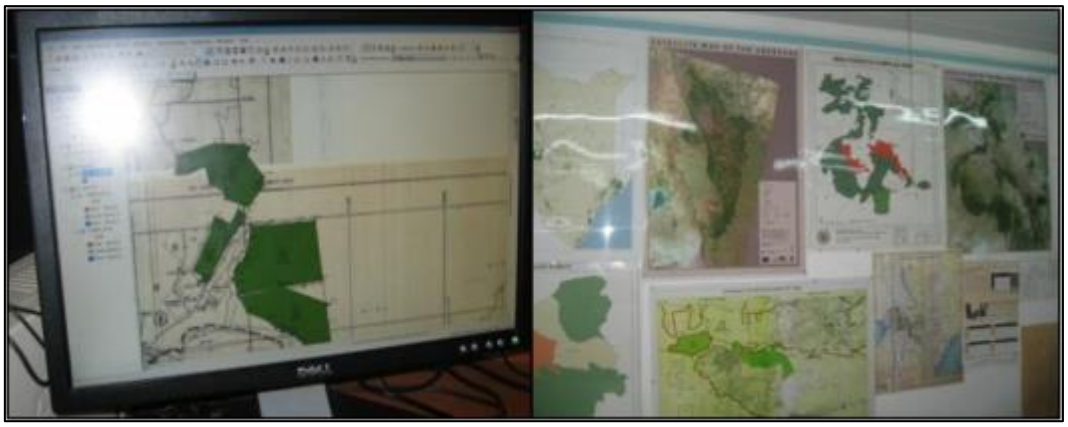


Figure 5.20: Photo showing use of Satellite technology in KFS Remote Sensing Unit.

(Source: Researcher Field Survey, 2014).

5.4.2.2 NEMA

Ngolo, (2014), in his view, the use of satellite data technology to monitor compliance of enforcement of forest regulation should have started long time ago. It is a very useful tool in monitoring the status of large forests. As a source of evidence to prosecute non-compliance in the Court of law, it is fool-proof evidence but the Courts need to be enlightened about these possibilities. The challenge of adopting such a technology is mainly Finances. This is mainly due to the cost of high resolution images and the licenses of the softwares like ArcGis used to carry out image analysis.

5.4.2.3 Ministry of Environment, Water and Natural Resources.

The DFC in his view acknowledged that satellite data technology can be used to monitor compliance and enforcement of forest regulations especially in determining the takeoff level of the forest by assessing the changes in the forest cover. This in particular is useful inside the forests where harvesting is legalized from time to time.

As a source of evidence to prosecute non-compliance in a court of law, the DFC in his view said the technology is noble but the capacity of the Kenyan Courts need to be enhanced to develop technology based evidence. The new Environment and Land Court

doesn't have the capacity to handle such evidence in their full capacity. This is due to challenges of expertise and finances to set up such a platform.

A summary of the respondent on the level of awareness toward use of Satellite data as a tool to monitor compliance and enforcement of forest regulation in Table 5.7 indicates that all the 3 respondents (100%) responded YES. This shows that the awareness is there and the technology is being used by the institutions interviewed.

Table 5.7: Level of awareness toward use of Satellite data as a Monitoring tool.

		AWARENESS OF USING SATELLITE DATA	
No.	**INSTITUTION**	**YES**	NO
1	KFS	1	
2	NEMA	1	
3	MEW&NR	1	

(Source: Researcher, 2014).

Table 5.8 shows that all respondents had positive attitude toward the use of satellite data as a tool to monitor compliance and enforcement of forest regulations in Kenya.

Table 5.8: Attitude toward the use of Satellite data as a Monitoring tool.

		ATTITUDE TOWARD USE OF SATELLITE DATA	
No.	**INSTITUTION**	**CAN BE USED**	**CANNOT BE USED**
1	KFS	YES	
2	NEMA	YES	
3	MEW&NR	YES	

(Source: Researcher, 2014).

This concludes that it is not the awareness neither the negative attitude that is holding the maximum use of satellite data technology but as most of the respondent pointed out, it is the issue of finances to purchase the high resolution imageries and sustain the expertise needed. Legal and policy frame work that is not restrictive and address the Satellite data use in a more elaborated manner.

5.5 Demonstrate the use of Satellite data as a tool for monitoring in Karura forest.

Ali, (2010) defines Remote Sensing as the process of acquiring data or information about objects or substances not in direct contact with the sensor, by gathering its inputs using electromagnetic radiation or acoustical waves that emanate from the targets of interest. Satellite data and in general remote sensed data are very reliable in monitoring expansive areas.

This study demonstrated the use of remotely sensed data in different time frame to show the changes that have taken place in Karura forest. Objective (i) of this study clearly demonstrated that Satellite data taken at different time frames have potential to map out spatial extent of encroachments.30m resolution Satellite images of 2000 (Figure 5.21), 10m resolution 2010 and 0.5m resolution 2013 (Figure 5.22) were the source of data to detect any change inside the Karura forest. Google Earth, 2014 was used to check the current activities detected during the field survey.

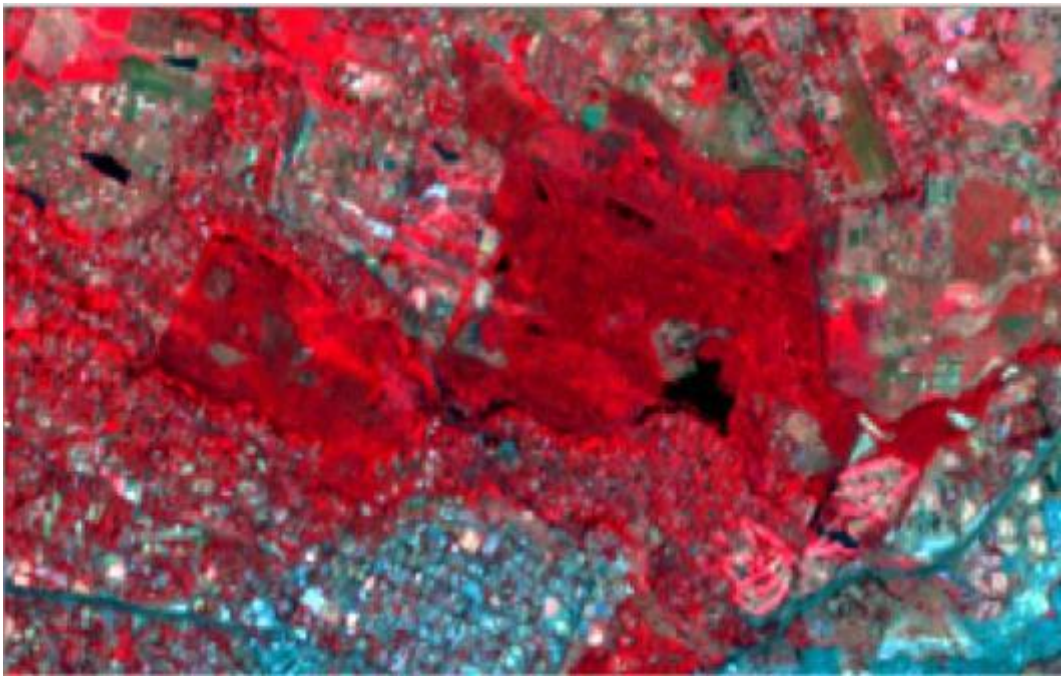


Figure 5.21: 30m Resolution Satellite Image of 2000.

(Source: Regional Centre for Remote Sensing and Mapping, 2012).

The resolution is too low making the image grainy when zoomed in.

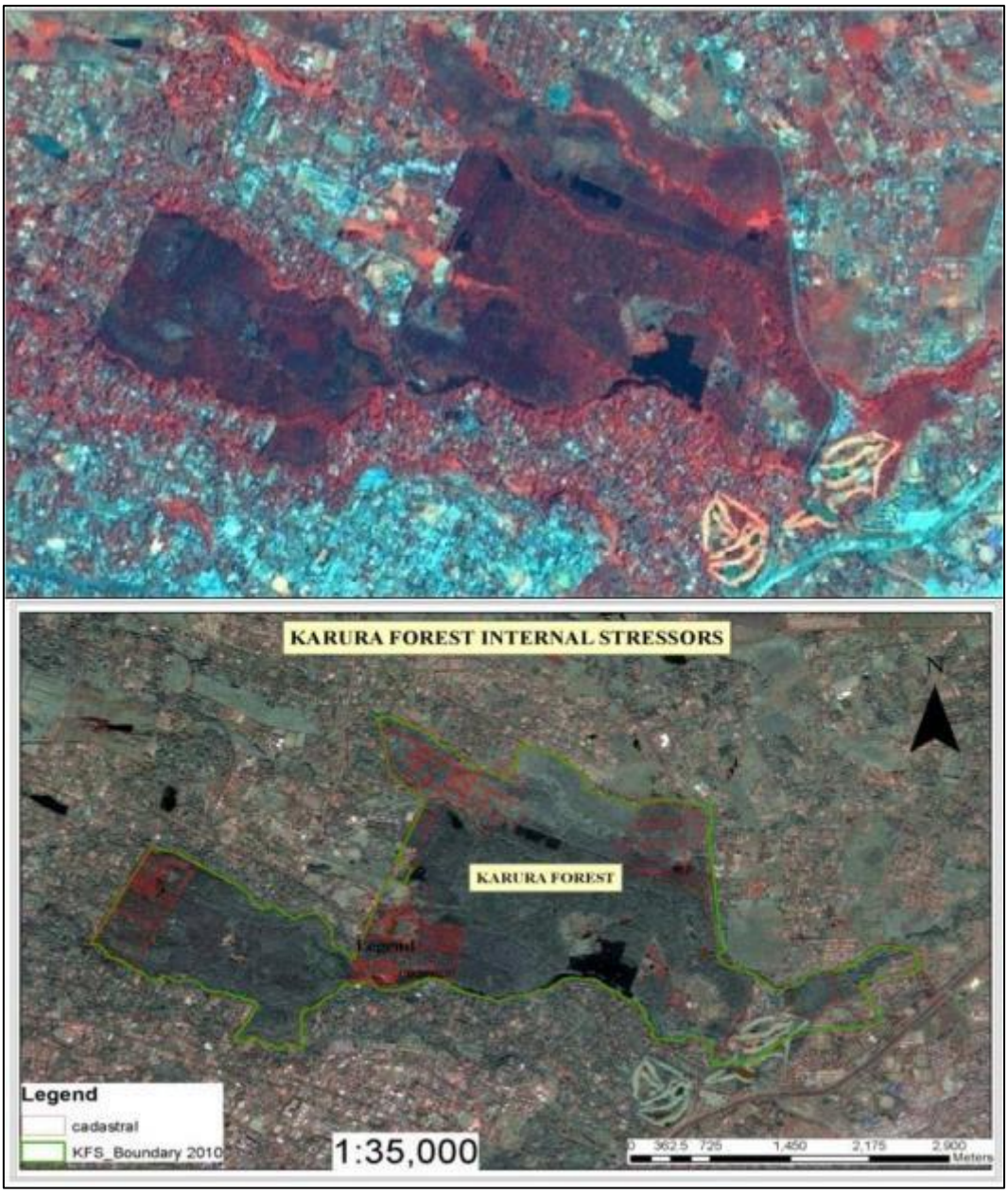


Figure 5.22: 10 m Resolution 2010 and 0.5m resolution 2013 Satellite Images.

(Sources: Regional Centre for Remote Sensing and Mapping, 2012& Kenyatta University Geo-database, 2013).

Figure 5.22 top image is the 10m resolution 2010 from Alos while the lower image is 0.5 m resolution from Quick Bird 2013. Both images were used to map the visible encroachment and where changes detected during the field survey, Google Earth 2014 was used to verify that indeed the changes are captured by the satellite images available online.

With the availability of the broad band internet such lower resolution images like 30m can be downloaded free from the website. Google Earth which is also free to view provided high resolution images to refine the changes detected using the medium resolution. High resolution image of 2010 available from KFS, 0.5m high resolution image 2013 from Quick Bird and Google Earth image 2014 available online were compared to detect any changes. The following noticeable changes were captured:

5.5.1 Changes inside the CID headquarters from satellite Images

The CID headquarters formerly Mazingila showed some new activities taking place between 2010and 2013 (Figure 5.23). The researcher through the Chief Forester Karura station learnt that this was the Forensic Laboratory that was being constructed. Asked how such new developments were allowed by NEMA, the Forester Said the Director of CID consults highly with KFS Director and stakeholders for such approval. Nema Head of GIS unit said that as long as KFS approves a project, Nema only looks at the effects of the project to the Environment before issuing EIA licenses.

Figure 5.23: Changes inside CID Headquarters 2010- 2013.

(Source: Researcher, 2014).

Figure 5.23 top satellite image of 2010, shows there was no development. In the lower image of 2013 from Quick bird, it is evident that there is a new building. This is the forensic Lab inside the CID headquarters. The 0.5m resolution image is so informative that a lot of features can be analyzed.

5.5.2 Changes inside the ICRAF from satellite image

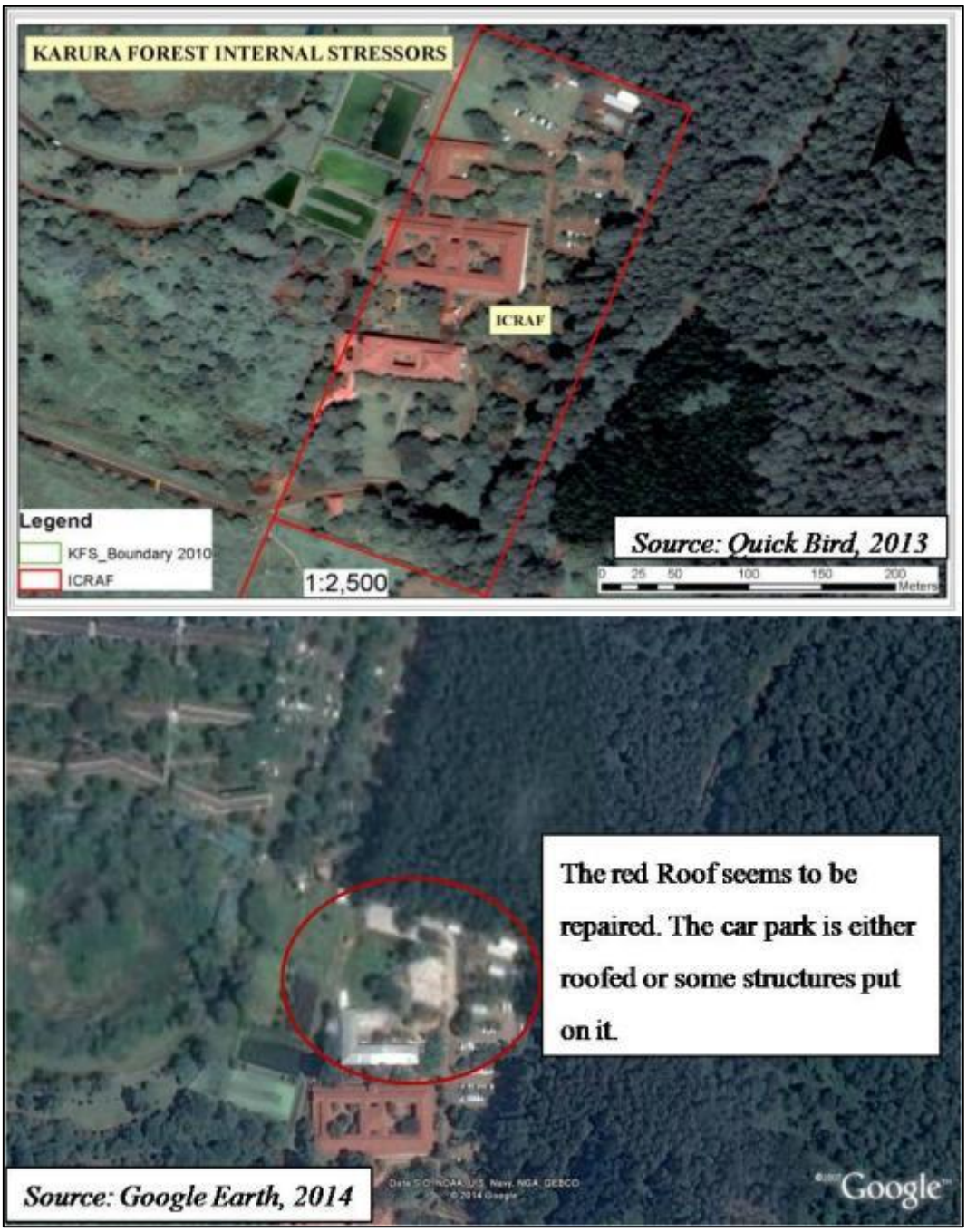


Figure 5.24: Changes inside ICRAF 2013 -2014.

The high resolution images of Figure 5.24 allow changes to be detected even when objects change color like the roof of the ICRAF buildings within a span of about 1 year. Noticeable is the 5.78 ha of land in the top image occupied by ICRAF encroaching inside the Karura forest.

5.5.3 Changes along the Swampy Area from Satellite Image

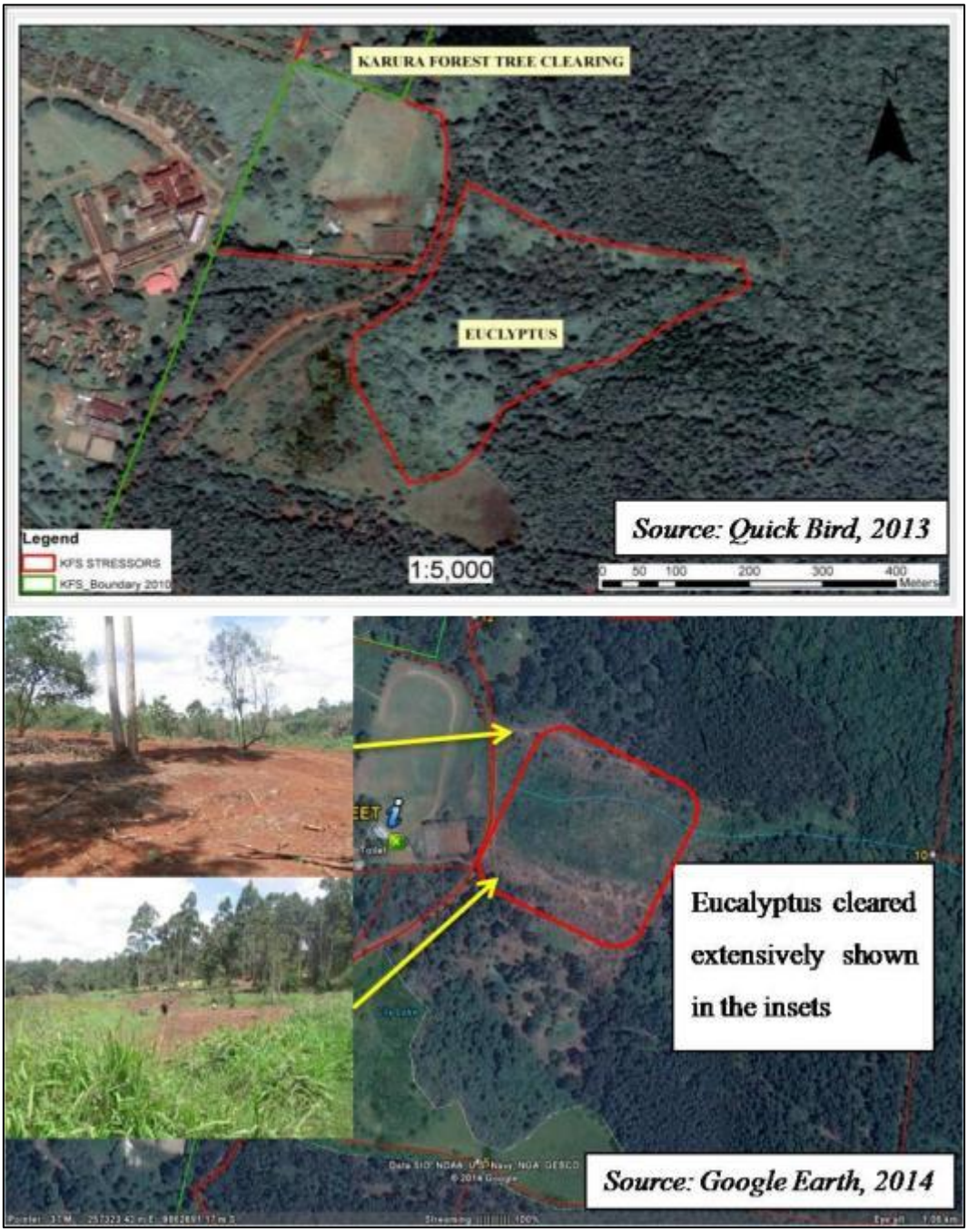


Figure 5.25: Eucalyptus clearing between 2013 and 2014.

(Source: Researcher, 2014).

Figure 5.25 top image shows that there was Eucalyptus tree covering the marsh area in 2013. In the lower Satellite image of 2014 indicates that the trees have been cleared. This is supported by inset photos taken on site by the researcher during field survey.

5.5.4 Reforestation of Wangari's corner from Satellite Images.

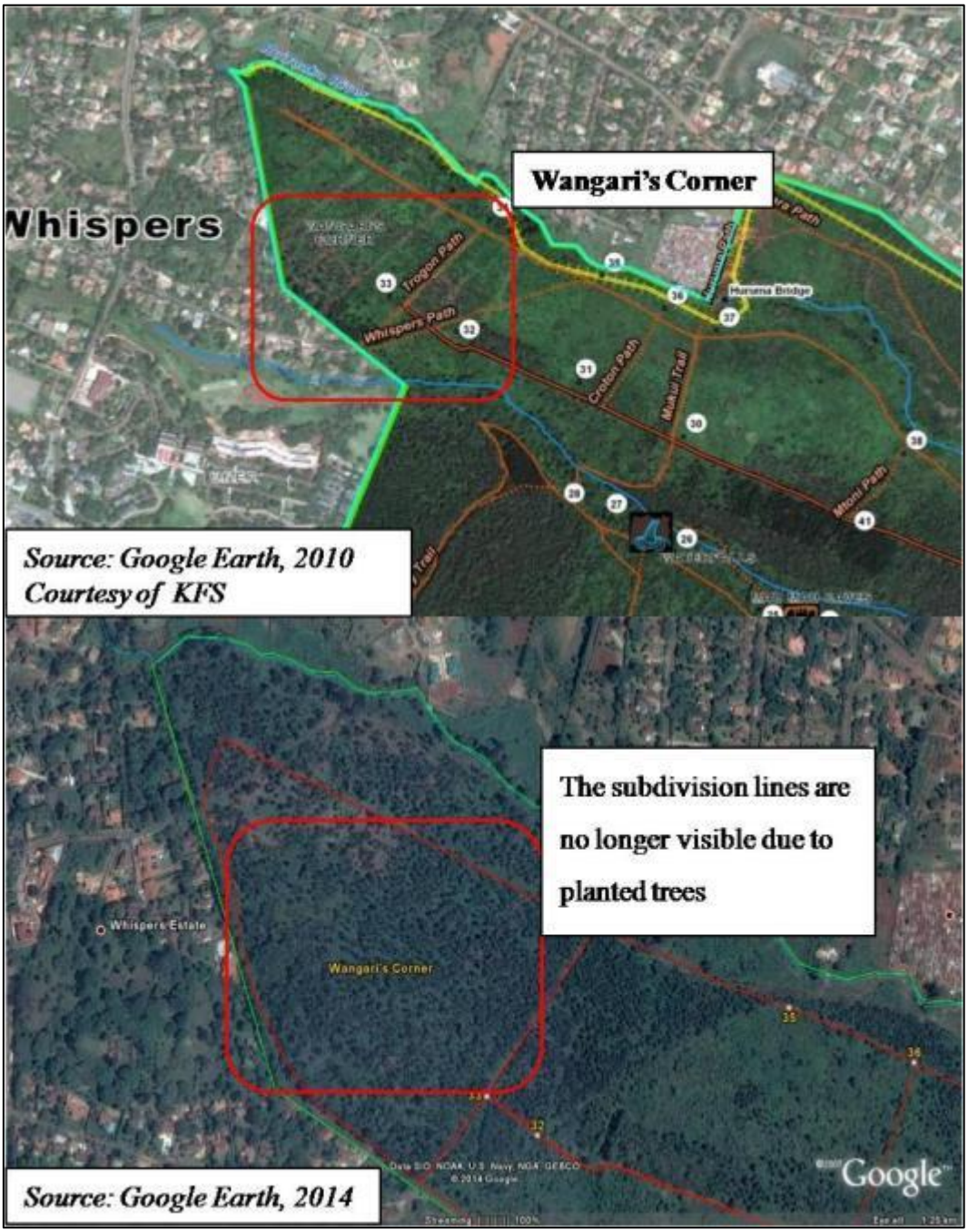


Figure 5.26: Wangari's corner 2010-2014

The access road tracks of 1999 and subdivision lines can be seen in Figure 5.26Top image which are missing in the 2014 lower satellite image. This shows the area has been covered by trees due to reforestation initiated by the Late Professor Wangari Maathai.

5.5.5 Changes inside Survey of Kenya from Satellite Images.

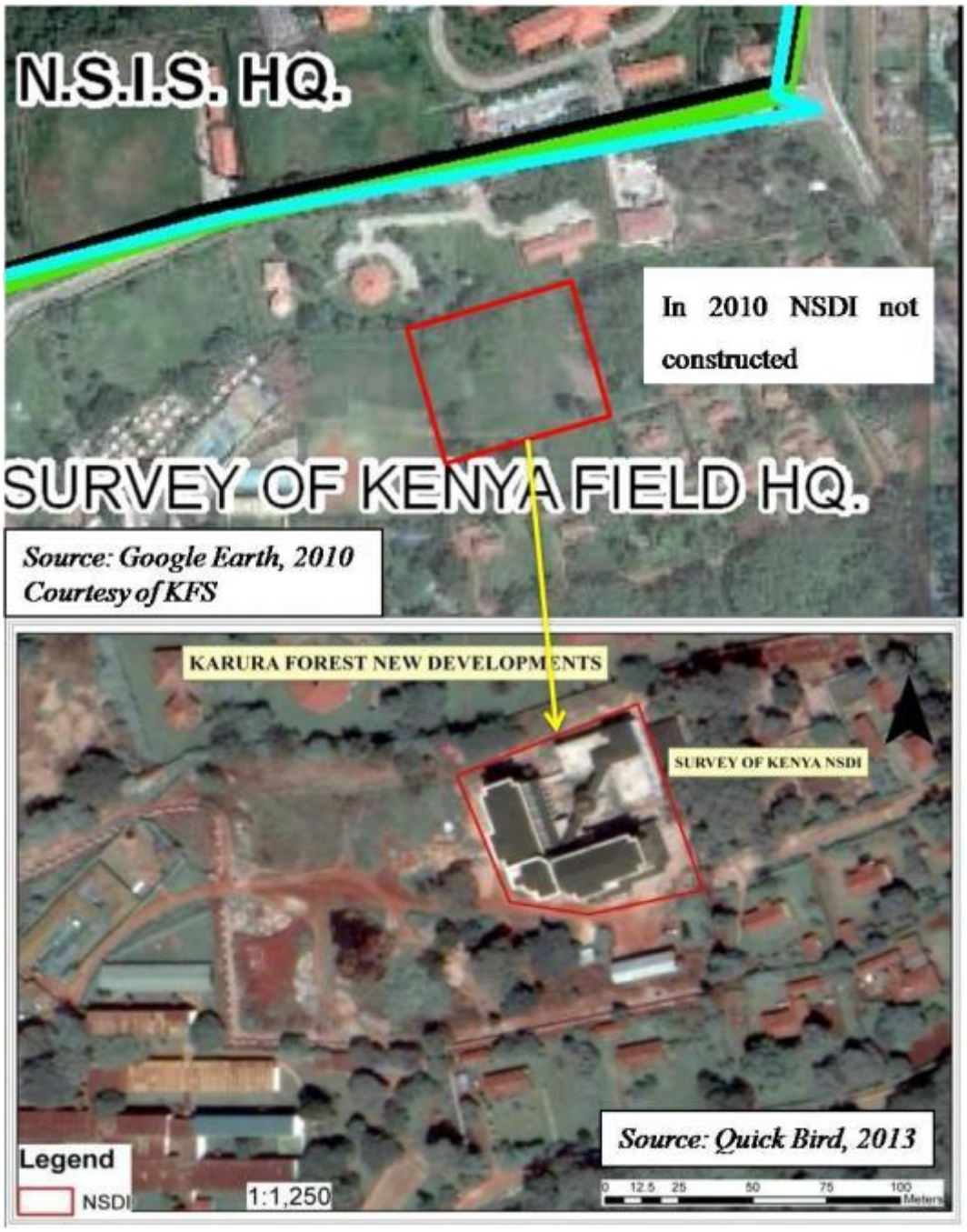
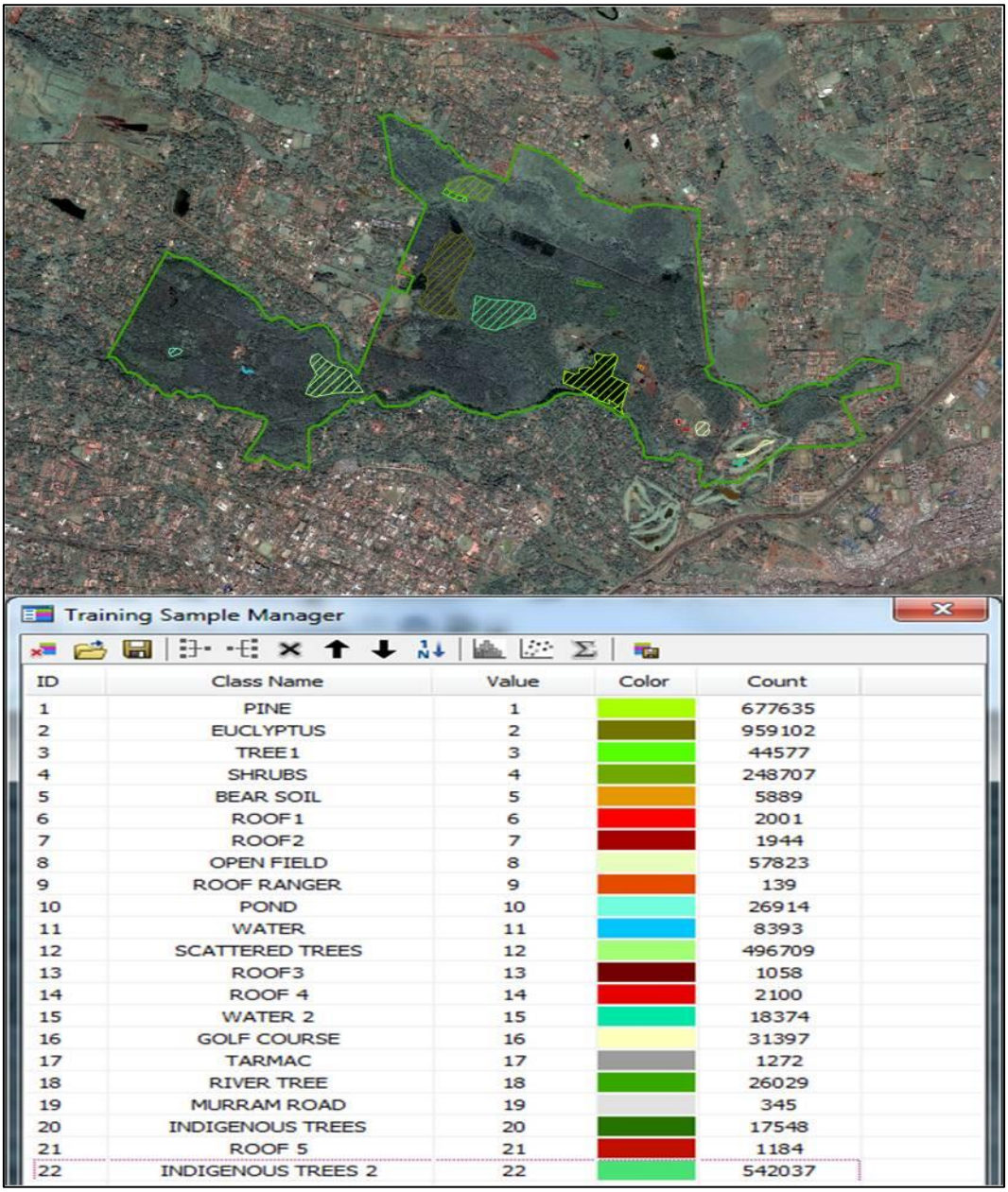


Figure 5.27: Survey of Kenya NSDI

The Survey of Kenya National Spatial Data Infrastructure (NSDI) building was constructed after the 2010 satellite data image was captured. It Figure 5.27 top image shows clear that the area was covered by trees in 2010. The NSDI is seen in Figure 5.27 lower 2013 Quick bird image.

5.6 Supervised Classification

The aim of this type of classification was to demonstrate that satellite data can be used to classify feature in different classes according to their capability to reflect electromagnetic waves. Training samples were selected and Digitized (Figure 5.28) using the high resolution 5M satellite image from quick bird. These were conspicuous feature with different shading as seen on the image and could be recognized by the researcher. The signature file was then created from the training sample.



ID	Class Name	Value	Color	Count
1	PINE	1		677635
2	EUCLYPTUS	2		959102
3	TREE1	3		44577
4	SHRUBS	4		248707
5	BEAR SOIL	5		5889
6	ROOF1	6		2001
7	ROOF2	7		1944
8	OPEN FIELD	8		57823
9	ROOF RANGER	9		139
10	POND	10		26914
11	WATER	11		8393
12	SCATTERED TREES	12		496709
13	ROOF3	13		1058
14	ROOF 4	14		2100
15	WATER 2	15		18374
16	GOLF COURSE	16		31397
17	TARMAC	17		1272
18	RIVER TREE	18		26029
19	MURRAM ROAD	19		345
20	INDIGENOUS TREES	20		17548
21	ROOF 5	21		1184
22	INDIGENOUS TREES 2	22		542037

Figure 5.28: Training sample Digitization

Supervised classification was then done using maximum likelihood classifier. Erdas, (2001) defines the maximum likelihood decision rule as based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes, and that the input bands have normal distributions. Figure 5.28 lower image shows the resulting supervised classified maps of Karura Forest.

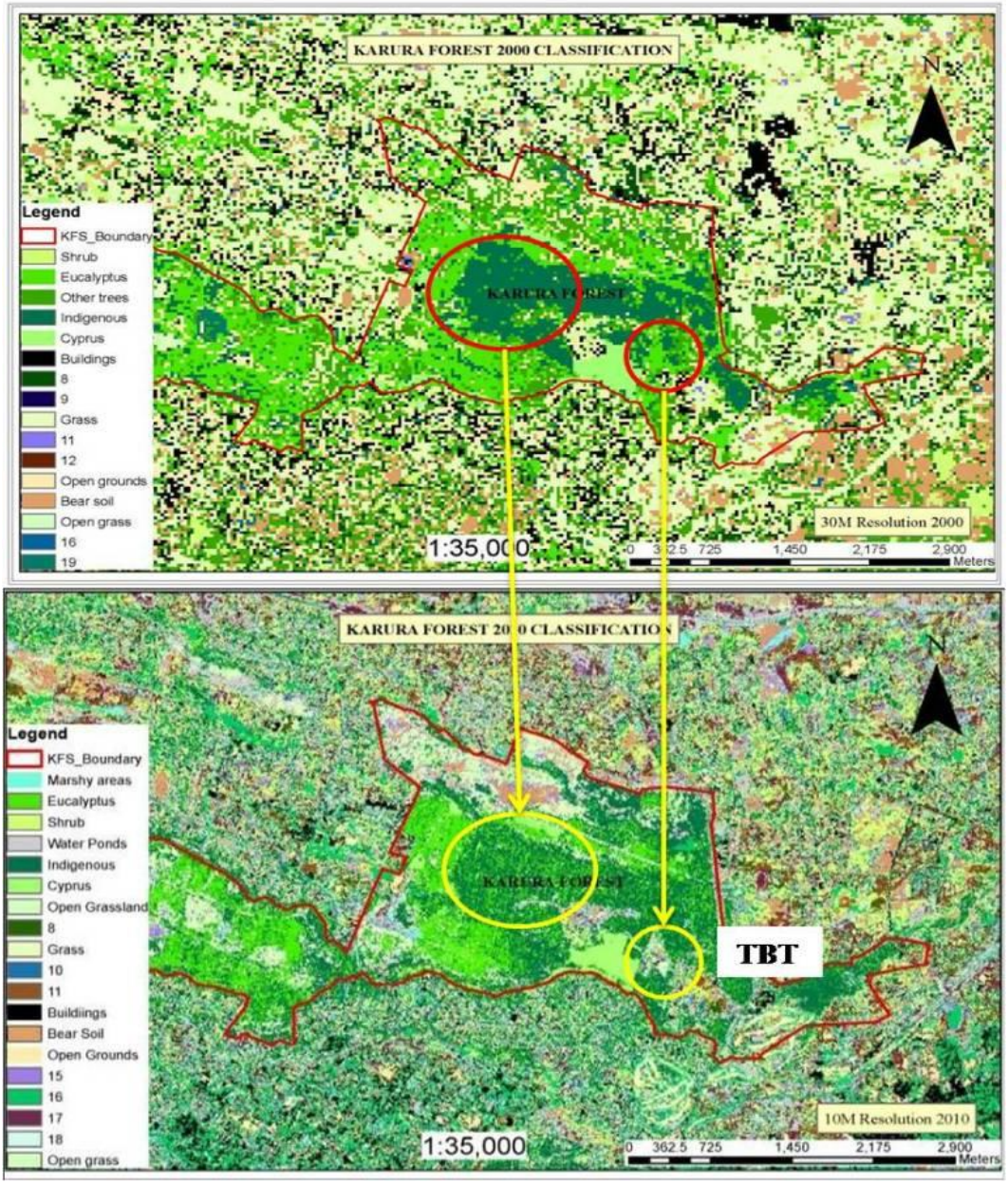


Figure 5.29: Supervised Classified Maps of Karura Forest 2000 and 2010.
(Source: Researcher, 2014).

Figure 5.29 shows the TBPT in the lower image which is not present in the top image as explained earlier. The 10 m resolution of 2010 has more features visible after classification unlike the 30 m resolution. The Indigenous trees are visible at the middle of the forest.

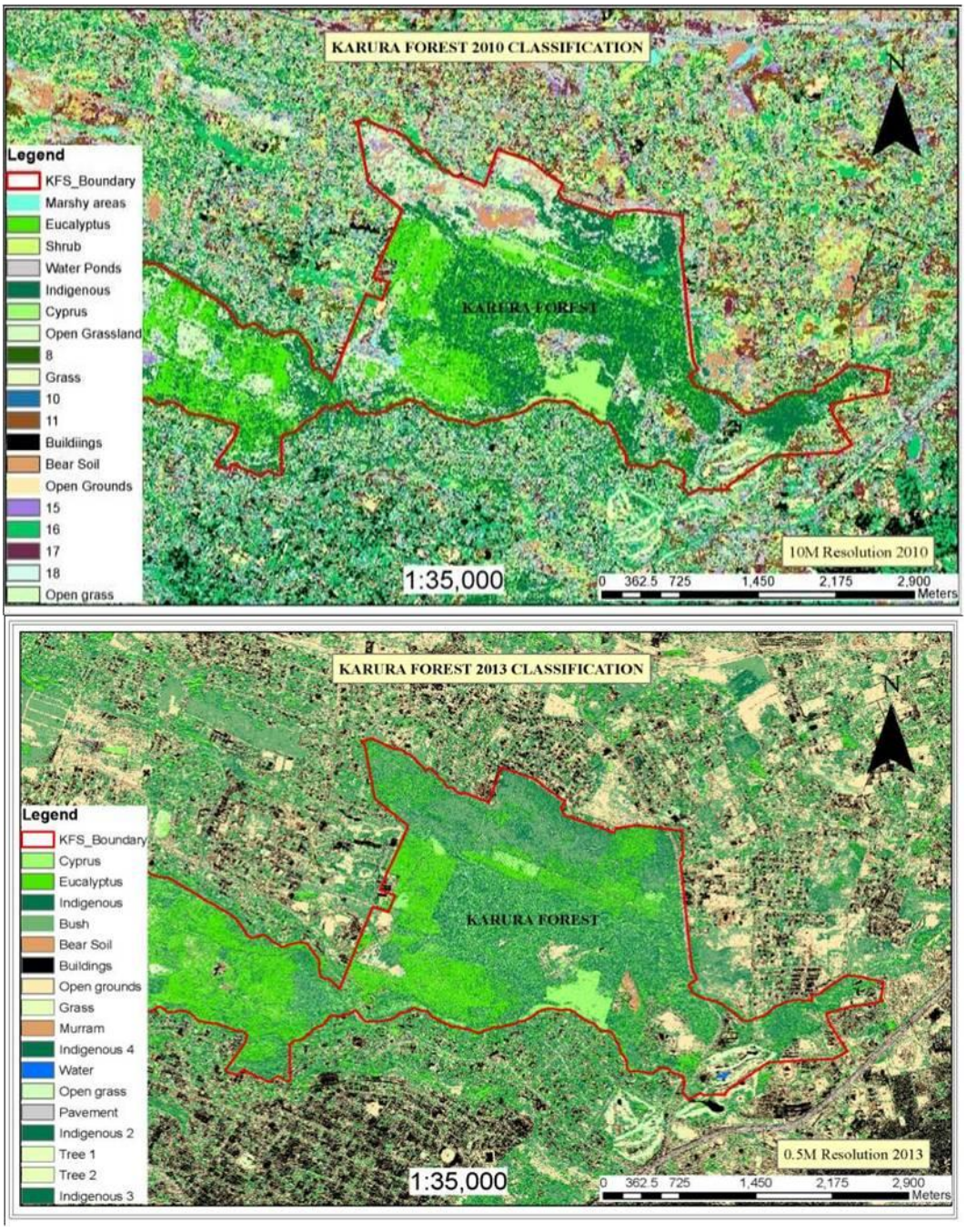


Figure 5.30: Supervised Classified Maps of Karura Forest 2010 and 2013.

(Source: Researcher, 2014).

Figure 5.30 top image of 2010 shows Wangari's corner with patches of bear soil which is not visible in the lower image of 2013 due to a forestation.

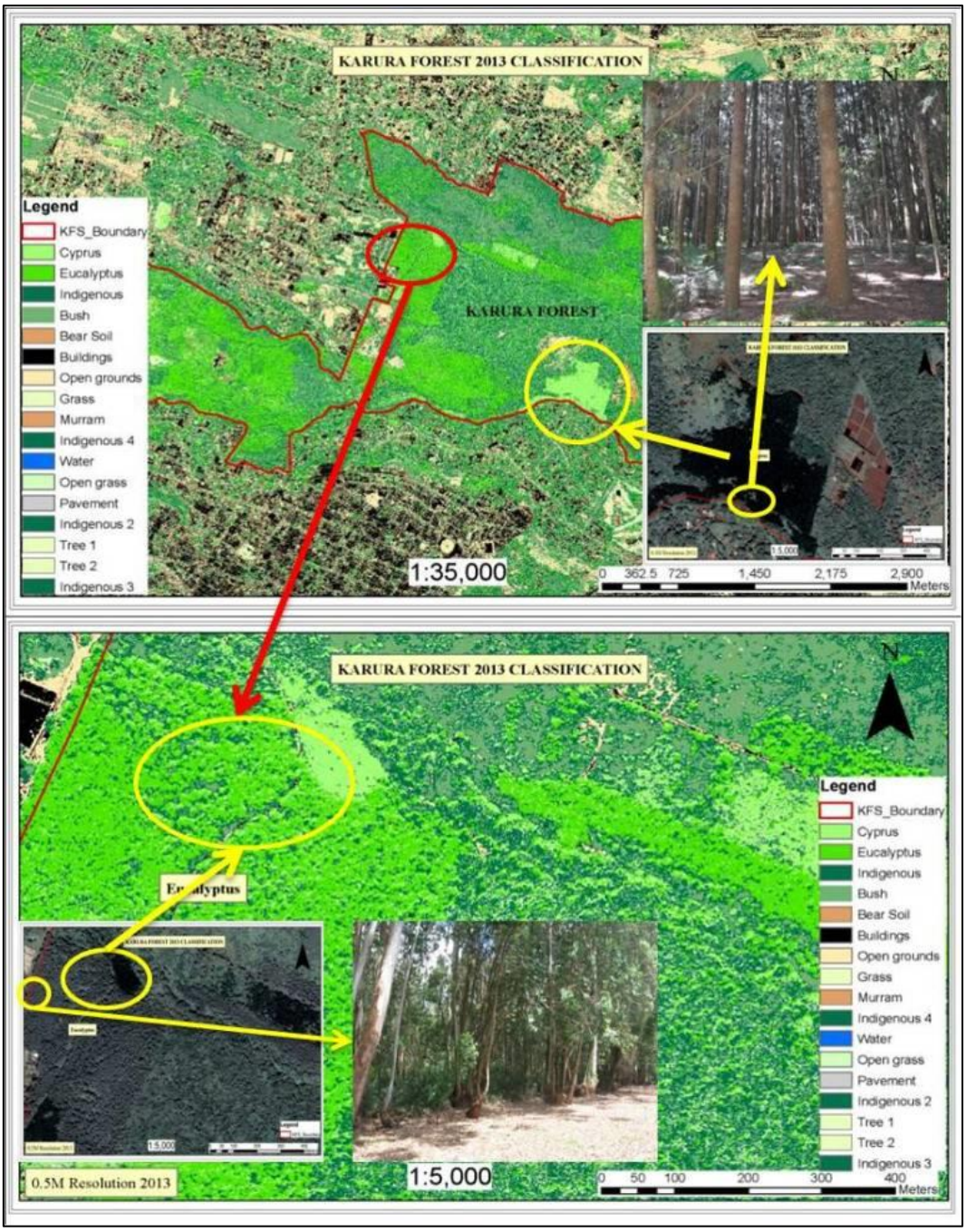


Figure 5.31: 2013 Satellite image Supervised Classification Analyses.

Source: The Researcher, 2014

The supervised Classification in this 0.5m Quick bird satellite images of 2013 (Figure 5.31) demonstrated that other than visual interpretations of features, classification to their genus is possible. Different type of trees and vegetation can be distinctively identified after the supervised classification is done. In the top image of Figure 5.31, the Cyprus trees are

classified just as they appear on the satellite image and as photographed during field survey (insets).the same is visible in the lower image for the Eucalyptus.

Remote sensed data of this resolution can therefore be used in the study of tree distribution in a vast forest and their species be linked to some spatial location. This can identify them with soil type for example, altitude and other topographical information.

This study has demonstrates how Satellite data of different time series can be used to analyze activities and changes inside Karura forest. Although the use of medium resolution has proved that it can equally help in monitoring vegetation cover, it was better if longer time series of 10 years were available with high resolution to allow the researcher compare vegetation cover of different epochs.

5.7 Testing the Hypothesis

From objective (ii), it was evident that the level of awareness toward use of satellite data technology as a tool for monitoring compliance and enforcement of forest conservation regulation in Karura forest is high. 100% of the respondents were aware of the use of the technology. This formed the basis of rejecting the hypothesis because Karura forest management has satellite technology as a tool to make decision about Karura Forest boundary extent.

The assumption that the forest management lucks information based decision tools is not supported by the findings of this study. The actual problem is the legal and Policy frameworks guiding the forest management. There is no mechanism to check the Forest management when the rule of law on conservancy is not adhered to. Kabugi, (2014) recommended that institutions policies should be harmonized in the management of Natural resources. This will remove competition and control of Natural resources from different institutions.

CHAPTER 6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

In summary, this study has demonstrated that Satellite data have the capability of revealing changes that have taken place over the years in any environment. The spatial extent and therefore the magnitude of such changes can be quantified by mapping the affected areas. Apart from monitoring and measuring the spatial changes, satellite data was used to monitor the actual activities taking place inside Karura forest. Tree covers inside the forest were monitored. This revealed that there are lose of trees in sections of Karura Forest. Advance image classification using supervised techniques available with the modern softwares could come in handle to monitor such lose. This can quantify the biomass volume Forest at different time frames. This study was limited to fully carry out this comparison due to lack of high resolutions images of all the three epochs. Although the medium resolution images can still be classified, the problem was at the comparison stage as they all had different bands for classifications. Noticeable by the researcher, the Principle of Forest conservation is still a mirage to the management of Karura Forest. The Karura Forest Natural biodiversity though destroyed by former Government regime is still not maintained.

6.2 CONCLUSIONS

Natural forest and their Natural biodiversity are beautiful not only to the eyes but to the soul. A walk in the woods of Karura forest restores a leafy green peace to the mind. This natural heritage therefore should be protected and conserved to its native biota without hosting any infrastructure for any other activity. The noticeable changes from satellite data bring forth the issue of activities going on inside a protected conservation area. This negates the principle of Conservation reserve as defined by Cronon, (1995) as generally large areas in which maintenance of native biota and natural ecosystem processes are the primary management objectives. According to Noss & Cooperrider, (1994) reserves are the dominant paradigm of modern conservation biology, the objective being to fully protect existing habitat and populations from direct human modification. Karura Forest is not

being protected as a conservation area as it should be, despite the fact that it is electrically fenced to keep off the intruders.

The issues of legislation and policy framework need to be readdressed to make the forest managers accountable for such activities. Otherwise the management is well aware of what is going on inside the Karura Forest reserve. The question is who are they answerable to? The National government which from the history of former regime initiated Forestland allocation should either tighten the rope or keep off the management of protected forest all together. Legal and policy framework in place to manage Karura forest and Kenya forests in general, need more refinements.

A closer look at the Forest Policy, 2014 didn't show any meaningful change from what is in the forest Act, 2005. The Forest Conservation and Management Bill,2014which according to Government of Kenya, (2014), is an Act of the National Assembly to provide for the establishment, development and sustainable management, including conservation and rational utilization of all forest resources for the socio-economic development of the country. All of them don't give a clear direction on what to be done by the Director of KFS and the forest management in case the conservation of natural forests is compromised. The consultation is only done to influence the approval of the activities and development but not how to stop them all together.

The remaining natural Karura forest as it is can be protected and monitored if the good will to hold the forest safe and secure for future generation is to be realised. Although the system in place with KFS to use satellite data technology to map forest boundaries and update old maps has proved that there is no resistance in technology adaption, it remain to see how far this can go to prosecute the non- compliance and enforcements of forest regulations in Kenya and Karura in particular.

6.3 RECOMMENDATIONS

6.3.1 Recommendation on the internal stressors of Karura Forest.

The institutions that have been allocated land inside Karura forest are autonomous. They can be sued and sue according to the Acts spelling their formation.KFS in particular should be held accountable for allowing itself to settle inside the Karura forest. The mare fact that it is bestowed with the responsibility of protecting and managing all the protected forests in Kenya should not give it an overriding benefit to settle inside the Protected conservation area. The regime issue should not be an excuse. The current constitution, 2010 dedicates a whole Chapter Five to matters of Environment and Land. The public land should not be a benefit to the same institutions entrusted to protect them. And because the mess is already done and to suggest that the institution vacate Karura will not be forthcoming, it is recommended that tough measures be put to stop the tread.

The Environment and Land Court should come out strongly and form a monitoring unit specifically dealing with protected natural reserves. There should be a proper profile of what is being held by government institutions inside Karura forest and what extent of land they hold. Proper information on how they should utilise the land should be filed in the court to form terms of reference for the monitoring unit. The institutions should also be compelled to restore what they have destroyed during their infrastructure development. This is according to the polluter-pay and the pre-cautionary principles which according to Government of Kenya, (2011), forms the guiding principles of the Environment and Land Court.

6.3.2 Recommendation on how the institution managed to settle inside Karura Forest.

Ngolo, (2014), the NEMA head of GIS lamented that this should not have happened in the first place. This recommendation is tired with the section in recommendation 6.3.1 where the institution mandated to protect and manage the Protected Natural forests should be held accountable. Strong legal instruments to address the issues should be setup and be delinked from political affiliations. The unit should have the capacity to regularly monitor using

satellite data of high resolution the activities inside public forest and more so the protected conservation reserves like Karura forest.

The County governments now in place should be closer custodians for the National government to even question what happened with the past regimes. This is the only sure way to discourage the government of the day settling its institutions inside protected natural heritage like Karura forest. The management of such Natural heritage should be retrained or recruited from people who understand what conservancy is and not seeing Forest as free land that can be converted at will to built environment. The approval of any development inside conservation reserves should go through parliament and made public to ensure that few management heads do not conspire to approve projects and allocations inside the protected forests.

6.3.3 Recommendation on awareness and attitude toward the use of satellite data technology as a tool for monitoring compliance and enforcement of forest regulations.

As observed during the interviews with KFS, NEMA and the Ministry of Environment, Water and Natural resources, Finances should be allocated to build capacity. High resolution satellite data can be procured by the national government to be used by all the stakeholders involved in environmental protection and management matters. This will ease the burden of each institution sourcing for its own satellite data individually. The issue of software and their licenses should be made easy to access when the government is the big consumer. The forest management, the foresters and rangers should be retrained to embrace satellite technology in their monitoring systems.

All government institutions dealing with matters of environment should be reading from the same script. Harmonized policies geared toward achieving the same goals of managing the Natural resources should be addressed. This will make institutions be aware that using satellite data they can monitor the state of the environment and alert each other on what is going on inside protected conservation areas like Karura forest. To crown it all the Environment and Land Court should fully embrace the satellite data technology as a source of evidence in prosecuting non-compliance with forest regulations.

6.3.4 Recommendation on use of satellite data as a tool for monitoring compliance and enforcement of forest regulations in Karura.

The use of satellite data in mapping Karura forest boundary by KFS is a big achievement in the modern time. The technology however goes beyond the mapping of the forest boundary which is actually now fixed. The remote sensing unit existing in Karura Forest KFS headquarters should be financially facilitated to build enough capacity in term of experts and satellite imageries. Kahuri, (2014), the head of FIS in Karura pointed out that if they were to do mapping for all the forests in Kenya within a short notice of 1 year, they cannot meet the target due to limited manpower. Satellite data being used are of 1990, 2000 and 2010 medium resolution downloaded free from the internet. This shows that although the initiative is there to use the satellite data technology, there is no funding for satellite data procurement. There should be a well organized way of getting the KFS as an institution, team up with other likeminded environmental management institutions like the UNEP, ESRI etc to have shared data access through their portal. These institutions have their headquarters in Nairobi and indeed the UNEP share a fence with KFS. The training of the key team players is instrumental so that the quality of analysis goes beyond mapping of the boundaries.

The satellite data as mentioned earlier in supervised classification can study the forage cover and stress of tree leaves. This especially where forest trees are attacked by diseases can be detected from satellite data of different epochs. The study of different species of tree distribution inside a forest can be analyzed from the satellite data to relate them to a particular type of soil or climate. The outcome of such study can inform the KFS management on what type of trees to use to reforest the Karura forest to its original natural status. When it comes to monitoring the biomass, the satellite data can be used to actually monitor if KFS and other stake holders are doing their work.

In Mau a forestation program for example, satellite data can be used to compare the tree cover before the program started and when it started. The status of the progress can be mapped using satellite data. This brings in the accounting and monitoring aspect into the satellite data technology.

6.3.4 Recommendation on Further Studies

Further studies should be carried out to cover more scope on the use of satellite data as a monitoring tool for compliance and enforcement of Forest regulations. The area touching the use of high resolution satellite images should be well funded to make the satellite data available to all the stake holders in the field of Environmental studies and management. Scholars can be able to carry out more research on the use of satellite data on various ecosystems apart from forest.

The uses of satellite data as evidence in the Court of law should be scoped further to align it with the existing legislation and policy frameworks. This will encourage more meaningful presentation of evidence using satellite data in the Environment and Land Court which is beyond ordinary challenges in Courts.

6.3.5 Recommendation on Integrated use of Satellite data

Forest management in Kenya cannot succeed if only one actor is left to manage and monitor activities inside the forest. To address this challenge, this study recommends that all actors involved in management of Natural resource harmonize their policy to include satellite data as a monitoring tool for all activities inside the protected and public forest. Table 6.1 below outlines the proposed integrated use of satellite data by all key actors.

Table 6.1: PROPOSED INTEGRATED USE OF SATELLITE DATA IN FOREST MANAGEMENT.

USE OF SATELLITE DATA	**KEY ACTIVITIES**	**ACTORS**
To monitor Forest encroachments	Digitize all existing maps and use the digitized boundaries as base maps to ascertain the Forest extent using high resolution Satellite images.	The Kenya Forest Service (KFS) The Ministry of Environment Water and Natural resources. NEMA Ministry of Lands and Settlement National Land Commission
To monitor illegal Forest clearance.	Use satellite data of different time series to monitor activities inside thick forest. Use supervised or unsupervised classification to track changes in forest biomass.	Kenya Forest Service NEMA
To present evidence of non-compliance	Build capacity to use of Satellite data in the Environment and Land Court. Harmonize Legal and Policy Framework to accommodate the use of Satellite data as a source of credible evidence in the Environmental and Land Courts. Finance institutions to build and update satellite data databases for analysis. Share available Satellite data among the stakeholders and learning institutions.	Kenya Forest Service (KFS) Environment and Land Court NEMA National Land Commission Ministry of Land and Settlement
Research and Development	Use satellite data for Environmental Resource Studies. Dissemination of Satellite data Knowledge to Environmental Managers and Planners.	Higher Institutions of Learning Kenya Forest Service All Actors in Environmental Studies. NEMA

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APPENDICES

Appendix 1: Research Authorization Letter

KENYATTA UNIVERSITY
SCHOOL OF ENVIRONMENTAL STUDIES
DEPARTMENT OF ENVIRONMENTAL PLANNING AND MANAGEMENT

P.O. Box 43844
NAIROBI
Tel. 8710901-19
Ext. 57221
Fax: 811575/811242
Website: www.ku.ac.ke

Our Ref. KU/EPM/STU/10

Your Ref

12th March, 2014

TO WHOM IT MAY CONCERN

REF: RESEARCH AUTHORIZATION

This letter is to confirm that **ANTONY GAKOBO MACHARIA** of Reg. No. **N50/21199/2012** is a 2nd year master's student in the Department of Environmental Planning and Management at Kenyatta University.

Currently the student is in his data collection phase in preparation for his research project titled ***"Using Satellite Data as Tool to Monitor Compliance and Enforcement of Forest Conservation Regulations in Karura Forest, Nairobi County".***

Kindly accord him any assistance he may require particularly with regard to acquisition of data and academic literature.

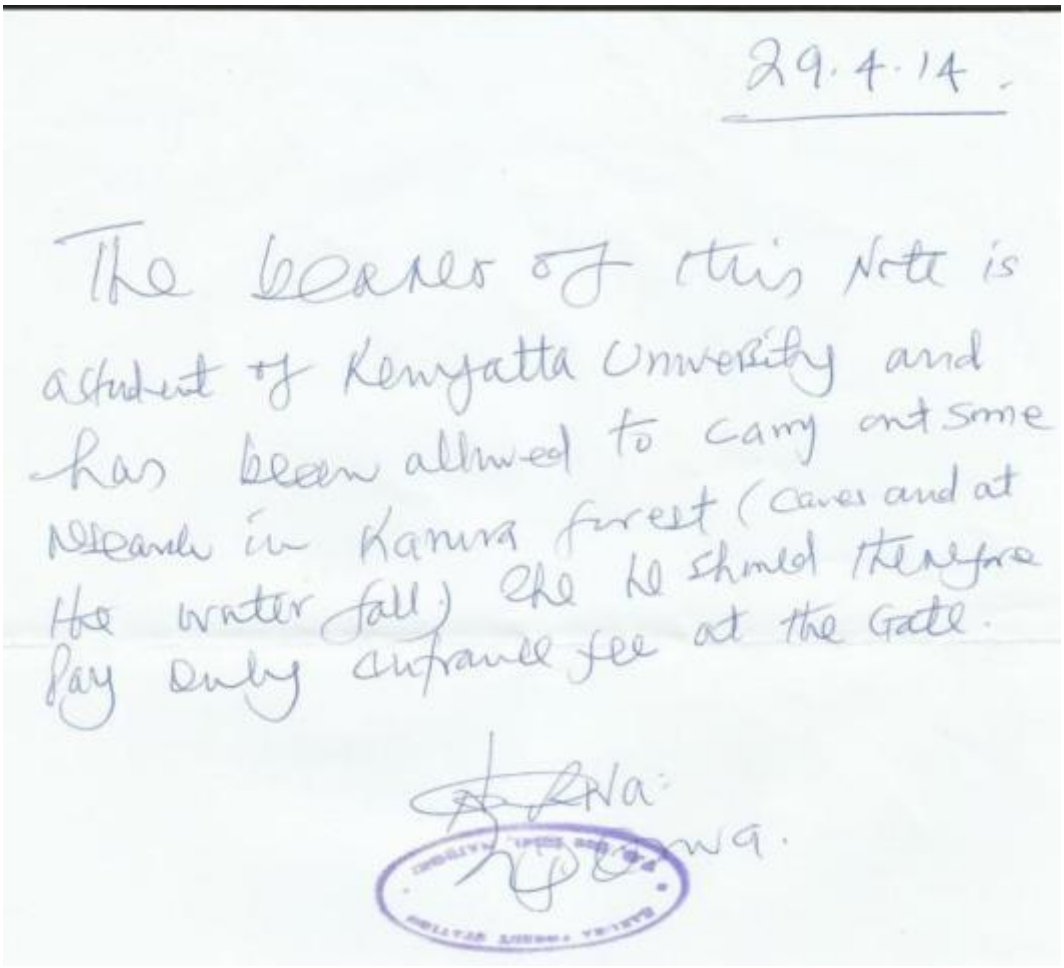
Thank you.

KENYATTA UNIVERSITY CHAIRMAN 12 MAR 2014 ENVIRONMENTAL PLANNING & MANAGEMENT DEPT. P.O. Box 43844-00100 NAIROBI

Prof. Caleb Mireri
Chairman, Dept. of Environmental Planning and Management

CM/enm

Appendix 2: Authorization Letter into Karura Forest (KFS)

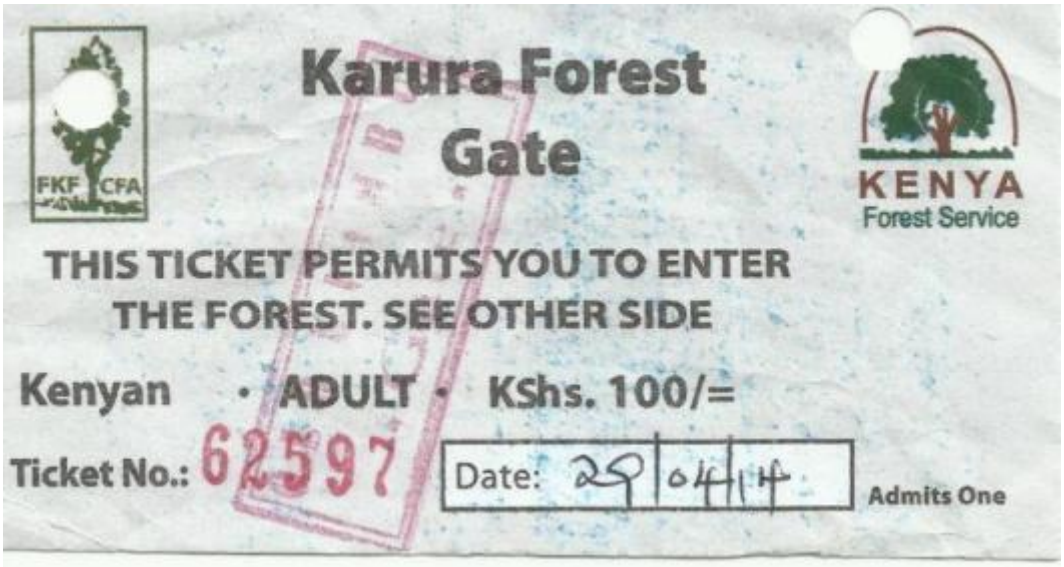


29.4.14.

The bearer of this Note is a student of Kenyatta University and has been allowed to carry out some Research in Karura forest (caves and at the water fall) She is advised therefore pay only entrance fee at the Gate.

Thanks.

Appendix 3: Karura Forest Gate Ticket



Appendix4: Interview schedule for Ministry of Environment, Water and Natural Resources

Kenyatta University

School of Environmental Studies

Department of Environmental Planning and Management

Interview Schedule for Kenya Forest Service (KFS)

My name is ANTONY G. MACHARIA Registration No: N50/21199/2012. I am a Masters student at Kenyatta University, School of Environmental Studies, Department of Environmental Planning and Management. I am undertaking My Project research on: **Using Satellite data as a tool to Monitor Compliance and Enforcement of Forest Conservation Regulations in Karura Forest.** The information collected with this research instrument will be for research purposes only. Please accord me your assistance to collect data for my Research study.

Thanking you in advance.

Objectives

i. To use satellite data to map out internal stressors of Karura forest.
ii. To investigate how institutions managed to acquire land to settle in Karura forest.
iii. To examine the level of awareness and attitude toward the use of satellite data technology as a tool for monitoring compliance and enforcement of forest regulations in Karura forest.
iv. To demonstrate the use of satellite data as a tool for monitoring compliance and enforcement of forest regulations in Karura forest.

Karura forest is a National Heritage and a protected area.

Questions

Q1. What is the mandate of KFS in protection and management of protected forests?

Q2. What are the policy and legal legislations that guide KFS in enforcement of forest regulations?

Q3. What are the strategies employed by KFS to monitor compliance and enforcement of forest regulations in Karura forest?

Q4. What is KFS capacity to enforce and monitor compliance of forest regulations in Kenya?

Q5. What are the challenges that KFS face in:

a. Enforcement of forest law in Karura forest?
b. Monitoring compliance of enforcement of forest law in Kenya and specifically in Karura forest?

Q6. Is KFS aware of satellite data technology as a tool to:

a. Monitor forest management? YES ☐ NO ☐
b. Monitor compliance of enforcement of forest laws? YES ☐ NO ☐

If yes

i. Have KFS used satellite imagery in (a.) or (b.) above?
ii. Where did KFS get the Satellite image?
iii. What was the resolution of the image; High ☐ Medium ☐ Low ☐

Q7. In your own view, to what extent do you think that Satellite data technology can be used to:

a. Monitor compliance of enforcement of forest law?
b. As a source of evidence to prosecute non-compliance in a Court of law?

Q8. What will be the challenges of adopting such a technology?

i. Expertise ☐
ii. Reliability ☐
iii. Finances ☐
iv. Sources of data ☐

Thank you for your contribution.

Appendix 5: Interview Schedule for Ministry of Environment, Water & Natural Resources

Questions

Q1. What is the mandate of MoE in forest protection and management?

Q2. What are the policy and legal legislations that guide MoE in enforcement of forest regulations?

Q3. What are the strategies MoE employ to monitor compliance and enforcement of forest regulations?

Q4. What is MoE capacity to enforce and monitor compliance of forest regulations in Kenya?

Q5. What are the challenges that MoE face in:

a. Enforcement of forest law?
b. Monitoring compliance of enforcement of forest regulations in Kenya and specifically in Karura forest?

Q6. Are you aware of satellite data technology as a tool to:

a. Monitor forest management? YES ☐ NO ☐
b. Monitor compliance and enforcement of forest regulations? YES ☐NO☐

If yes

i. Has MoE ever used satellite imagery in (a.) or (b.) above?
ii. Where did MoE get the satellite imageries?
iii. What was the resolution of the image: High ☐ Medium ☐ Low ☐

Q7. In your own view, to what extent do you think the satellite data technology can be used to:

a. Monitor compliance and enforcement of forest law?
b. As a source of evidence to prosecute non-compliance in a court of law?

Q8. What will be the challenges of adopting such a technology in MoE?

i. Expertise ☐
ii. Reliability ☐
iii. Finances ☐
iv. Sources of data ☐

Appendix 6: Interview schedule for National Environment Management Authority

Questions

Q1. What is the mandate of NEMA in forest protection and management?

Q2. What are the policy and legal legislations that guide NEMA in enforcement of forest laws?

Q3. What are the strategies NEMA employ to monitor compliance and enforcement of forest regulations?

Q4. What is NEMA capacity to enforce and monitor compliance of forest regulations in Kenya?

Q5. What are the challenges that NEMA face in:

a. Enforcement of forest law?
b. Monitoring compliance of enforcement of forest regulations in Kenya and specifically in Karura forest?

Q6. Is NEMA aware of satellite data technology as a tool to:

a. Monitor forest management? YES ☐ NO ☐
b. Monitor compliance of enforcement of forest regulations? YES ☐ NO ☐

If yes

i. Has NEMA ever used satellite imagery in (a.) or (b.) above?
ii. Where did NEMA get the imageries?
iii. What was the resolution of the image: High ☐ Medium ☐ Low ☐

Q7. In your own view, to what extent do you think that satellite data technology can be used to:

a. Monitor compliance of enforcement of forest regulations?
b. As a source of evidence to prosecute non-compliance in a Court of law?

Q8. What would be the challenges of adopting such a technology by NEMA?

i. Expertise ☐
ii. Reliability ☐
iii. Finances ☐
iv. Sources of data ☐

Appendix 7: Interview schedule for Friends of Karura/Green belt movement

Questions

Q1. What is your mandate in the protection of Karura forest?

Q2. What motivated you in protecting Karura forest?

Q3. How was your public-private partnership to protect Karura forest formulated?

Q4. To what extent do you take decisions about the way Karura forest is to be protected and managed?

Q5. Do you use satellite data technology in monitoring and managing Karura forest?

Q6. If yes in Q5.above,

(a) How is the satellite monitoring program undertaken?

(b) Is it used to monitor compliance and enforcement of forest regulations in Karura forest?

Q7. What are the challenges you encountered in protecting Karura forest

i. Capacity? ☐

ii. Government interference? ☐

iii. Financial constraint? ☐

iv. Reliable monitoring tools? ☐

Q8. What mitigation measures have you taken to overcome the above challenges?

Q9. To what extent can satellite data technology be used as a monitoring tool for compliance and enforcement of forest regulations in Karura forest?

i. To the extent of detecting non-compliance ☐

ii. To the extent of prosecuting the non-compliance in a court of law ☐

iii. To assess the extent of damage caused to the forest ☐

Appendix 8: Interview schedule for Institutions

Kenyatta University

Department of Environmental Planning and Management

Interview schedule for Institutions

My name is ANTONY G. MACHARIA Registration No: N50/21199/2012. I am a Masters student at Kenyatta University, School of Environmental Studies, Department of Environmental Planning and Management. I am undertaking My Project research on: **Using Satellite data as a tool to Monitor Compliance and Enforcement of Forest Conservation Regulations in Karura Forest.** The information collected with this research instrument will be for research purposes only. Please accord me your assistance to collect data for my Research study.

Thanking you in advance.

Objectives

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iii. To examine the level of awareness and attitude toward the use of satellite data technology as a tool for monitoring compliance and enforcement of forest laws in Karura forest.
iv. To demonstrate the use of satellite data as a tool for monitoring compliance and enforcement of forest regulations in Karura forest.

Name of the institution……..

Name of the Interviewee……

Karura forest is a protected National heritage which is supposed to be to be conserved for sustainable development and for future generations.

Questions

Q1. What interest motivated your institution to settle inside Karura forest?

Q2. How did your institution manage to get land to settle inside the forest?

Q3. Was it through government arrangement or your own arrangement?

Q4. What were the criteria used to consider your Institution for allocation?

Q5. In your own view and understanding of environmental regulations on protection and conservation of forest ecosystem, do you think it is justified to have institution like your own settled inside Karura forest?

Q6. Is there lack of awareness of the importance of Karura forest with forest management institutions to fully protect and conserve the forest?

Q7. Is the government directly involved in the allocation of land inside the Karura forest?

Q8. What do you think is the way forward to monitor compliance and enforcement of forest regulations in Karura forest?

Thank you for your contribution.