JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

DEPARTMENT OF GEOMATIC ENGINEERING AND GEOSPATIAL INFORMATION SYSTEMS

FINAL YEAR PROJECT REPORT

POTENTIAL AND SUITABILITY ANALYSIS OF AFFORESTATION IN SEMI-ARID LANDS: CASE OF MACHAKOS COUNTY

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EN281-0261/2010

Project report submitted in partial fulfillment of the requirements for the award of Bachelors degree in Geomatic Engineering and Geospatial Information Systems

JANUARY 2016

DECLARATION

I hereby declare that this project is my original work and effort and has not been submitted by anybody else in any university or any other institution for the award of a degree or any other purpose.

Sources of information used have been acknowledged.

Muraba Richard Wanjohi EN281-0261/2010

Signature---------------------------------- Date-------------------------------

CERTIFICATION

This research project has been submitted for examination with my approval as the candidate's supervisor and thus can be used for further research by the institution for any topic of research.

Project Supervisor:

Ms. Eunice Nduati

Sign ……………..............................   Date: …………………........

DEDICATION

I dedicate this work to my parents, Dr. John Muraba Wanjohi and Mrs. Loise Muraba, for their unwavering support and care throughout my educational journey until now, and who have been phenomenal in supporting and encouraging me in the course of the project work. I also dedicate it to my siblings, Grace Micere, Stella Wambui and Wilson Njoroge for their numerous encouragement and support as I worked on the project.

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I would like to thank first of all my project supervisor, Ms. Eunice Nduati, for the philanthropic support, guidance, encouragement and corrections that have led to the successful completion of this work. Many thanks also go to all my lecturers in the Geomatic Engineering department, who imparted me with knowledge and skills that I will apply for years to come.

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Moreover, I greatly thank my classmates in the Geomatic Engineering class with whom we greatly assisted each other in the achievement of our project goals, these including Sophia Murage, Victor Ng'eno, Stephen Wanjama, Byron Sunkuli, Gloria Mugo, Allan Thuku, Martin Gikunda, Samuel Mwatha, Duncan Kebut, Benson Rutto, and Felix Arego, among the many others. Their contribution to my project work in different ways was phenomenal and shall never be forgotten.

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LIST OF ABBREVIATIONS

KFS	Kenya Forest Service
KEFRI	Kenya Forestry Research Institute
FAO	Food and Agriculture Organization
ICRAF	International Centre for Research on Agroforestry
MCE/ MCDM	Multi-Criteria Evaluation/ Decision Making
UNEP	United Nations Environmental Programme
AHP	Analytical Hierarchy Process
CDM-AR	Clean Development Movement Afforestation – Reforestation
KP	Kyoto protocol
JIFPRO	Japanese International Forestry promotion and co-operation centre
GBM	Green Belt Movement
ASAL	Arid and Semi-arid Lands
UNFCCC	United Nations Framework convention on climate change
REDD/REDD+	Reducing emissions from deforestation and forest degradation
CFA	Community forest associations
GDEM	Global Digital Elevation Model
NASA	National Aeronautics and Space Administration
GIS	Geospatial Information Systems
CSR	Corporate social responsibility
WGS	World Geodetic System

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ABSTRACT

Afforestation is a crucial technique for the restoration of degraded drylands, whose benefits and aims include minimizing soil erosion, replenishment of soil nutrients, lowering of saline ground water table, acting as a carbon ink for carbon sequestration, combating climate change and global warming, improving the drylands climatic conditions and combating desertification.

Numerous efforts are being made to achieve these aims through afforestation, worldwide and within the country. With the advent of Geospatial technologies such as GIS and remote sensing, these can be used for multi criteria decision making/ evaluation for the determination of the most suitable areas for afforestation in a region, considering certain tree species and their characteristics. The current study thus evaluates the use of these techniques to determine the potential of afforestation in the study area; Machakos county of Kenya, which is generally a dryland. Specifically, the study aims to investigate the factors/ criteria to consider for this, the most suitable tree species and their suitability for afforestation, and the overall afforestation suitability, considering the many species.

The species chosen are Acacia Xanthophloea, Melia Volkensii and Gliciridia sepium, and the criteria considered include soil physical and chemical characteristics, altitude, climate and land covers, with the data being obtained from various online and open sources, as well as consultations with experts. The weights for the multi-criteria decision making are obtained using the AHP process, and they are combined with the criteria data using weighted overlay analysis in a GIS environment.

The results of the analysis show that there is indeed a great potential for afforestation in the study area using drylands tree species, with about 64.6% of the total land area being found to be very suitable in general, with all the tree species individually showing great afforestation potentials in the area.

Key words: Afforestation, Semi-arid lands/ drylands, GIS, multi-criteria decision making.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Afforestation is the process of planting trees in a barren land devoid of any trees before. Arid lands experience high ambient temperatures, with wide di-urnal ranges. Low and erratic rainfall is received in the areas, and varies greatly with space and time. Average annual rainfall is 150-450mm in such areas. Soils in these areas are highly variable, shallow and light textured, with low fertility, and are subject to capping, erosion and compaction. Water availability is also greatly varying, and is a great barrier to agriculture. Semi-arid lands receive 500-850mm of rainfall annually and include areas such as Kajiado, Machakos, Narok, Kitui, Transmara and Baringo, (United Nations Development Program, 2013).

Arid and semi-arid lands (ASAL) cover about 80% (467200 sq. km) of Kenya’s land, and are grouped into various geographical zones. These include the savannah covering most of the north and south eastern regions, the coastal region, north rift valley and the Lake Victoria basin. About 35% of Kenya’s population are hosted in the ASAL, (United Nations Development Program, 2013).

In arid and semi-arid lands, vegetation undergoes deterioration due to human activities, culminating to deforestation, land degradation and desertification. These affect water resources directly and indirectly. Afforestation in such regions contributes to natural environment conservation, and improving rural community livelihoods, through the production of building materials and fuel wood. In the long-term, forest vegetation restoration can improve the properties of soil, improving to the local water balance by flood control in rainy seasons and drought mitigation in the dry season. Thus, afforestation is a very important and effective environmental measure, (Ken Yoshikawa & Chikamai, 2014).

Desertification is the degradation of land in arid, semi-arid and sub-humid dry areas, caused by climatic changes and human activities. It occurs in natural deserts and on land prone to desertification processes. It is a worldwide phenomenon, which causes the deterioration of earth’s ecosystems. About a sixth of the world’s population is affected by it, as well as 70% of all dry lands, amounting to about 3.6 billion Ha, and a quarter of the total land area of the world, (Choji, 2008).

A forest, according to FAO, is as wooded area with a crown density of over 10%, trees that are at least 5 meters tall and cover a surface of at least 0.5 hectares. Thus, plantations qualify as forests, as do rubber trees and palm trees. Kenya has defined “forest” as an area with at least 30% canopy cover, 2 m potential tree height and 0.1 hectares area, (Goldmann, Skogsagarna, & Persson, 2012).

The Kenya Forest Service (KFS), a state corporation, was formed under the ministry of Water and Natural resources in February 2007, under the forest act 2005, to conserve, develop and ensure sustainable management of forest resources, for Kenya’s socio-economic development. The role of KFS in the drylands is sustainable management and utilization of drylands forest resources for community livelihood improvement and climate change mitigation. The service is thus increasing and maintaining the area under tree cover in ASALs, through institutional tree planting approaches and rehabilitations of degraded areas for enhanced environmental conservation and livelihood improvements. The service has also started programmes to ensure that sustainable forestry management practices are achieved in the drylands. These include the promotion and establishment of suitable multipurpose tree species in the ASALs as well as water harvesting and conservation measures, (Kenya Forest Service, 2014).

Kenya’s Vision 2030, establishes that by 2030, 10% of Kenya’s surface should be tree covered, though there is no specific required percentage for forest. In the Forest Act of 2011, every landowner is required to set aside 10% of the land for trees, which is primarily how Kenya aims to reach its goal, (Goldmann et al., 2012).

1.2 Problem statement

Desertification, which causes the reduction of the land’s natural potential, and depletion in surface and ground water resources, is rampant in the arid and semi-arid lands. It has negative effects on the economic well-being and living conditions of those affected by it. It not only occurs in natural deserts, but can also take place on land prone to desertification processes. Desertification is a worldwide phenomenon which causes the earth’s ecosystems to deteriorate. It affects about one sixth of the world’s population, 70 percent of all drylands, amounting to 3.6 billion hectares, and one quarter of the total land area of the world. The most obvious impact of desertification, in addition to widespread poverty, is the degradation of 3.3 billion hectares of the total area of rangeland, constituting 73 percent of the rangeland with a low potential for human and animal carrying capacity; decline in soil fertility and soil structure on about 47 percent of the drylands areas constituting marginal rain fed cropland; and the degradation of irrigated cropland, amounting to 30 percent of the drylands areas with a high-population density and agricultural potential, (Choji, 2008).

Figure 1 below illustrates some of the effects of desertification (sourced from the internet).

Figure 1: Effects of desertification

Human activity has significantly altered the global carbon cycle as land use change and fossil fuel burning have increased levels of Carbon dioxide in the atmosphere, causing changes in our climate at an alarming and accelerating rate, (Zomer, Trabucco, Bossio, & Verchot, 2008). There is also increased run-off, flash flooding, soil erosion and reduced infiltration in these areas as a result of the bare nature of the land, when it rains, (Kenyan vision 2030, 2007).

Tree planting in the drylands poses a big challenge to farmers in arid and semi-arid areas. There is therefore need for better technical information to promote tree planting in water deficient soils, (Ken Yoshikawa & Chikamai, 2014).

As of 2008, forests make up 6.1% of the Kenyan land area, an area that during the period 1990-2008 decreased by 5.9%. Kenya is a major importer of timber products, spending roughly USD 37.5 million per year on these. This has impacts such as over-cutting private forests that are meant for soil and water conservation on farm lands. Furthermore, timber demand is expected to increase to 38 million cubic meters annually.

Kenya consumes an estimated 1.2 million tons of charcoal annually with the sub-sector providing a source of livelihood to at least 200,000 persons, (Goldmann et al., 2012).

Land degradation and desertification affect about two-thirds of the world's countries, and 40 per cent of the earth's surface, on which one billion people live. They experience unsustainable, intensive agricultural exploitation. Most severely affected are the semi-desert areas where biomass cover and soil are dramatically reduced and in extreme cases completely absent, (Abu, Elaine, Stefan, & Leu, 2008).

Figure 2 below illustrates some of the effects of severe land degradation (sourced from the internet)

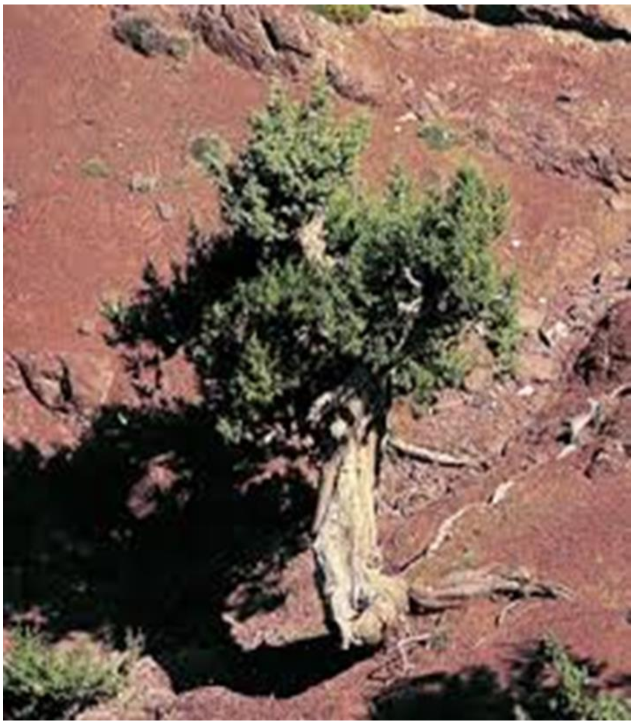

Figure 2: Effects of severe land degradation

1.3 Objectives

1.3.1 General Objective

To investigate the potential and suitability of afforestation in arid and semi-arid lands

1.3.2 Specific Objectives

- To investigate and map the factors affecting afforestation in the study area.
- To determine the tree species most suited for afforestation in these areas, and their appropriate spatial suitability and distribution based on the factors.
- To determine the overall most suitable areas for afforestation in the study area.

1.4 Justification of the study

Afforestation is one of the key methods for ecological restoration in dry areas, its benefits including soil erosion prevention, replenishing of soil nutrients and lowering further of shallow saline groundwater tables. It is also useful as a carbon sequestration option, eligible under the Clean Development Mechanism (CDM) of the Kyoto Protocol. It thus provides an opportunity to combine the efforts of countering land degradation, (Olena Dubovyk, Tilman Schachtsiek, Asia Khamzina, Gunter Menz ZEF (Centre for Development research), 2015).

Afforestation is one of the measures for countering global warming, and has been proposed and tested before. Arid and semi-arid land used for vegetation usually does not create competition between it and crop production, and other land uses. Thus, afforestation on a large scale area can be used with relatively little difficulties. It also contributes to the restoration of degraded land, and reducing water runoff and soil erosion, (Uganuma et al., 2012).

Climate change has introduced both a new opportunity and a new threat to sustainable forestry. Reforestation and afforestation are important tools for mitigating climate change and the potential for this is particularly large in Sub-Saharan Africa, (Goldmann et al., 2012).

Vegetation in dry land regions has a strong effect on the energy exchange in the atmosphere and local environmental conditions. Thus, massive afforestation in these regions could have a meaningful influence on global climate and on Carbon dioxide mitigation in the atmosphere, (Rotenberg, Maseyk, Lin, Yaseef, & Mair, 2015). Afforestation must be done in degraded stand (unproductive stand), glade and some state and agricultural land. Also to have enough of the existence of forest and land preservation is vital for the countries. In general terms, it is a must for sustainable development. As a result, one of the primary problems of Turkey and the world is afforestation in terms of ecological, social, cultural and economic, (Ateşoğlu, 2015).

Moreover, the current forest cover in Kenya is less than 3%, which is below the internationally recommended 10% of the total land area. Thus, as one of the country's vision 2030 initiatives towards achieving a 10% forest cover, the country, through the Kenya Forest Service, is promoting farmland and dry land tree planting initiative that seeks to introduce high value tree species, to control desertification in ASALs and to improve livelihoods, (Kenyan vision 2030, 2007).

The country’s arid and semi-arid areas, which cover about 80% of Kenya’s total land surface area and hold 25% of the human population, offer the greatest potential for intensified afforestation towards achieving the national objective of 10% tree cover. The Kenya Forest Service is as a result striving to increase and maintain the area under tree cover in ASALs, through institutional tree planting approaches and rehabilitation of degraded areas for enhanced environmental conservation and livelihood improvements, (Kenya Forest Service, 2014).

There is a huge demand for tree and forest products, as indicated on the problem statement. A partial answer to the demand challenge is fast-growing plantations. FAO projects that with an expansion of plantation areas and rising yields, harvest from plantations could more than triple between 2005 and 2030, and that plantations could one day satisfy most of the world’s demand for industrial wood, thus helping protect the world’s remaining natural forests. If the trees are planted on degraded land, it may reduce soil erosion and help combat climate change, (Goldmann et al., 2012).

The most appropriate use for saline/sodic wastelands is the production of high-yielding fuel-wood, fodder and timber species. The salt affected soils exist in areas such as the semi-arid and sub-humid Indus plains of Pakistan, (Ahmed, 2004).

Restoring natural grazing lands as well as establishment of forests, dry woodlands, savannahs or agroforestry projects can dramatically increase the productivity of degraded drylands, even in hyper-arid regions that are generally considered unproductive. Such activities also contribute significantly to mitigation of global warming by sequestering carbon into soil and biomass, (Abu et al., 2008).

1.5 Scope of the study

The study area chosen is Machakos County. Machakos County is a county in Kenya, formed in March 2013, after the promulgation of the new Kenyan constitution, though it was formerly Machakos district under the previous provincial administration. Its capital and largest town is Machakos town, the county's first administrative headquarters. The county’s population, as per the 2009 census, is about 1,098,584.

The county borders Nairobi and Kiambu counties to the West, Embu to the North, Kitui to the East, Makueni to the South, Kajiado to the South West, and Muranga and Kirinyaga to the North West. It occupies an area of about 6200 km^2, and an average elevation of 1138m above sea level. Its spatial extents are 36.632º to 38.513º East and 0.631º to 1.953º South, (OpenDataKenya, 2015).

The map of the study area is as shown in figure 3 below.

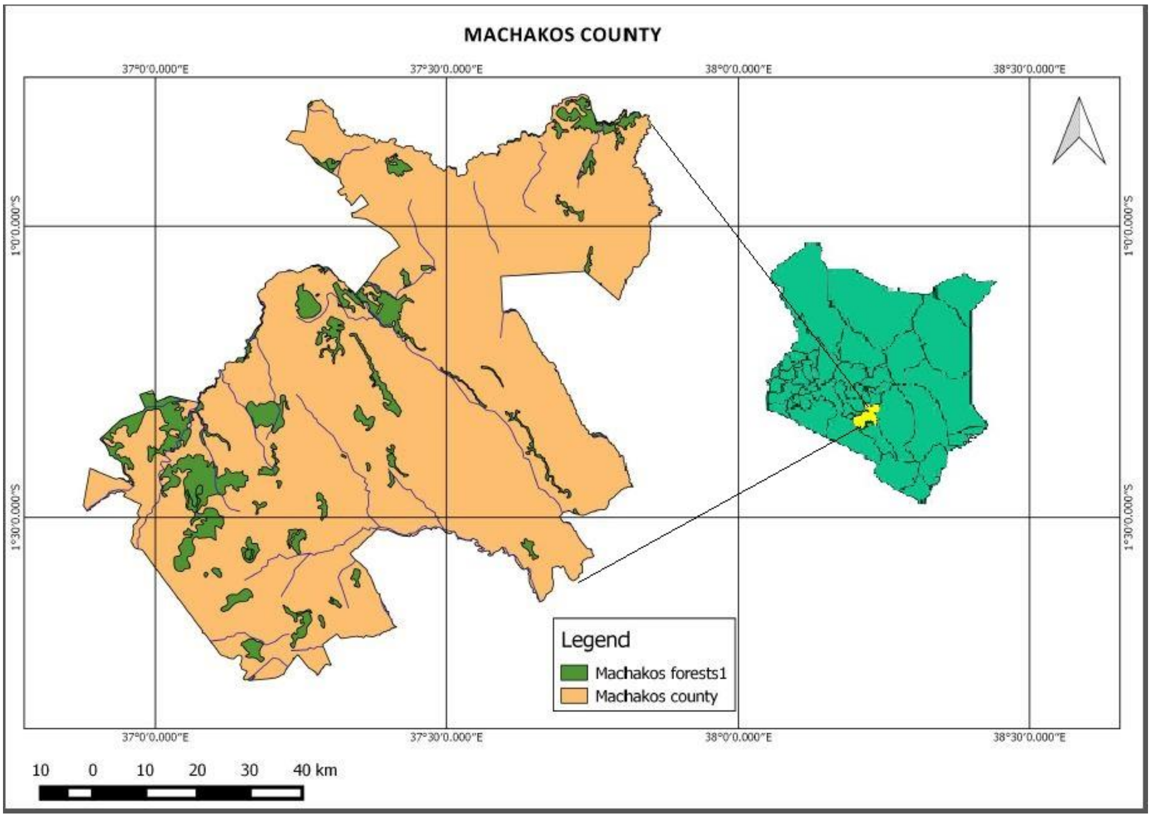

Figure 3: Map of the study area, Machakos County

The study focusses on native or indigenous, and exotic tree species, with only three out of the many drylands tree species being chosen. These are Acacia Xanthophloea and Melia Volkensii, which are indigenous, and Gliciridia sepium, which is an exotic species.

In previous studies involving afforestation in arid and semi-arid lands, soil factors such as salinity, texture, profiles, cation and anion concentration, physiochemical properties, porosity and water table fluctuation have been considered, (Taylor, Tomar, Gupta, & Dagar, 1998). Other factors considered in the previous studies include rainfall, slope, settlement, water or drainage, roads, population and Normalized Difference Vegetation Index (NDVI), (Nyeko, 2012)

However, for this research project, only 8 criteria are used for the analysis, these being soil pH, drainage, depth and texture, as well as elevation, precipitation, temperature and the area's land covers.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The chapter mainly involves a study and analysis of studies previously done related to the research problem being addressed. An overview of related studies done worldwide is given, as well as an overview of related forestry studies in Kenya. This is to acquire background information on forestry and afforestation.

The theory behind the methodology used, the criteria selected and data sources used is also given, in order to understand their suitability and relevance to the achievement of the study objectives. The study gap to be filled is also identified.

2.2 Studies on afforestation conducted globally

Over the past century, afforestation and reforestation have been implemented extensively and increasing attention has been paid to their ecological impact. Artificial forestation was initially undertaken as an effective way to alleviate water loss and soil erosion, control desertification and conserve biodiversity, but it has recently gained attention as a potential mechanism for carbon sequestration. (Jin, Fu, Liu, & Wang, 2011)

Within the Kyoto Protocol, the clean development mechanism (CDM) is an instrument intended to reduce greenhouse gas emissions, while assisting developing countries in achieving sustainable development, with the multiple goals of poverty reduction, environmental benefits and cost-effective emission reductions. The CDM allows for a small percentage of emission reduction credits to come from afforestation and reforestation (CDM-AR) projects. A global analysis of land suitability was conducted for CDM-AR carbon 'sink' projects and identified large amounts of land as biophysically suitable and meeting the CDM-AR eligibility criteria. Forty-six percent of all the suitable areas globally were found in South America and 27% in Sub-Saharan Africa.

International efforts to address climate change and other global environmental problems have largely been through global treaties and other policy frameworks, including such agreements as the United Nations Framework Convention on Climate Change (UNFCCC) with the Kyoto Protocol (KP), the Convention on Biological Diversity, the UN Framework on Forests, the Convention to Combat Desertification, and others, (Zomer, Trabucco, Verchot, & Muys, 2007).

Land degradation and desertification threaten livelihoods of more than a billion dryland inhabitants. Traditional approaches are presented for agricultural exploitation of the arid drylands that is sustainable in Southern Israel, and zones with similar climatic conditions. The potential for rehabilitating degraded drylands and increasing agricultural productivity was thus investigated, (Abu et al., 2008).

The investigated area is about 120 hectares of semi-desert land east of Beer Sheva, consisting of rocky hills and deep loess soil plains. The average rainfall amount received per year is about 200mm. Activities on the land include raising livestock, wheat cultivation on high quality soil, and agroforestry, mainly using olive trees. The activities provide a basic income and cover a significant amount of the families' food requirements, but do not provide a full income for a family head in a developed country like Israel. Thus, improving the quality of the grazing land by silvipasture, further investments into high value dryland tree crops and simultaneous production of wood for industry dramatically increases the farm's income, as well as its resilience to drought and ecological sustainability. The analysis thus demonstrates the potential of dryland agroforestry for sustainable development while solving a number of economic and social problems of poor dryland inhabitants, and it contributes to fighting desertification and global warming, (Abu et al., 2008).

Afforestation plays a significant role in Israel's general strategy to combat desertification. Almost 200,000 hectares – a tenth of the nation's lands, are designated woodlands, with 60,000Ha already planted, and 30000 Ha more being planned for, most in the arid southlands. The remaining 110000 Ha are to remain as open space, with natural woodlands and these have contributed to greater soil fertility in the Negev with its associated benefits such as recreational resources for the public and in many cases sanctuaries for protected wildlife, (Tal, 2004).

Large tracts of Israeli forests have been planted on initially degraded lands, and they directly contribute to soil conservation. Furthermore, plots used for afforestation have been coordinated with pastoralists' seasonal grazing schedules, thereby reducing grazing pressures. Reduced grazing and the shading effect of the trees have promoted the rehabilitation of indigenous vegetation in many places, which has further contributed to soil conservation. Afforestation improves the infiltration of precipitation, thus promoting soil moisture and local aquifer recharge. Afforestation has also been used in Israel to prevent gully and bank erosion through planting along creeks; for stabilizing sand dunes; for reducing impacts of wind and dust, and especially in recent years, for recreation and leisure activities, (Tal, 2004).

Long-term field studies were conducted on about three dozen woody perennial species to develop suitable techniques for afforestation of water logged saline soils in arid and semi-arid regions of India. The soils in the study area were mainly saline sandy loams with sodium, calcium and magnesium chlorides and sulphates. The water table was shallow, fluctuating between 1.5m depth to the surface in different seasons of the year, and the water was brackish. Prosopis juliflora, Tamarix sp., Casuarina glauca, Acacia farnesiana, A.nilotica, A.tortilis, and Parkinsonia aculeate were found to be the most promising tree species for these saline soils. Casuarina glauca and Salvadora oleoides survived even prolonged stagnation of flood waters for 9 months, (Taylor et al., 1998).

In another study, the opportunities for Kazakhstan to participate in voluntary carbon markets were investigated, by submitting forest protection, afforestation and reforestation projects that could be offered to domestic or foreign participants willing to take corporate social responsibility (CSR) and reduce their anthropogenic impact on the climate system by buying these projects. The findings revealed that the issues of CSR, participation in voluntary carbon markets and domestic forestry sector, involving afforestation, could be integrated if addressed properly, (Sabitova, 2012).

In Nigeria, desertification only began being tackled in 2001, when the then President Obasanjo launched a National Action Programme (NAP) on desertification, with a call for more concerted effort from all levels of government to check the menace of desertification. He lamented that not much had been done in the past to combat the scourge, a situation he said, had given rise to the current problems. He said that with the country losing as much as 350999 hectares of land yearly to desertification, it could not afford to watch while arable land was being lost to desert encroachment. It is because of this, that the government approved the establishment of a Green Belt across most of the northern parts of the country, spanning a length of 1500 kilometres and a width of one kilometre. Under the program, the Federal Ministry of Environment was expected to plant about 150 million trees along the arid northern zone, (Johar, 2011).

The state of desertification in Nigeria was reviewed, with historical trends and previous national efforts, as well as active programs for containing the fast-spreading desert conditions in the country's arid zones being investigated. The Greenbelt Programme (2001-2015) was thus initiated. In order to combat desertification and increase vegetative cover and soil productivity in the dry lands of the country, the government approved the greenbelt program, which included the establishment of a shelterbelt across the extreme strip of the northern parts of the country (i.e. from the Sokoto basin in the Northwest to the Lake Chad Basin in the Northeast). The project was to be jointly executed by the Federal, State and Local Governments, and would spread over a period of 14 years, (Johar, 2011).

Afforestation is the priority of China’s ecological restoration projects, undertaken to alleviate the problem of grassland degradation. The Chinese government has invested huge amounts of money in planting trees over the past 30 years. China’s Bureau of Forestry has naturally prioritized afforestation, with 2.2 billion ha being converted into forest by planting trees and shrubs from 1949 to 2005, amounting to nearly 22.91% of China’s total area. An additional 30 million ha were regenerated by aerial seeding, (Cao, 2008).

In recent decades, afforestation using tree species has become an increasingly important method of land-cover change in the arid and semiarid regions of northern China, including a large sandy area. These plantations have been established in the interest of desertification control and timber production in sandy areas. The Mongolian pine (Pinus sylvestris var. mongolica Litv.) and poplar (Populus spp.) are two of the most commonly planted trees. The planting of Mongolian pine began in the 1950s in Zhanggutai, Zhangwu County, Liaoning Province, located in the south eastern Keerqin Sandy Lands. Encouraged by this success, Mongolian pine has been planted in most areas of the Keerqin Sandy Lands that are suitable for forest growth. By 1998, the area of Mongolian pine and poplar plantations had reached 0.26 and 1.78 million ha, respectively, in inner Mongolia, (Hu et al., 2008).

The replanted Yatir forest, the largest in Israel, is a key factor in preventing desertification processes in the arid region, north-east of Beersheba. Since 2000, the forest has been serving as a living laboratory, with a sophisticated Long Term Ecological Research (LTER) monitoring station that checks natural data - precipitation, moisture, growth, the trees' natural development mechanisms, their emission of gases, the air's composition, and other factors. The research at this station is important for afforestation efforts in arid areas, as it is the only monitoring station located in a forest receiving only 200 mm of annual rainfall.

Partial results of the research conducted by the Desert Research Institute of Ben-Gurion University show that the forest's trees have adapted to arid environmental conditions by efficiently utilizing the high level of carbon dioxide in the air. Measurements revealed that, contrary to expectations, the Yatir forest absorbs 2.5 tons per hectare of carbon dioxide, just about the same as worldwide averages of 2.6 tons and European averages of 2.7 tons. The assumption is that the rising percentage of carbon dioxide in the atmosphere aids the growth of forests in semi-arid and desert areas, (Tal, 2004).

Moreover, as one of the methods to sequester greenhouse gases, arid land afforestation had been proposed, and some trial experiments carried out in Western Australia. The authors attempted to apply this type of afforestation method to Tunisian arid and semi-arid area, and then conventional land-use types and vegetation were investigated. Baseline net greenhouse gases removal by sinks, allometric equations and biomass amount of representative perennial vegetation in Tunisian arid and semi-arid land were estimated in this study, (Uganuma et al., 2012).

2.3 Afforestation and combating of land degradation in Kenya

According to (National Environment Management Authority, 2013), the forestry sector must upscale afforestation and reforestation efforts in order to increase our tree cover and subsequently enhance carbon sinks. The government has developed and gazetted farm forestry rules that require up to 10% tree cover.

Kenya ratified the United Nations Convention to Combat Desertification (UNCCD) on 24 June 1997. UNCCD, adopted on 17 June 1994, is an international legal agreement for action to combat desertification and mitigate the effect of drought in arid, semi-arid and dry sub-humid zones. One of the main commitments of the affected and developing country Parties to the Convention is to develop national action programmes (NAPs), which serve as guiding frameworks for the implementation of the convention. In Kenya, the NAP was developed in 2002 through a popular consultative process. The Kenya NAP aims at reclaiming severely degraded areas, rehabilitating partly degraded areas, reducing further degradation of affected areas, and conserving areas that are not yet degraded.

Various communities in the arid and semi-arid lands have taken up afforestation as one of the NAP activities aimed combatting land degradation and desertification, these including the Naitushurr Enkolia Widows Group in Narok, which engages in tree planting, where each member planted at least 25 trees in their homestead that increased tree cover in the village by 40%. Mandate, the Future Youth Initiative of Ngaremare Division, Isiolo, was able to increase local tree cover by 9% following free distribution of seedlings to households willing to participate in environmental conservation efforts. Moreover, the Nuru community based

organization, Kinango, has led to the establishment of tree nurseries that have supplied over 600000 tree seedlings, causing the tree cover on farm to increase by about 4%, with community members have now coming up with their own tree planting timetables during the rainy seasons. In the case of Morulem Community Irrigation Scheme, Turkana, a private tree nursery was started as a result of the scheme activities. Over 300000 trees have been planted in the past 7 years by the community adjacent to the scheme, and within the irrigation Scheme Land, where the multipurpose trees planted fix nitrogen, thus reducing fertilizer use by 10% over the past 10 years. Another case study is that of the Kitobo community based organization, Taita- Taveta, who have enabled the planting of more than 650000 tree seedlings, distributed and planted by households to conserve the environment since 2005, (United Nations Development Program, 2013).

The Blaustein Institute for Desert Research (BIDR) investigators established a runoff agroforestry system Turkana. Growing shallow-rooting annuals and deep-rooting perennials, the system takes advantage of blue leaf wattle (Acacia saligna) as the tree component, due to its drought resistance, and sorghum (Sorghum bicolour) and cowpea (Vigna unguiculata) as intercrops. Studies showed that trees grew particularly well, and when the soil was deep enough, large volumes of runoff water could be stored underground, producing high yields of intercrops, (Tal, 2004).

Kenya and Tanzania are nations where Swedish development aid has long focused on the forestry sector. Both countries are in focus for Swedish development assistance, and
Kenya hosts the headquarters of UNEP, ICRAF and other related organizations, as well as the regional headquarters of the Swedish Trade Council and many Swedish companies, while the Swedish Embassy in Nairobi is Sweden’s third largest.

Reducing Emissions from Deforestation and Forest Degradation (REDD/REDD+) is a UN effort to offer developing countries incentives to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. The UNDP/UNEP, the WB and the ITTO all have specific support programs for REDD with a strong emphasis on Africa. In Kenya, GEF proposals are being developed to support REDD readiness activities, (Goldmann et al., 2012).

In June 2011, the Aberdare Range and Mt. Kenya Small Scale Reforestation Initiative was registered as a CDM project. 1649 hectares of degraded forest lands were to be reforested with indigenous trees by the Green Belt Movement (GBM) on behalf of Community Forest Associations (CFAs) in association with the Ministry of Environment and Natural Resources and Kenya Forest Service (KFS). A detailed Forest Bill has recently been launched, while a national framework for REDD is being prepared by the government.

A Strengths, weaknesses, opportunities and threats (SWOT) analysis on Kenyan forestry was carried out, with the aims of simplifying the registration process for CDM and REDD, clarifying local benefits of carbon credits, establishing a government policy on tree-planting and biofuels and advancing technology on fast-growing species and energy efficient appliances, (Goldmann et al., 2012).

2.4 GIS and Multi-criteria decision making in Forestry Management

A Geographic Information System (GIS) is a set of tools, or a system that is used to capture, store, manipulate, analyse, manage, and present spatial or geographical data.

With the advent of information technology, GIS and remote sensing, biophysical data known for having influence on land use allocation can easily be accessed. GIS-Multi-criteria analysis can be applied in modelling future land use scenarios for resources planning and management using easy to construct biophysical parameters known for influencing future land use allocation. Biophysical data such as roads, drainage networks and others known to influence land use allocation are now easy to access.

GIS is a computer-based system that offers a convenient and powerful platform for performing land suitability analysis and allocation. The integration of multi criteria methods of suitability assessments and allocation methods into a GIS system improves the spatial capabilities of GIS and the analytical power as a formal decision making tool, (Nyeko, 2012).

Afforestation using well-adapted tree species was examined as a workable option for cropland rehabilitation in the lower river Amudary basin regions, in Uzbekistan. The aim was to extend site-specific information for the entire landscape of the region, providing spatially explicit guidance in support of afforestation land rehabilitation efforts. A GIS based multi-criteria decision making approach was thus developed to assess the suitability of the degraded irrigated croplands for the introduction of Elaeagnus angustifolia tree species. Expert knowledge and a weighted linear combination were used to produce an afforestation land suitability map. The results showed that about 18% of the degraded croplands was suitable for the afforestation, with irrigation water supply and water table depth identified as the main factors for suitability. The findings improved the understanding of the spatial variability of areas suitable for agroforests initiation and better informed decisions on cropland rehabilitation, (OLENA DUBOVYK, GUNTER MENZ, 2015).

Land suitability for forestry differs spatially, thus the need for spatially explicit information in order to allocate land resources effectively. Multi-criteria decision making is a useful approach for this, as it allows the analyst to combine qualitative and quantitative criteria to determine site-specific suitability values for a proposed land use. GIS is also well suited for the manipulation of a wide range of data for cost effective and time efficient analyses. A number of GIS based multi-criteria evaluation methods have been used in research applications.

The development of a GIS-based MCE in the suitability analysis for afforestation basically involves the steps of identification of the factors determining survival and establishment rates of the species, followed by specification of the quantitative relationships between tree establishment and each selected criterion, then definition of a range of suitability values for each criterion and finally the combination of the criteria to determine the overall suitability of the land for tree planting, (OLENA DUBOVYK, GUNTER MENZ, 2015).

A global analysis of land suitability was conducted for CDM-AR carbon ‘sink’ projects and identified large amounts of land as biophysically suitable and meeting the CDM-AR eligibility criteria. In the study, the availability of suitable land for climate change mitigation activities was investigated, as per the rules of the clean development mechanism-afforestation/reforestation (CDM-AR) provisions of the UNFCCC’s KP. A spatial modelling procedure was developed and implemented in ArcGIS (ESRI Inc.) using ArcAML programming language; This was used to identify areas meeting a range of suitability criteria. (Zomer et al., 2008)

2.5 Remote sensing

A study was done in Turkey to determine the potential afforestation areas using remote sensing data and GIS. Arit and Esme-Gure forest district areas, with different site conditions, vegetation and topographic conditions were chosen. A Landsat TM image was used do pixel based supervised classification, with maximum likelihood classification method being used.

At first, the criteria that would be potential afforestation areas were determined, then the training regions selected on the remote sensing imagery using on maps to the best classification of potential afforestation areas. The accuracy assessment was evaluated for supervised classification and the result images generated vector. The study revealed that 2032 ha is total potential afforestation forest area for Arid Forest district (overall accuracy of 81%) and 38447 ha is total potential afforestation forest area for Esme-Gure Forest district (overall accuracy of 89%). The study thus demonstrated a method that can be used, owing to the high accuracy.

The vegetation types and the climate differed spatially, with many criteria such as topography, aspect, slope and soil acting on vegetation diversity. All these criteria were important in the determination of the afforestation area.

For determination of afforestation areas, remote sensing and GIS were found to be the most appropriate methods in terms of time, cost and labour. The study was exhibited as a simple and effective method with regard to rehabilitation and the protection of forests that are a national wealth. In terms of increasing accuracy, it determined different techniques and modelling studies that were based on remote sensing and GIS, (Ateşoğlu, 2015).

On this project, supervised classification using the Support Vector Machine (SVM) method was used to classify and obtain the land covers.

2.5.1 Support Vector machine classification method. (SVM)

Support Vector Machines (SVMs) are a relatively new supervised classification technique to the land cover mapping community. They have their roots in Statistical Learning Theory and have gained prominence because they are robust, accurate and are effective even when using a small training sample, (Anthony, Greg, 2003).

A study was done to compare different classification techniques in forestry mapping in Iran. Results showed that support vector machine (SVM) with Kappa coefficient 0.7069 and overall accuracy 88.65% is more accurate than other methods, with the other methods' accuracies following in the order of the maximum likelihood, then mahalanobis distance, then minimum distance, to spectral information divergence, binary codes, and parallelepiped to spectral angle mapping, (Niknejad, Mirzaei, & Heydari, 2014).

A study was also done to map Land Use Land-Cover classes using multispectral WorldView-2 (WV-2) data, and SVM in a fragmented ecosystem; and to compare the accuracy of three

WV-2 spectral data sets in distinguishing amongst various LULC classes in a fragmented ecosystem. The study showed that SVM is a known versatile classifier that constructs models based on a small data from different classes, maximizing the margin between the support vectors and the hyperplane, thus significantly minimising the classification error. Analysis was performed of SVM for classifying remotely-sensed data and it concluded that the classifier leads to improved classification accuracy, (M.I, 2016).

2.6 The Analytical Hierarchy process (AHP)

A study was conducted at the Shemroud watershed, Guilan province of Iran, to investigate the ecological requirements of 16 tree species for afforestation using GIS, with environmental conditions such as elevation, climate and soils being determined on the study site. According to their importance, the maps were classified with ranges from 1 to 9, with 9 representing the most suitable growth conditions and more unsuitable conditions assigned gradually reducing values. The AHP method was used for the weighting of the maps with regard to the factors, (A. Eslami, M. Roshani, 2010).

A Fuzzy multi criteria approach was used towards the assessment of land suitability for the plantation of Eucalyptus grandis tree species in the Gharnaveh Watershed of the Golestan province of Iran, with climatic, edaphic and topographic factors being considered, and the AHP being used to assign weights to the criteria, (Mashayekhan ARMIN, 2010).

In multi-criteria decision problems, AHP has been found to be very useful to impose a hierarchy on clusters of the aspects or dimensions defining a problem, and their relative importance cluster-wise. The heart of this method is the analytical hierarchy process, (Bunruamkaew, 2012).

It is one of the Multi Criteria decision making methods, originally developed by Prof. Thomas L. Saaty and is used to derive ratio scales from paired comparisons. The inputs are obtained from actual measured quantities such as price and weight, or from subjective opinions such as satisfaction feelings and preference. The AHP entails the construction of pairwise comparison matrices, and the weights are extracted by means of the principal right Eigen vector. With a pairwise comparison matrix for n items the decision maker indicates how much more important item i is than item j (the two items being compared), (Dijkstra, 2010).

Some small inconsistencies in judgment are allowed, since humans are cannot always be perfectly consistent. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value, (Saaty, 1980).

AHP is a flexible and powerful tool as the scores and final ranking are obtained based on the pairwise relative evaluations of both the criteria and the user provided options. The computations made by the AHP are always guided by the decision maker's experience, and thus the AHP can be considered as a tool able to translate the evaluations (both qualitative and quantitative) made by the decision maker into a multi-criteria ranking, (Saaty, 1980).

In the project, the AHP was used to generate the weights of the various factors used for the suitability analysis for afforestation. Questionnaires were issued to foresters in the field, at KFS Machakos, containing pair-wise comparison matrices, which they filled with vales indicating the relative importance of each factor relative to every other factor.
The scales used for comparison of factors were as shown in table 1below, (Bunruamkaew, 2012).

Table 1: Preference scales used in AHP

Scale	Degree of preference
1	Equal Importance
3	Moderate Importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Values for inverse comparison

2.7 Criteria selected

The list of criteria selected was based on consultation with experts (foresters), as well available GIS data on the various criteria for the tree species. Local environmental factors, together with the land characteristics, were included. As a result, the criteria selected were:

2.7.1 Precipitation

Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth. Most precipitation falls as rain. The amount and regularity of rainfall varies with location and climate types and affects the dominance of certain types of vegetation and trees, (Cropsview, 2012). For the study, the term rainfall and precipitation are used interchangeably since rainfall is the main form of precipitation experienced in the area.

2.7.2 Temperature

This is the degree of hotness or coldness of a substance. It is commonly expressed in degrees Celsius or centigrade (C) and degrees Fahrenheit (F). This climatic factor influences all plant growth processes such as photosynthesis, respiration, transpiration, breaking of seed dormancy, seed germination, protein synthesis, and translocation. At high temperatures the translocation of photosynthate is faster so that plants tend to mature earlier, (Cropsview, 2012).

2.7.3 Elevation

The altitude or elevation of the land is the height above sea level, and influences plant growth and development primarily through temperature effect. The relationship of this abiotic factor to temperature is like that of distance from the equator to the arctic poles. Temperature decreases by 1degree centigrade for every 100 m increase in altitude in dry air.

This abiotic factor is an important consideration in crop or site selection for more productive crop and trees growth. The effect of land elevation on plant growth and development is apparent when exploring a high-rise mountain. Dominance of certain plant and tree types varies with elevation. With change in height from sea level to 16,000 feet (4,876.8 meters) from the foot to the top of a mountain in the Peruvian Andes or New Guinea, temperatures change from tropical to subtropical, temperate, and subarctic to arctic, (Cropsview, 2012).

2.7.4 Soil chemical property: Soil pH

Soil pH generally refers to the degree of soil acidity or alkalinity. Chemically, it is defined as the log10 hydrogen ions (H+) in the soil solution. The pH scale ranges from 0 to 14; a pH of 7 is considered neutral. If pH values are greater than 7, the solution is considered basic or alkaline; if they are below 7, the solution is acidic. Soil pH affects the soil's physical, chemical, and biological properties and processes, as well as plant growth. The nutrition, growth, and yields of most crops decrease where pH is low and increase as pH rises to an optimum level, (Batie S.S, 1994). It is used as an index of soil suitability for crops and plants, and is rated as follows:

- (<4.5) - extremely acidic
- (4.5-4.9) - strongly acid,

- (5.0-5.9) - medium acidity
- (6.0-6.4) - slightly acid,
- (6.5-6.9) - near neutral
- (7.0-7.4) - Slightly alkaline,
- (7.5-8.4) - moderately alkaline
- (8.5-8.9) - strongly alkaline,
- (>9) - extremely alkaline

Soil physical properties:

2.7.5 Soil Drainage

Drainage ensures proper soil aeration is maintained in the field. Excess water (after a rainfall for example), can cause standing water (or saturated soil) which will chokes crops, (Yahoo answers, 2015).

This is the present drainage of the soil component, described according to one of the classes mentioned below

- Excessively drained- water is removed from the soil very rapidly
- Somewhat excessively drained-water is removed from the soil rapidly
- Well drained-water is removed from the soil readily but not rapidly
- Moderately well drained-water is removed from the soil
- Somewhat slowly during some periods of the year. The soils are wet for short periods within the rooting depth
- Imperfectly drained-water is removed slowly so that the soils are wet at shallow depth for a considerable period.
- Poorly drained-water is removed so slowly that the soils are commonly wet for considerable periods. The soils commonly have a shallow water table
- Very poorly drained-water is removed so slowly that the soils are wet at shallow depth for long periods. The soils have a very shallow water table

2.7.6 Soil Depth

This is the estimated depth in cm to which root growth is unrestricted by any physical or chemical impediment such as impenetrable or toxic layer. Soils that are deep, well-drained, and have desirable texture and structure are suitable for the production of most garden or landscape plants. Deep soils can hold more plant nutrients and water than can shallow soils with similar textures, (College of Agriculture of the University of Arizona, 1998). Its values are as given:

- Very shallow (<30cm)
- Shallow (30-50cm)
- Moderately deep (50-100)
- Deep (100-150)
- Very deep (≥150cm)

2.7.7 Soil Texture

Soil texture refers to the relative quantities of inorganic matter in soil. It is a measure of the proportion of sand, slit and clay particles in the soil. Texture has a major effect on many aspects of the soil including: Fertility levels, Infiltration and drainage rates, Water holding capacity, Bearing strength, Ease of cultivation, Shrink and swell potential, Ability to crack on drying and Susceptibility to erosion, (Agriculture Technology avenue, 2010). This is thus a very crucial factor to afforestation, and its values are given as:

- Very clayey - more than 60% clay
- Clayey - sandy clay, silty clay and clay texture classes
- Loamy - loam, sandy clay loam, clay loam, silt, silt loam and silty clay loam
- Sandy - loamy sand and sandy loam texture classes
- Extremely sandy - sand texture classes

2.7.8 Land covers

These were considered since different tree species do better on different land covers, as was evident on the data given on the tree species selected for use. Some dryland tree species do well on bare land and shrub land, while others are more suitable for intercropping and agroforestry and thus prefer croplands.

2.7.9 Slope and Drainage

Slope and drainage had initially been considered, but on consultation with the experts, the two criteria were dropped as it was determined that:

For drainage, it was determined that this was not an important factor as semi-arid tree crops rely solely on rainfall, with drainage not being an important factor, while for slope, it was determined that tree growth can basically occur on both steep and gentle slope, and thus slope was not a major factor determining tree growth as it is with most other crops.

2.8 Tree species selection

Native plants (plants from the local area) grow easily in local conditions. They also preserve biodiversity by attracting and providing homes for native insects, birds, and animals. Sometimes, plants and trees that are not native to the local area become popular because they grow fast, produce good lumber, or help improve the soil. Some trees, such as eucalyptus, pine, teak, neem, and Leucaena have been planted all over the world, (“Restoring Land and Planting Trees,” 2012).

For the study, native or indigenous, and exotic tree species were thus selected and their prevalence and suitability for the area tested. The tree species selected are listed below.

2.8.1 Acacia Xanthophloea

This is a large tree, 15-25 m tall, with a crown that is somewhat spreading, branching fairly up the trunk. It is indigenous, and has a number of benefits that contributed to its selection including:

- Highly drought resistant
- Can grow in shallow soils , usually unsuitable for other species
- Used as a stabilizer of swamplands, riverbanks and dams
- A fast growing tree species
- A nitrogen fixing species, used as shade intercropping in agroforestry
- Hard, heavy wood, good for timber, though should be seasoned before use , (Ken Yoshikawa & Chikamai, 2014).

2.8.2 Melia volkensii

This is an open crowned deciduous tree, of height 6-25 m tall. It distributes naturally in semi-arid zones of Ethiopia, Somalia, Kenya and Tanzania, and was strongly recommended as it is a species largely over harvested and over depleted and thus the need to re-introduce it. Some of its benefits include:

- Land reclamation, and environmental conservation in arid and semi-arid areas
- Source of fodder during dry seasons when fodder is hard to come by
- A good timber source; its wood easily worked and shaped

- Suitable for agroforestry
- An indigenous tree species in the area, that has been over-exploited and thus the need to re-introduce it to the eco-system, (Ken Yoshikawa & Chikamai, 2014).

2.8.3 Gliciridia sepium

This is a small to medium-sized thorn less tree, up to 10-12 (15) m high. It branches frequently from the base. Its bark is smooth, varying in colour from whitish grey to deep red-brown. Trees display spreading crown. It is native to seasonal dry forests of Central America, and thus exotic to the study area. Its benefits include:

- Nitrogen fixing, and shade/ nurse tree in agroforestry
- Soil Erosion control, a strong consideration in its selection
- Rapid growth in light or little shade, (Ken Yoshikawa & Chikamai, 2014).

2.9 Research gap

From the literature review done, it was found that a number of studies have been conducted on suitability analysis of afforestation in various areas worldwide, using remote sensing, GIS and multi-criteria decision techniques. However, such studies are yet to be conducted in the study area, and in Kenya at large. Thus, this research project aims to fill this gap, by assessing the application of these techniques for the subject of afforestation potential and suitability analysis. As no previous similar studies were noted to have been done in the study area, the research is expected to act as a baseline for future research work of a similar nature in the area.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

The chapter describes the methodology and approach used in achieving the results, from a description of the study area, to the criteria and data sources used for the study, including their sources and resolutions, and the procedure adopted towards the achievement of the aforementioned objectives.

3.2 Study area

Machakos County is a county in Kenya that borders Nairobi and Kiambu counties to the West, Embu to the North, Kitui to the East, Makueni to the South, Kajiado to the South West, and Murang'a and Kirinyaga to the North West. Machakos County stretches from latitudes 0º 45' South to 1º 31' South and longitudes 36° 45' East to 37° 45' East. Its altitude varies from 715m to 2112m at its highest point, though most areas lie within the 1000 to 1600m altitude range. Its area is about area of 6,208 km^2, (Machakos county government, 2014). A hilly terrain covering most parts of the county. The local climate is semiarid with the county experiencing erratic and unpredictable rains of less than 500mm annually, with short rains in October through to December and the long rains in late March to May, This is depicted by the county's agro-climatic zones map below, on figure 4.

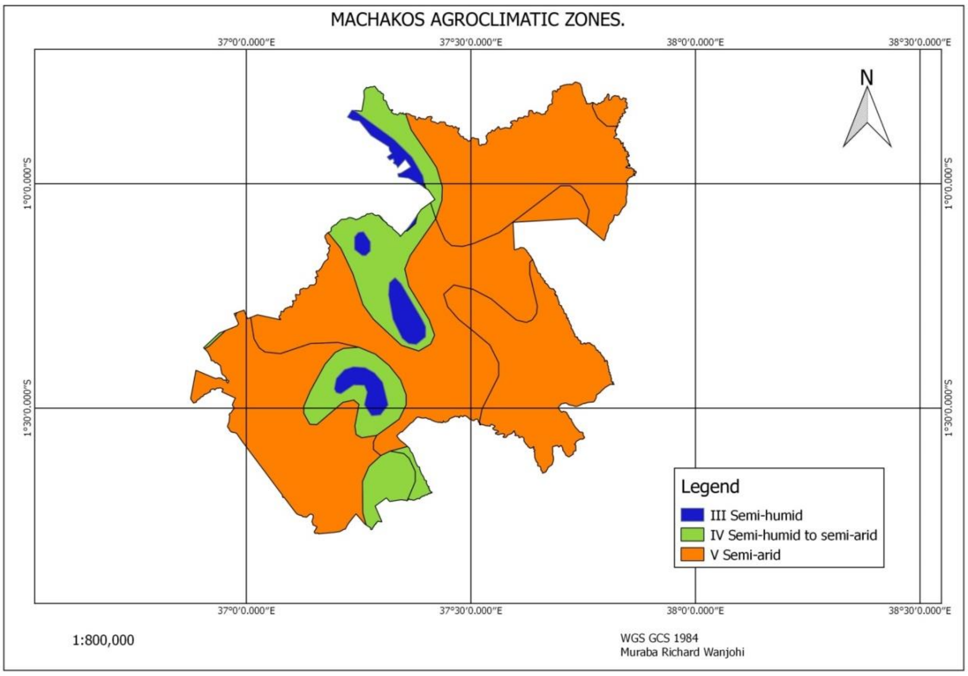

Figure 4: Machakos Agro-Climatic zones map

The county lies within the drainage basins of River Athi and Tana, which, together with River Thika, a tributary of the Tana, are the only perennial rivers. The hills in the central part of the county, namely Kanzalu Range, Mango, Kangundo, Iveti, Mua and Kiima Kimwe are a source of a few permanent springs and streams, whose flow is intermittent at low attitude. Other Rivers are Miwongoni, Manza, Mitheu and Iiyini within Machakos municipality.
The National Park of Ol Donyo Sabuk is also one of the natural resources in Machakos county, (The County Platform, 2015).

Agriculture is one of the economic activities in the county, with cereals, grain legumes and root crops dominating, including drought-resistant crops such as sorghum and millet, and several industrial crops like cotton and coffee, (Machakos county government, 2013). Vegetables are also planted and sold in the market places. Irrigation is practised using the rivers within the county and, and boreholes. Livestock keeping also promotes the economy, with some of the animal products being sold locally and in other major towns such as Thika and Nairobi, and to the Kenya Meat Commission (KMC), (JOYLEP ENTERPRISES LTD, 2015).

Moreover, the county has 8 constituencies including Machakos Town, Mavoko, Masinga, Yatta, Kangundo, Kathiani, Matungulu, and Mwala. Machakos Town is the administrative capital of the county, with Kenya Forest Services offices in these regions, where they deal with forestry management and conservation activities within the county.
The Bureau of Environmental analysis (BEA) international has initiated a carbon sequestration project in the area, involving afforestation and reforestation, (Degradation, 2012).

3.3 Overall work flow

The overall work flow approach used involved three main steps of data collection, followed by data analysis and finally the results. It can be summarised as in figure 5 below:

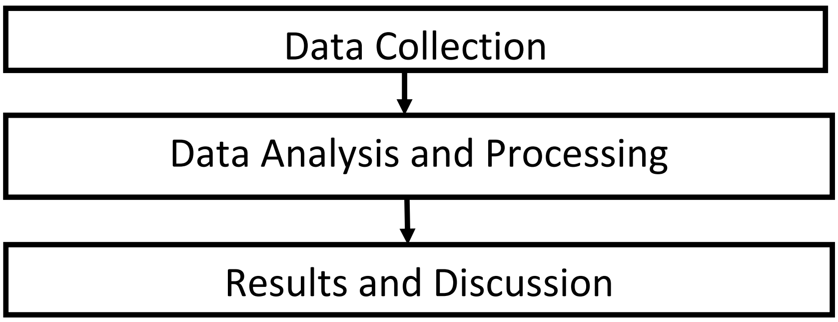

Figure 5: Overall project work flow diagram

Where the first major step was to ensure all the relevant data was acquired. In some cases, data collection had to be redone where better data was discovered afterwards. The data processing and analysis then followed, where the data was prepared for use in various ways, before it was analysed in a GIS environment. Results were then obtained, which were discussed and conclusions drawn from them.

3.4 Data sources

Various types and resolutions of data were required and used for the analysis. They were obtained from different sources. Below is a summary of the data and the sources, in table 2.

Table 2: Data sources used in the project

DATA	SOURCE	RESOLUTION
Landsat 8 Imagery	USGS portal	28.5m
Digital elevation models: SRTM,	USGS portal	SRTM: 30m horizontal, 16m vertical
Climate data (Rainfall and Temperature)	KMD(Machakos Meteorological station) ; WorldClim data	1 km grid for WorldClim, 1 weather station's data from KMD
Soils data	KENSOTER soils database	1:1
Tree species data	ICRAF Agroforestry database JIFPRO and KEFRI documentation on ASALs tree species and requirements	

3.4.1 Descriptions of the data

1. Landsat image

   A Landsat 8 image, dated March 2015, was acquired from the USGS website/ portal. It was of the level 1T- terrain corrected processing level, and had the least cloud cover among the available latest Landsat 8 images for the area. The part of the image covering the study area was thus not affected by cloud cover. The path and row of the image were 168 and 061 respectively, with the spatial resolution of the image being 28.5m, radiometric resolution being 12 bits.

The data was used to determine the land covers in Machakos county, which were crucial in the analysis.

2. Digital Elevation model (DEM)

This was also acquired from the USGS portal. The shuttle radar topography mission (SRTM) DEM was acquired and used. Initially, a 90m spatial/horizontal resolution DEM was used. However, upon realisation of its availability, a 30m horizontal resolution SRTM DEM image was downloaded and used. The vertical resolution of the DEM was about 16m, which was good enough considering the areal extent of the study area.

Definition

The Shuttle Radar Topography Mission (SRTM) Global Digital Elevation Model (GDEM) is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA), NASA, the Italian Space Agency (ASI) and the German Aerospace Centre (DLR). The SRTM GDEM Version 1.0 is the almost raw data contained in the mission, considered as research-grade. It is in geographic projection and referenced to WGS84 datum. It is composed of a 1arc second (approximately 90 m) grid, in 1°by 1° tiles.

However, the White House announced on September 23th, 2014, during the United Nations Heads of State Climate Summit in New York, that they would release the high-resolution images of SRTM globally. Until then, the high-resolution imagery was only available for US areas. Due to this release, the 30m x 30m imagery was made available globally and substituted the 90m x 90m data. After its release the data is now accessible on EarthExplorer by the US Geological Service (USGS).

The data acquired and used from the DEM was the elevation/ altitude, while the slope, which was initially considered, was eventually not used, following consultations with forestry experts, and the lack of data on slope preferences for the tree species.

3. Climate data

The aspects of climate required for the study were rainfall and temperature. The data was initially sourced from the Kenya Meteorological Department (KMD), in Nairobi, but it was insufficient, despite it covering all the months of the year for the previous fourteen years, from 2000 to 2013. This is because the data availed was only for one meteorological station within Machakos county, which could not be used for interpolation to come up with temperature and rainfall data surfaces useful for GIS analysis.

WorldClim data, which is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometre, was used. The data was freely available for academic and non-commercial use. It consisted of monthly temperature and rainfall data for the whole world, averaged for a period of 50 years. This was sufficient enough as it gave a good approximation of the most recent climate situations.

WorldClim version 1 was developed by Robert J. Hijmans, Susan Cameron, and Juan Parra, at the Museum of Vertebrate Zoology, University of California, Berkeley, in collaboration with Peter Jones and Andrew Jarvis (CIAT), and with Karen Richardson (Rainforest CRC). The data used was obtained from thousands of people, from all countries of the world, who day after day recorded the weather data from which WorldClim was derived, and from those who compiled national and international databases from these records.

4. Soils data

Soils data was crucial for the analysis, with both physical and chemical properties of the soil being required. The Kenya soils shapefiles from various open source online sources such as Kenya GIS data and ILRI shapefiles were initially considered for use. However, it was realised that some components of the data in the study area had large gaps, making it unsuitable for use.

However, on further research, the KENSOTER Soil and Terrain Database for Kenya (version 2.0), which is open source and available online as well, was downloaded and used for the analysis. It consisted of separate spatial data (shapefiles and KML format) for the Kenya soils polygons, and attribute data, i.e. the various physical and chemical properties, in Microsoft access database format. The data was suitable for use, as it had all the required properties, with no gaps in it.

The physical properties of the soils data obtained were the texture, depth and drainage, while the chemical property was the soil pH, which is a measure of the alkalinity or basicity of soil.

KENSOTER Soils database

The Soil Terrain Inventory of Kenya (KENSOTER) is a digital database inventory recently developed by the Kenya Soil Survey following the UNEP/ISRIC SOTER procedures (Kenya Soil Survey of 1995). The soil map includes attribute files with aggregated soil and terrain characteristics per soil unit. The data files are linked to KENSOTER databases that provide access to detailed soil unit, terrain and profile information of the KENSOTER database.

The KENSOTER map is an updated map of the Exploratory Soil Map of Kenya (ESKM) at a scale of 1:1M. Thus, the delineations of the KENSOTER mapping units largely coincide with the unit boundaries on the ESMK. However, a small number of additional mapping units have been defined and the 21 boundaries of few ESMK units modified. The rasterized version of the KENSOTER map is geodetic latitude and longitude coordinate system, (Batjes, 2004). Metadata for a selection of ISRIC's data sets may also be accessed through the WDC portal at GCMD-NASA. In 2007 the dataset was updated in respect of attribute data for the Green Water Credit project in the Upper Tana River.

The non- spatial KENSOTER database is structured according to the SOTER Procedures Manual whereby the SOTER unit is defined by one or more terrain components, and each terrain component consists of one or more soil components. It contains a number of interlinked, but physically separate data files.

5. Tree species data

   This was obtained from the ICRAF Agroforestry database, and the JIFPRO and KEFRI documentation on ASALs tree species and requirements. The data involved various attributes about the plantation requirements of about 15 drylands tree species in detail, and more documentation on hundreds of other drylands tree species, but not as detailed. The tree species chosen for the study were selected from amongst the 15 that were more detailed. The figures 6 and 7 below illustrate the structures of the available tree species catalogues.

Acacia nilotica (L.) Del. (subsp. *nilotica*) (Fabaceae)

General description

Moderate-sezed evergreen tree, with a short , thick and cylindrical trunk, growing to a height of 25 m. It has considerable variation with nine subspecies presently recognized, three occurring in the Indian subcontinent and six throughout Africa. (1).

Environmental reqirements

Altitude	0-1340 m a.s.l. (1)
Mean annual rainfall	200-1270 mm (1)
Soils in natural range	Grows on a wide variety of soils, thriving on alluvial soils, black cotton soils, heavy clay soils, and can tolerate poorer soils. (1)
Soil water regimes	Drought resistant and occurs in plain, flat or gently undulating ground and ravines (1). The subspecies nilotica is adapted to periodic flooding followed by extended droughts (2).
Suitable site for planting	Strong light requirement. Grows best on alluvial soils in ravine areas subject to periodic inundation (1) but also grow well on heavy, clay soil with a pH range of 5 to 9 (2).
Root system	Forms a deep and extensive root system on dry sites, the tap root developing first and then the laterals, which become compact and massive, but on flooded sites the root system is largely lateral (3).

Phenology and Ecophysiology

Phenology

The trees generally lose their leaves during the dry season, though riverine subspecies can be almost evergreen.The flowers are bright yellow and borne on globe-shaped flower heads. The flowers are sweetly scented and appear near the beginning of the rainy season. Flowering is prolific, and can occur a number of times in a season. Often only about 0.1% of flowers set pods. The nutritious pods retain their seeds at maturity and are dispersed by animals (2).

Ecophysiology of water use

According to the experiment comparing water use of four species (*Acacia nilotica, Albizia procera, Azadirachta indica and Eucalyptus camaldulensis*) grown in pots in a green house, water consumption by one year old *Eucalyptus* was more than three times that of by *Acacia* and *Azadirachta* . However, water use efficiency was found as 0.32 g L^{-1}, 0.48 g L^{-1}, 0.16 g L^{-1} and 0.77 g L^{-1} for *Acacia, Albizzia, Azadirachta* and *Eucalyptus* respectively (6). *A. noltica,* also other two native species, showed traits of low water comsumption and small biomass production in comparison with *E. camludulensis*.

Tree Management

Planting and weeding

The species will tolerate only light frost, but is extremely resistant to drought and heat. It is also tolerant of saline soil. Young trees coppice well, and the species can be propagated from truncheons, root suckers and cuttings.But the subspecies *nilotica* coppices very weakly (1). Some subspecies can be invasive (and can be extremely invasive in exotic habitats). The species can be direct seeded or established by seedlings. In the nursery long poly-tubes (20 x 7 cm) should be used so as not to restrict rapid tap root growth. Frequent root pruning is advised. Nursery grown seedlings are usually planted out after six months, but in some cases stay in the nursery for up to a year. Establishment varies depending on the site. Seedlings are shade intolerant(2). Young seedlings are said to require full sun and frequent weeding(1).

Agroforestry

In the Central plain of Indian subcontinent *A.nilotica* grow naturally in the agricultural fields and forms an important agroforestry system. It was reported that *A. nilotica* generally reduced crop yield under its canopy and this reduction varies with distance from the tree trunk. Crop production depend upon distance from tree trunk and tree canopy size. Reduction in grain yield was maximum (30%) under the large tree canopy and lowest (12%) under the small tree canopy due to decreased availability of light by 44 to 62% under the canopy that resulted in slow photosynthetic rates and growth(4). However, when the tree is felled after the completion of rotation cycle (>12 years) grain yield increased 126% for the first cropping season and 30 % for the fifth cropping season at 1 m distance from the tree stump and declined with distance(5). These results suggest that the crop may exploit the greater amount of nutrients to increase productivity, if the tree canopy is open to facilitate greater light availability.

When intercropped with *A. nilotica* ssp. *nilotica* in semi-arid Nigeria, sorghum showed heavily depressed yields (1).

Plantations for timber production

Since the time of the Pharoahs, large timber trees have been exploited from the riverine forests of the Nile. Sapwood is yellowish-white and heartwood reddish-brown, hard, heavy, durable, difficult to work, although it takes a high polish. Because of its resins, it resists insects and water, and it is harvested for boat making, posts, buildings, water pipes, well planking, ploughs, cabinet work, wheels, tool handles, carts, mallets and other implements. It is an attractive wood, good for carving and turnery. Sudan forests have been managed on a 20-30 year rotation producing termite resistant timber especially suitable for railway sleepers(1).

In irrigated plantations in the Sind and Punjab, 10-15 seeds are spot sown at 2 x 3 m spacing on the tops of trenches. They are thinned to three to four seedlings after three to four months. Further thinning occurs at five year intervals. Rotations are 20-25 years. In the Thal desert, Pakistan (where there is 250 mm annual rainfall), promising growth resulted from irrigation at ten day intervals. Growth rates varied considerably depending on the sites, with maximum mean annual increment of 13 m3 /ha at 20 years old and 10.5 m3 /ha at 30 years recorded (2).

Benefit and Products (1, 2)

Reclamation: In India, this species is used on degraded saline and alkaline soils.
Medicine: It is used for stomach upset and pain, the bark is chewed to protect against scurvy, an infusion is taken for dysentery and diarrhoea.
Poison: The aqueous extract of the fruit, rich in tannin (18-23%), has shown algicidal activity against*Chroccoccus, Closteruim, Coelastrum, Cosmarium, Cyclotella, Euglena, Microcystis, Oscillatoria, Pediastrum, Rivularia,* and etc.
Food: Tender pods and shoots are used as a vegetable, and roasted seed kernels are sometimes used in Sudan for food flavouring. Air-dried seeds contain crude protein and are eaten raw or roasted in India in time of acute food scarcity.
Fodder: The crude protein content of the leaves is 14-20%, and 11-16 % for the highly palatable pods. Pods and shoots are used as forage for camels, sheep and goats, especially in Sudan, where it is said to improve milk from these animals.
Apiculture: The fragrant flowers are popular bee forage.
Fuel: The calorific value of the sapwood is 4500 kcal/kg, while that of the heartwood is 4950 kcal/kg. This valuable source

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Figure 6: Tree species documentation

1	*Acacia brevispica*	Fabaceae (M) •12)	Ⅱ－Ⅵ			0–2,100		Sh－St	5m
2	*Acacia drepanolobium*	Fabaceae (M)	Ⅱ－Ⅴ		500–1,300	1,300–2,400		Sh－St	6m
3	*Acacia elatior*	Fabaceae (M)	Ⅳ－Ⅶ			0–1,750		Tt	25m
4	*Acacia gerrardii*	Fabaceae (M)	Ⅲ－Ⅴ			1,300–2,200		Mt	15m
5	*Acacia mellifera*	Fabaceae (M)	Ⅰ－Ⅵ		400–900	0–1,800		Sh－St	9m
6	*Acacia nilotica*	Fabaceae (M)	Ⅲ－Ⅵ	4–47	500–1,000	0–2,500		St	6m
7	*Acacia paolii*	Fabaceae (M)	Ⅵ－Ⅶ			100–1,250	D	Sh－St	4.5m
8	*Acacia polyacantha*	Fabaceae (M)	Ⅲ－Ⅳ		200–800	0–1,900		Mt	18m
9	*Acacia senegal*	Fabaceae (M)	Ⅲ－Ⅶ	–4–48	300–450	200–2,200		Sh－St	9m
10	*Acacia seyal*	Fabaceae (M)	Ⅲ－Ⅴ	18–28	150–900	0–1,650		Mt	10m
11	*Acacia tortilis*	Fabaceae (M)	Ⅳ－Ⅶ	23.4–31.3	100–1,000	600–2,300		St	5–8m
12	*Acacia xanthophloea*	Fabaceae (M)	Ⅲ－Ⅴ		—	600–2,100		Tt	25m
13	*Acrocarpus fraxinifolius*	Fabaceae (C) •11)	Ⅱ－Ⅴ			1,900	D－SD	Sh－St	10m
14	*Adansonia digitata*	Bombacaceae	Ⅱ－Ⅵ		300–900	0–1,300	D	Tt	20m
15	*Adenium obesum*	Apocynaceae	Ⅲ－Ⅵ			0–1,500	D	Sh	2m
16	*Albizia amara*	Fabaceae (M)	Ⅳ－Ⅶ	10–47	400–1,000	500–2,000	D	Mt	15m
17	*Albizia anthelmintica*	Fabaceae (M)	Ⅲ－Ⅵ	＞40	400–1,000	0–1,350	D	Sh－St	4m
18	*Albizia glaberrima*	Fabaceae (M)	Ⅲ－Ⅳ			0–900	E	Mt－Tt	15–30m

Figure 7: Tree species catalogue

3.5 Hardware and Software used

3.5.1 Hardware

The hardware used for the project mainly was personal computers on which the software was run. Peripheral devices used included a mouse and keyboard, as well as an external hard disk for back up storage of all the project progress in case of anything.

3.5.2 Software

Varying software was used for the achievement of the tasks in the project. These include:

- ENVI 4.7 – Was used for the remote sensing processes, involving pre-processing and classification of the satellite image, and the accuracy assessment of the classification.
- ESRI ArcMap 10.2– This was the main software used for the GIS data analysis
- QGIS 2.8.1 – Was used in conjunction with ArcGIS for data preparation, pre-processing and some analysis.
- Microsoft Office – Was used for some of the data analysis (Microsoft Excel and Access), report writing (Microsoft Word) the preparation of presentation slides (Microsoft PowerPoint) and editing figures (Microsoft Publisher).
- Google Earth – This was used in conjunction with ENVI during the image classification and accuracy assessment for ground verification.

3.6 Flow of Activities

Figure 8 below shows the overall methodology flow diagram that was used for the project.

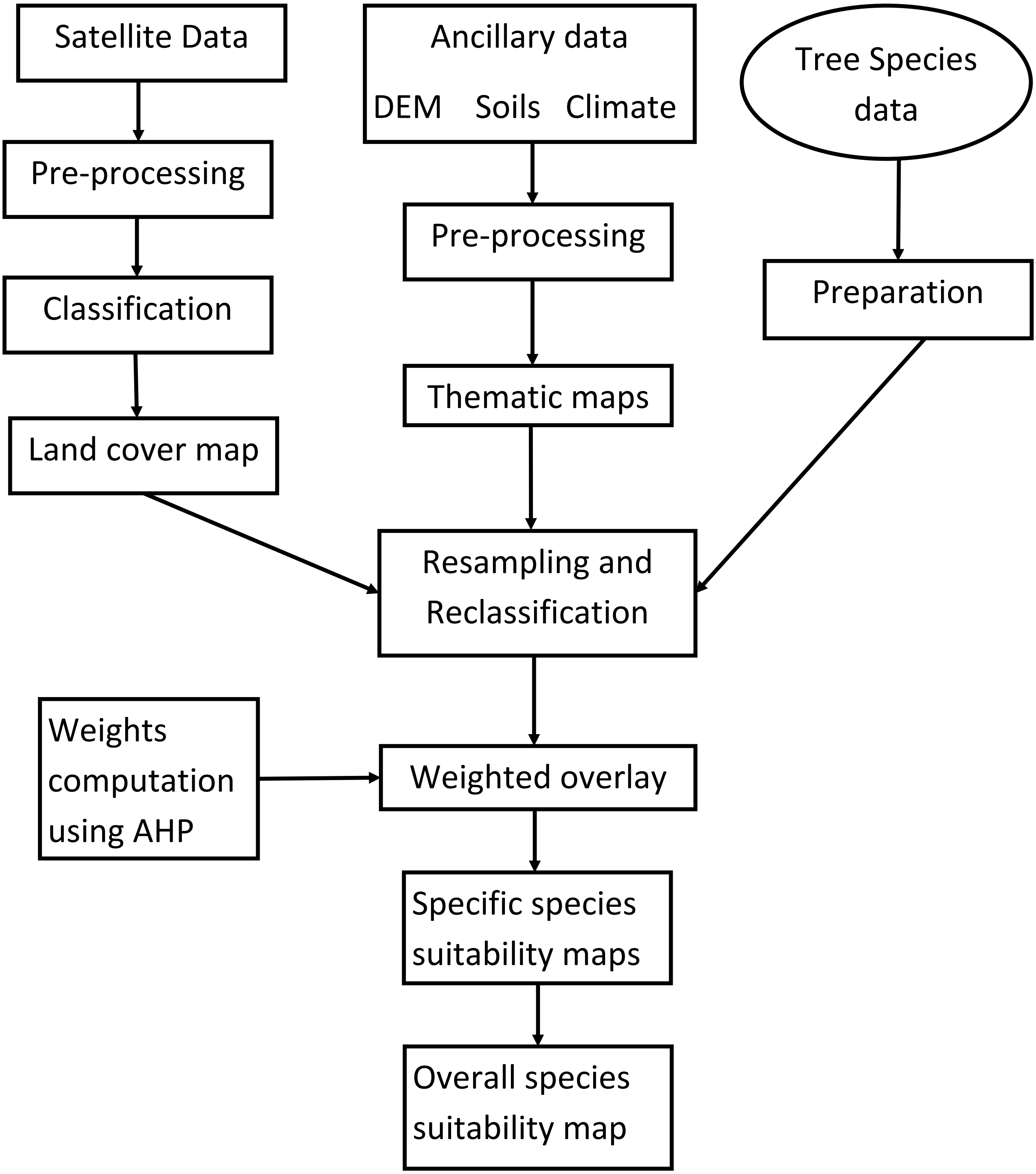

Figure 8: Methodology Flow Diagram

3.6.1 Satellite data processing

A Landsat 8 image, path 162, row 061, and dated March 2015 was used. The data was of level 1T correction, which had been corrected for terrain from the source, and thus did not require any geometric correction.

The processing mainly involved image classification using ENVI.

- The first step was to layer stack the Landsat 8 bands, as they were downloaded each separate from the other in a compressed file format. The downloaded bands were from band 1 to 11, but only bands 1 to 7 were stacked together to form a 7 bands composite image.
- The next step was the sub-setting of the composite image to the study area. This involved the clipping of the image with reference to the Machakos county shapefile, thus leading to a satellite image covering only the study area.
- Image classification then began. This involved opening of the image subset in ENVI and using visual interpretation and the appropriate band combinations, picking homogenous training regions for each distinct land cover and storing the picked regions of interest as a ROI (Regions of interest) file.

  Band combinations used included (in RGB format for Red then Blue then Green):
    - 4,3,2 – True/natural colour where the bands were stacked as red, blue and green as they naturally are for coloured vision.
    - 5,4,3 - False colour(coloured infrared) for vegetation identification
    - 7,6,4 – False colour for urban areas identification
    - 5,6,4 – For distinguishing between water features and land

  Only bands 2 to 7 were used for the combinations, as band 1 is a coastal band while band 8 is a panchromatic 15m resolution band. The varying band combinations could be opened simultaneously on different views/ screens linked to each other, for more comprehensive comparison.

  The spear tool was used to open Google Earth directly from ENVI at the location specified, showing the latest Google satellite image for the area and thus useful for verification.
- On the picking of all required training regions and their saving, the classification tool was run, basing on the image. Support Vector Machine (SVM) method of supervised classification was used to do a first classification with 22 distinct land covers identified.

- The distinct land covers were then combined, with similar classes such as croplands 1, 2 and 3 being merged to cropland, to form 6 classes. These were urban areas, water, woodland consisting of areas covered by trees or forest, transitional land which consisted of bare land and shrub land, cropland which consisted of all land on which agricultural crops were growing, and rangeland, which consisted of land left fallow, where there were signs of agricultural activities such as cultivation or crop growth having taken place, but with no crops on them, and they have been left fallow.

  The final land covers for the area are as shown on figure 9 below:

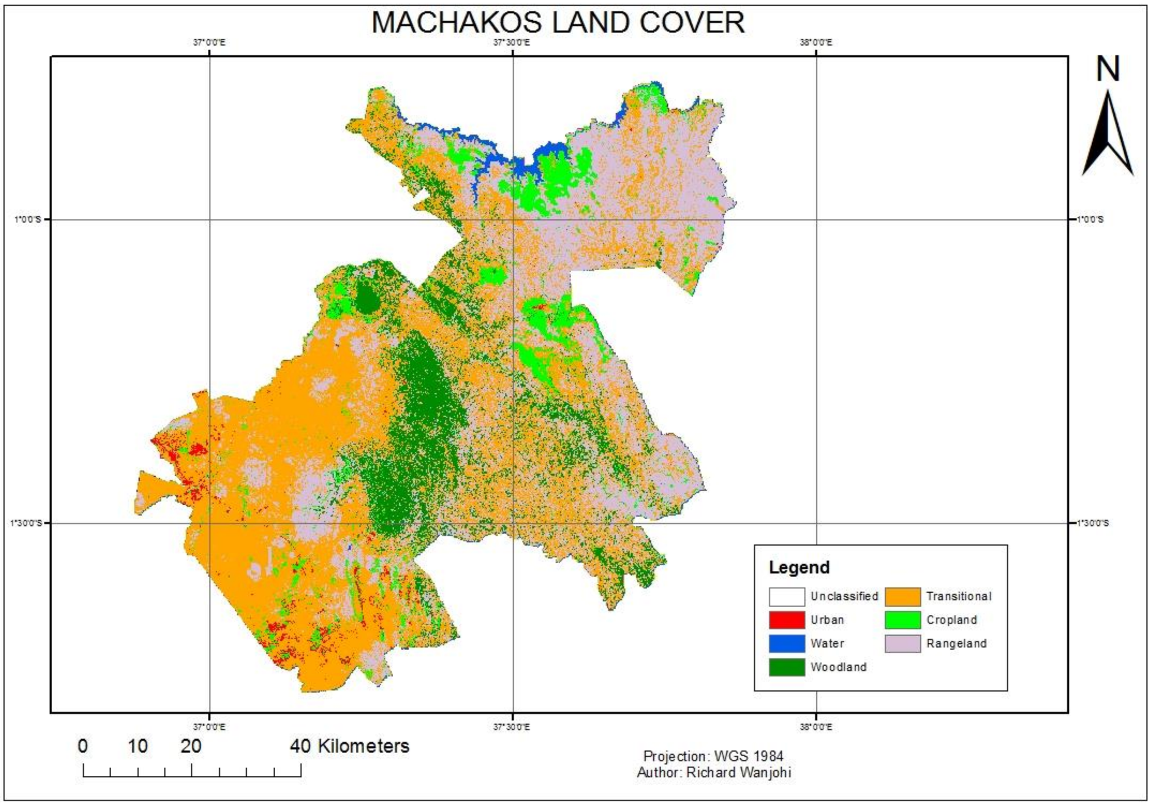

Figure 9: Machakos land cover map

The areas of the land covers obtained were as shown in table 3 below:

Table 3: Area and percentage of land covers

Land covers	Pixel count	Pixel area (m^2)	Class area (km^2)	% of total area
Rangeland	2283615	900	2056.3	33
Cropland	448533	900	403.9	6.5
Transitional land	3155788	900	2842.5	45.7

Woodland	863980	900	778.4	12.5
Water	76394	900	69.2	1.1
Urban areas	82142	900	74.1	1.2

Transitional land and range land were thus found to be the dominant land covers in the study area.

- For post classification, an accuracy assessment was then performed, with new training regions being picked from the original unclassified image, independent of the first picked training regions. The spear tool was also used for ground verification with Google Earth.

  The accuracy assessment results are as follows, as shown on the confusion matrix, on table 4 below:

Table 4: Classification confusion matrix

	Ground Truth Pixels						
Class	Urban	Water	Woodland	Transitional	Cropland	Rangeland	Total
Urban	**1345**	0	2	17	11	0	1375
Water	4	**1636**	21	1	7	6	1675
Woodland	12	6	**4413**	34	181	40	4686
Transitional	453	42	35	**2827**	29	509	3895
Cropland	16	9	46	34	**2453**	41	2599
Rangeland	26	16	170	307	32	**2951**	3502
Total	1856	1709	4687	3220	2713	3547	**17732**
Sum of correctly classified pixels (along the diagonal)							**15625**

The overall accuracy was determined as the ratio of the number of correctly classified pixels to the total number of pixels, as (1345+1636+4413+2827+2453+2951)/17732 = 15625/17732 = 88.12%, and the Kappa Coefficient determined as 0.85

3.6.2 Soils data processing

The soils data from KENSOTER was available in various formats. There were shapefiles that could be loaded in any GIS software; a KML file that could be opened from Google earth, an ArcGIS xml file that could be opened from ArcGIS, containing the soil layers and some attribute fields. A Microsoft Access database file was also available, containing a lot of soil properties not availed in the GIS files’ attribute tables.

Before its use, the data required some processing, which involved:

- The ArcMap file was opened, which contained the Kenya soils feature class vector file. This contained some attributes, excluding those required for the analysis.
- The attribute table of the feature class was linked with the various Ms Access database tables containing the required soil characteristics, with various primary keys consisting of various fields common within the tables were used to establish relationships amongst them, that eventually led to a link of all the tables with the soils feature class attribute table.
- The soils data was then grouped according the 4 soils criteria required. These are as shown in the figures below:

  Soil depth: The area is seen too be mostly covered by deep and very deep soils, with a few occurrences of moderately deep and shallow soils, as in figure 10 below.

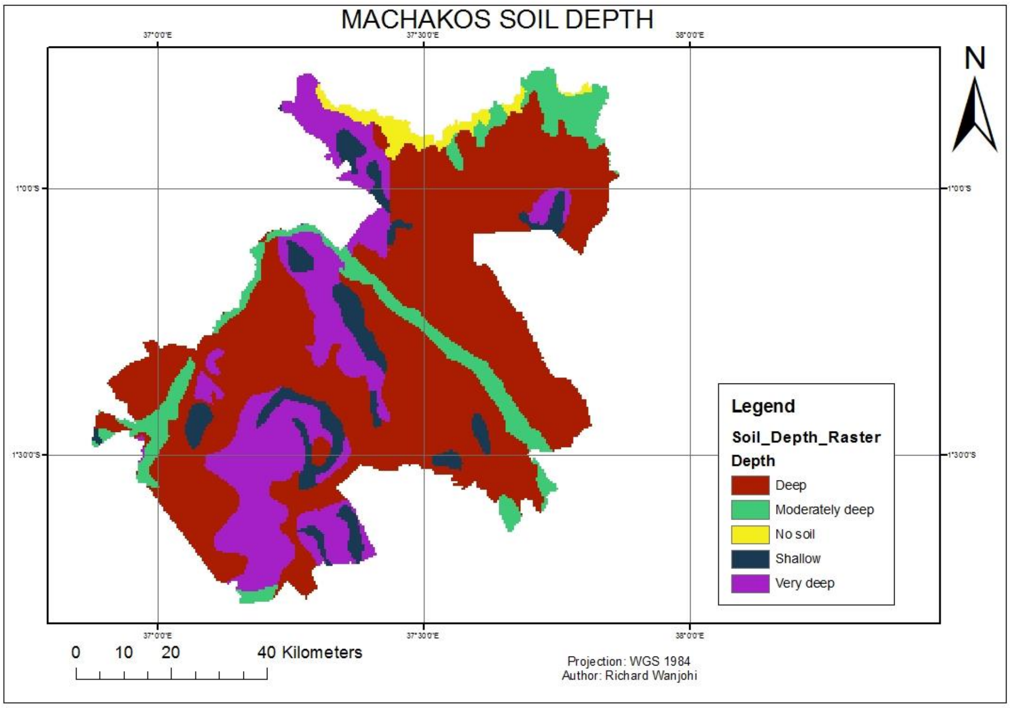

Figure 10: Machakos soil depth map

Soil pH: The region is seen to have diverse soil pH ranges, from 5 to around 8.3, as shown in figure 11 below.

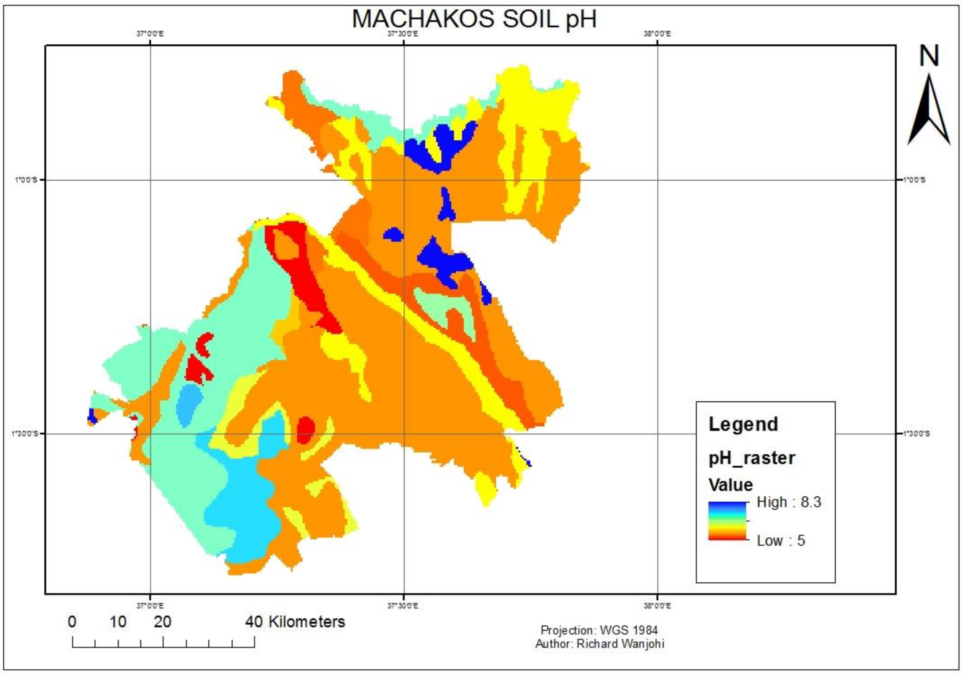

Figure 11: Machakos soil pH

Soil texture: The most common texture is clayey soils, with a few occurrences of loamy and very clayey soils, as shown in figure 12 below:

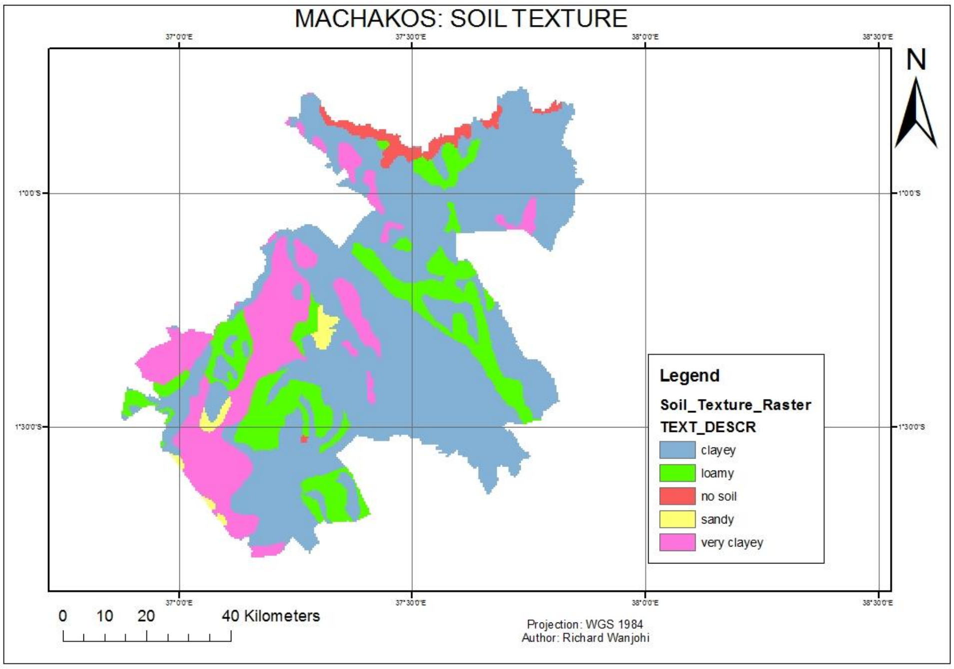

Figure 12: Machakos soil texture

Soil drainage: Majority of the soils were found to be well drained, with some parts on the south west containing poorly drained soils. Other parts have somewhat poorly and excessively drained, as well as excessively well drained. This is shown on figure 13 below:

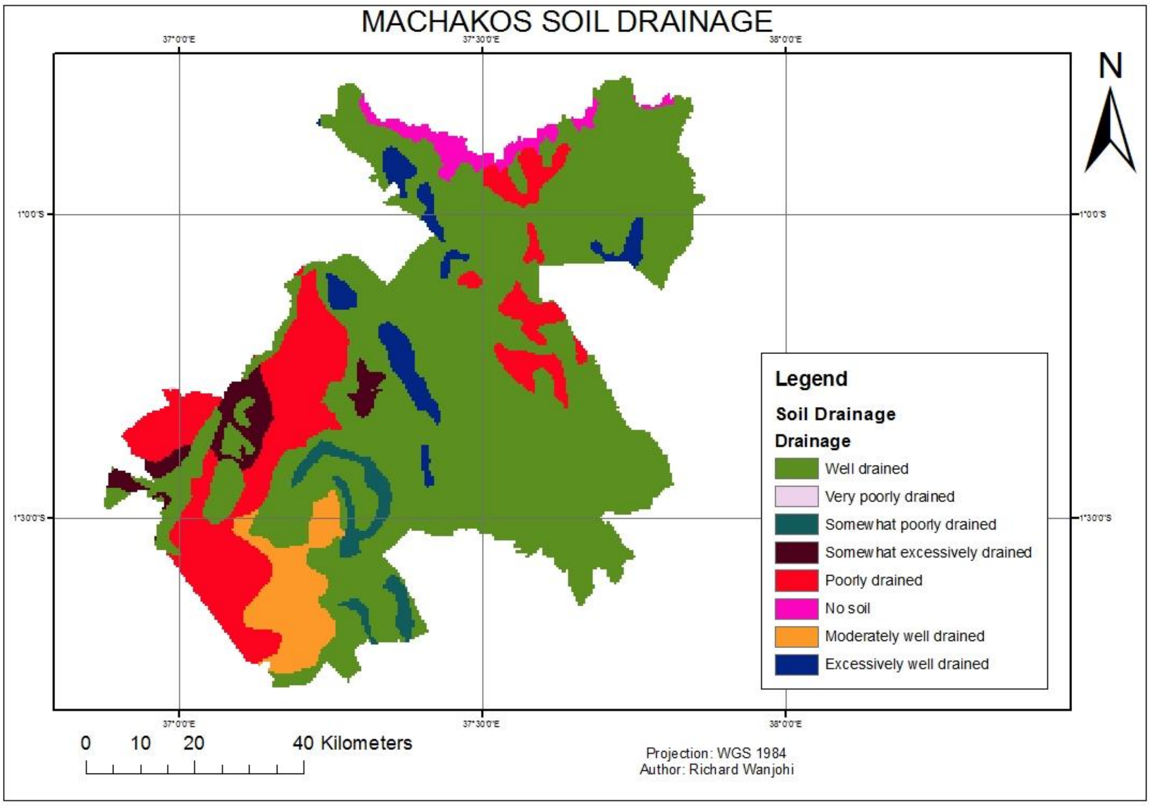

Figure 13: Machakos soil drainage

3.6.3 Climate data processing

The WorldClim data downloaded required some processing before it could be used. It consisted of a raster dataset for each month for both temperature and precipitation, thus a total of 24 climate datasets. Two models were created using ArcGIS model builder for the processing of both the temperature and precipitation components, and the model steps applied are as shown in the figures 14 and 15 below:

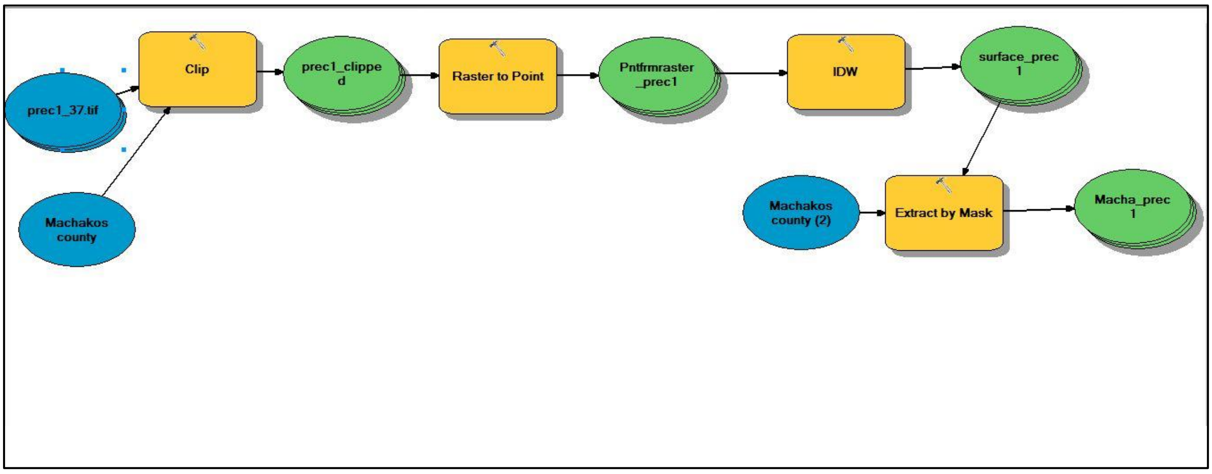

Figure 14: Precipitation data processing model

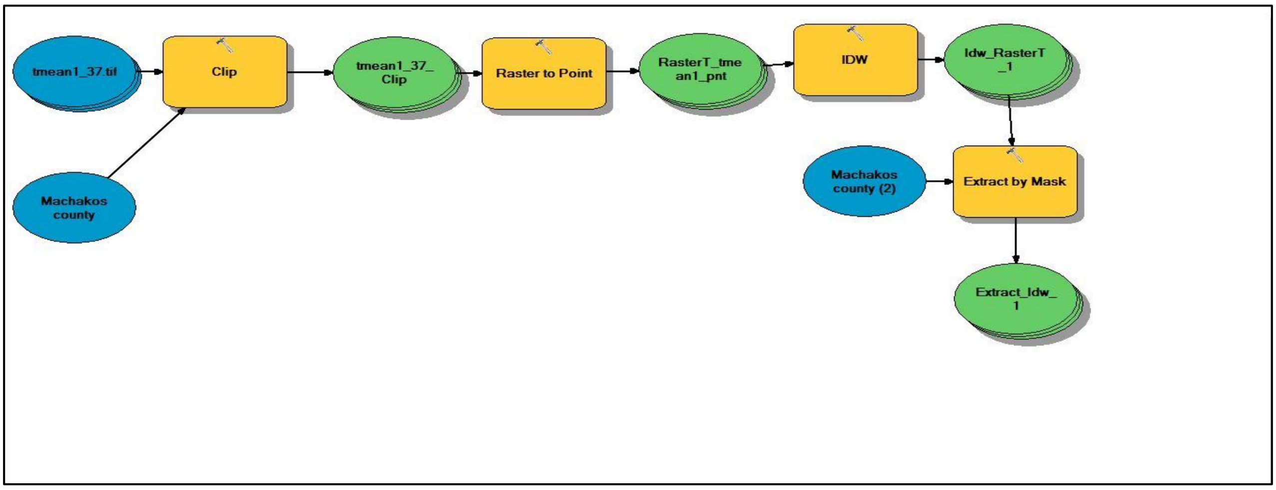

Figure 15: Temperature data processing model

Where the steps involved were similar for each dataset, and were:

- Sub setting/ clipping – The datasets covered the entire extent of region/ tile 37 as per the dataset description and thus they had to be clipped to the project area
- The next step was to smoothen the coarse data, which was highly pixelated due to its relatively low resolution (1 km). These steps involved:
    - Raster to point conversion, where the raster data was converted to a dense vector grid of points covering the whole area
    - Surface creation from the points grid using Inverse distance weight (IDW) interpolation technique. The raster surface thus created was much smoother than the initial dataset
    - Extraction by mask was then done, where the surface, whose extents occupied the entire square limits of the study area, was clipped to the study area, and the

environment of the final data was related to that of the Landsat 8 image for more smoothness, resulting in the final images having a 30m resolution as the Landsat 8 image.

- The datasets represented monthly climate statistics averaged over a 50 years period. Thus, the monthly precipitation averages were added to each other to get the mean annual precipitation, while the 12 temperature datasets were averaged to get the mean annual temperature.
- The ground weather station data was also processed, to obtain mean annual rainfall total and temperature average from it as well, over a 14 years period.
- For validation, the ground station weather point, coordinates (37.233,-1.583) was mapped onto ArcMap, and all the monthly temperature and rainfall values extracted from the WorldClim raster datasets. The values were tabulated, and compared with the tabulated ground data in a Microsoft Excel environment.

The general flow of the climate data processing for 1 WorldClim dataset could be illustrated in figure 16 below.

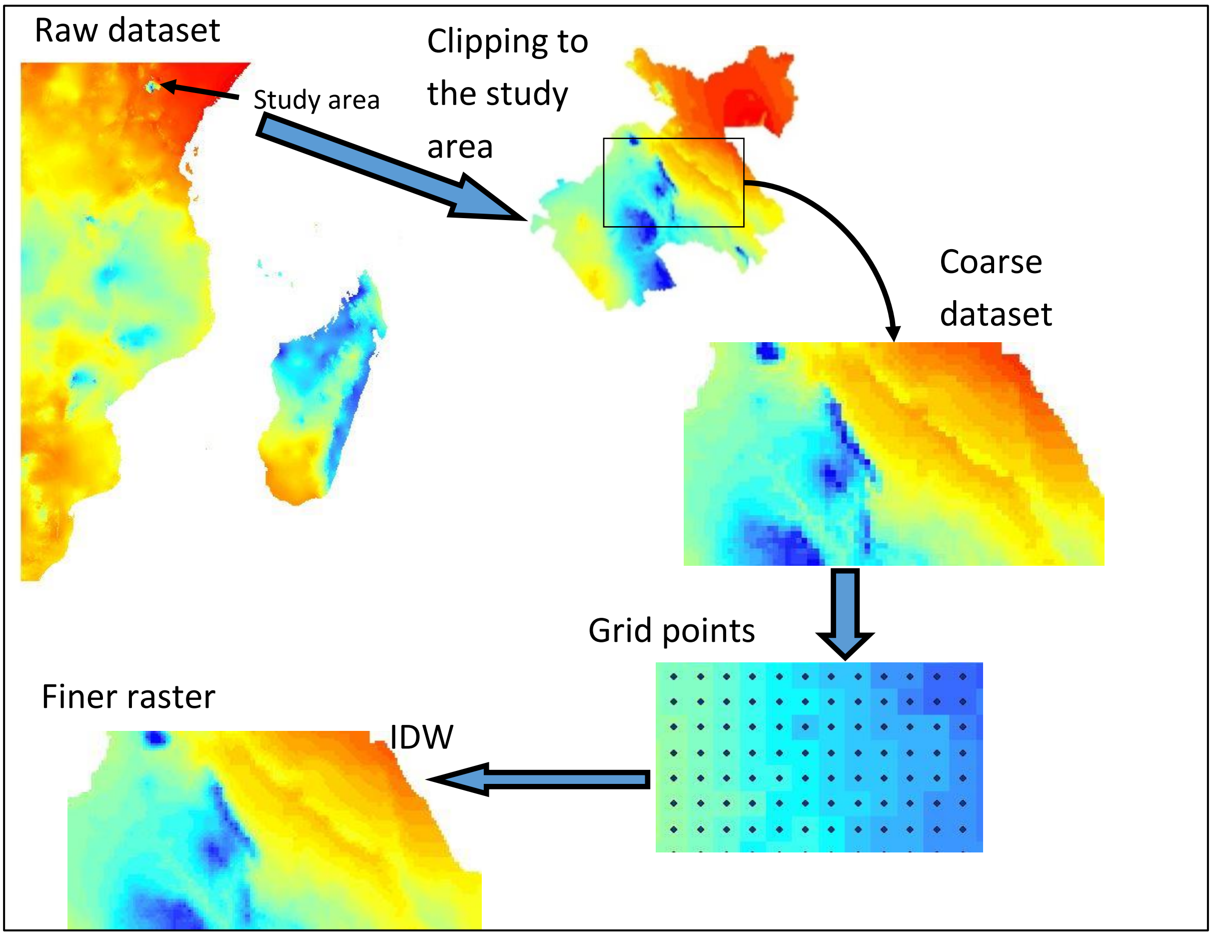

Figure 16: Illustration of the WorldClim data processing stages

Validation

The final processed WorldClim was compared to the processed ground weather station data, and the former's accuracy tested relative to the latter's, which was taken to be the true record. Microsoft Excel was used for this. The results obtained were represented graphically as shown in the figures 17 and 18 below:

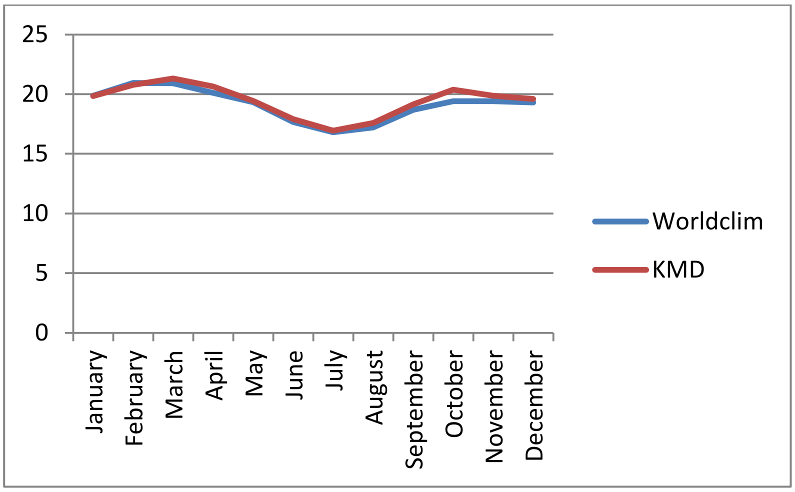

Figure 17: Precipitation datasets graphical comparison

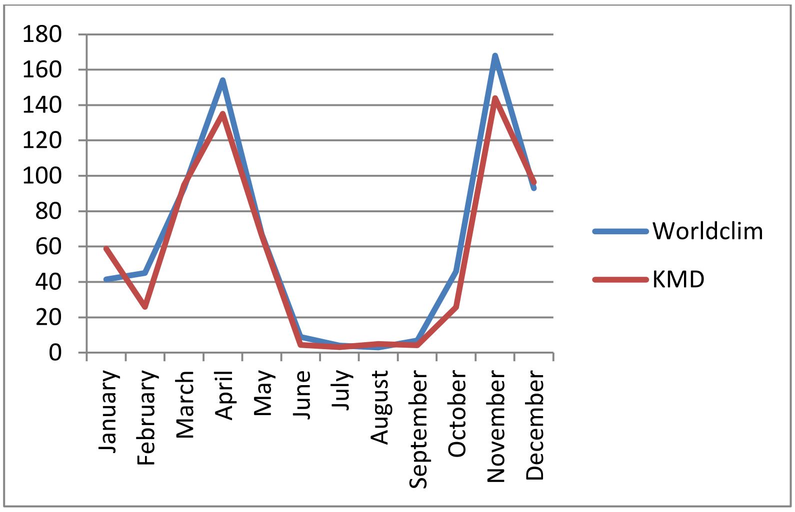

Figure 18: Temperature datasets graphical comparison

To determine the level of accuracy, the coefficient of determination (R^2), the root mean square error (RMSE), the bias and the mean absolute error (MAE) were used to evaluate results, (Zheng Duan, 2013).

Where RMSE = $\sqrt{\frac{\sum_{i=1}^{n}(P_i - M_i)^2}{n}}$;

Bias = $\frac{\sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} M_i} - 1$;

MAE = $\frac{\sum_{i=1}^{n} |P_i - M_i|}{n}$

With P_i and M_i being the satellite and ground stations datasets respectively.

The coefficient of correlation, (R^2), (Sean, 2014), was obtained using the Excel CORREL function.

For the precipitation data, the validation results obtained were RMSE = 13.1mm, Bias = 0.1, MAE =9.6 and R^2 = 95.6%, showing a high accuracy of the satellite rainfall data relative to the rain gauge data.

For the temperature data, the validation results were RMSE = 0.42, Bias = -0.01, MAE = 0.34 and R^2 = 99.97%, also showing a high accuracy of satellite temperature data relative to the ground thermometric data.

The final precipitation map obtained as in the figure, where the mean annual rainfall was seen to range from 506mm to 1470mm. The regions around the central part of the area are seen to receive the highest rainfall amounts, while the areas towards the north and south borders receive the least rainfall. This is visualised in figure 19 below.

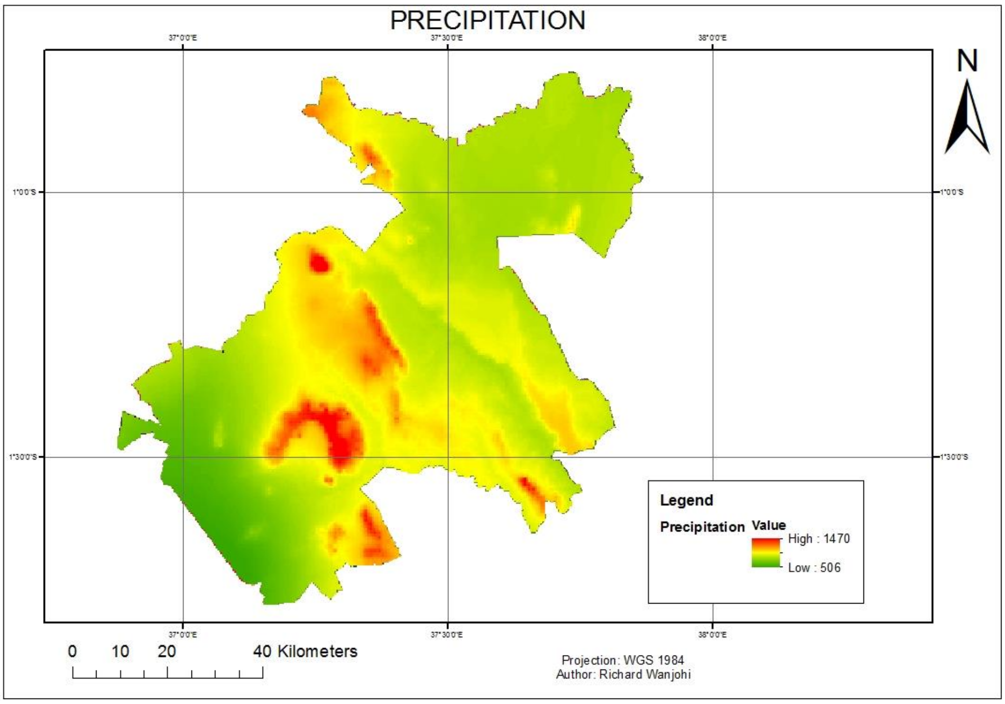

Figure 19: Machakos average annual precipitation map

The final temperature map was as shown in figure, where the lowest temperatures are seen to be experienced around the central parts, with the south-south west regions warmer and the northern parts warmest/hottest. The temperatures averagely range from 19 to 28 degrees Celsius. This can be visualised in figure 20 below.

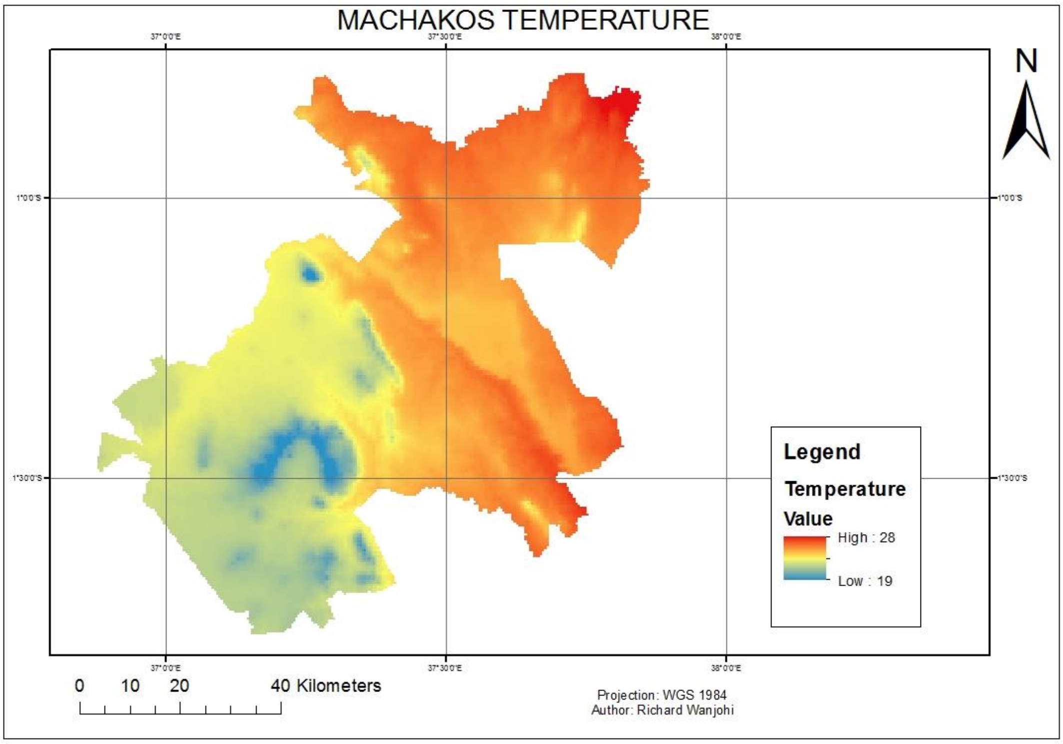

Figure 20: Machakos mean annual average temperatures map

3.6.4 SRTM DEM

The 30m SRTM DEM, in raster format, was used for the elevation data. It was downloaded in different blocks/ grids covering the study area, and thus mosaicking had to be done to the various images covering the area, to come up with a continuous surface. The raster mosaic was then subset to the study area.

The data generally displayed elevation without being processed, and thus was a ready to use dataset for the analysis.

For map making purposes however, its symbology was altered for it to be more appealing and discernible, as the original image was in black and white shade.

The elevation map is as shown in the figure 21 where the central part of the study area has the highest elevation, which reduces sharply away from the region, depicting a hilly region. The highest peak is 2112m. The rest of the regions are at lower altitude, with the northern part having the lowest altitude. The lowest elevation is 715m a.s.l.

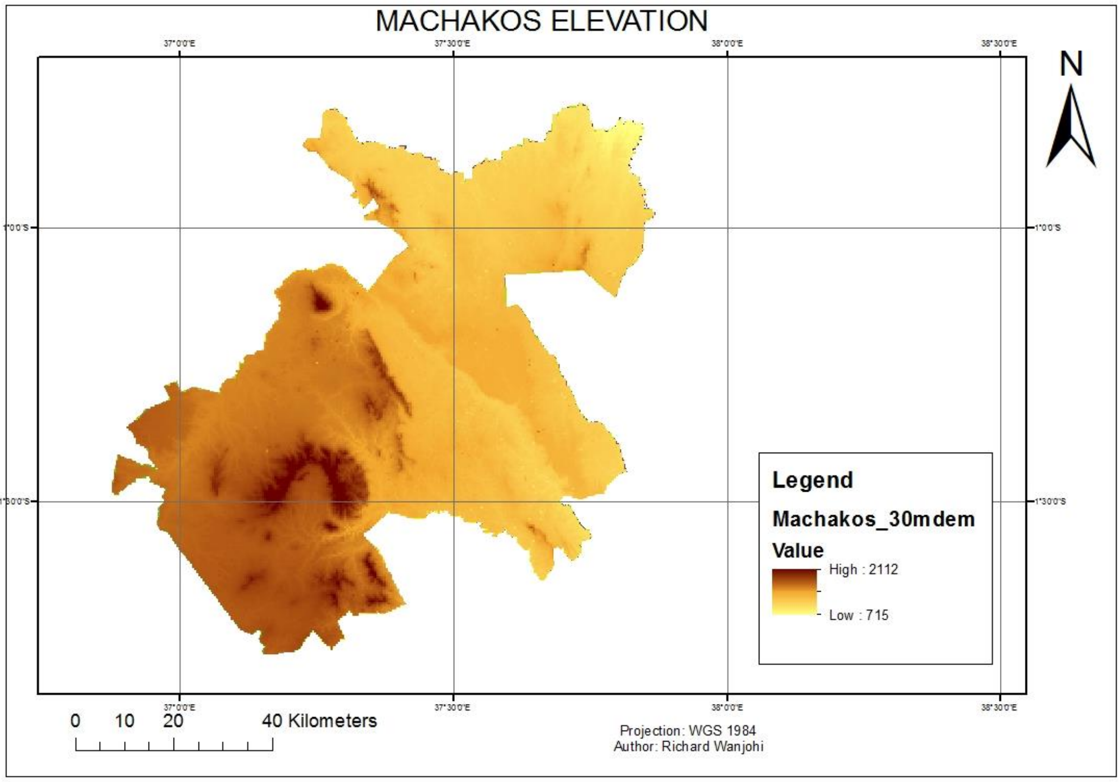

Figure 21: Machakos elevation map

3.6.5 Tree species catalogue

The required data was extracted from the available tree species catalogues, and tabulated for ease of use on table 5 below:

Table 5: Tree species criteria data

Species	Acacia Xanthophloea	Melia Volkensii	Gliricidia sepium
Annual Precipitation	200-1270	300-800	600-3500
Annual Temperature	5-30	15-35	10-30
Soil pH	7-8	6.8-7.3	4.5-6.2
Soil Texture	Sandy	Sandy, loamy	Sandy, clayey
Soil Drainage	Somewhat poorly drained	Well drained	Very well drained
Land cover	Transitional land, Range land	Transitional land, Range land	Cropland

Altitude	600-1200	350-1700	0-2100
Soil depth	Shallow	Deep	Deep
Agro-Climatic zones	III to V	V to VI	III to IV

3.7 Data analysis

The data analysis was then done in ArcGIS and in Microsoft Excel where required.

3.7.1 Computation of weights

This was done using the AHP process, in Microsoft Excel. The weights were computed from the pairwise comparison values filled in the questionnaires issued to the foresters in the field.

The process involved in the weights computation was (done for each of the questionnaires) :

- A pairwise comparison matrix and reciprocal matrix was first formed for each of the questionnaires, on either side of the diagonal of the composite questionnaire matrix. The pairwise matrices formed for each questionnaire are as shown on table 6 below:

Table 6: AHP pairwise comparison matrix

	Texture	Temperature	Soil pH	Rainfall	Drainage	Landcover	Altitude	Depth
Texture	1	0.2	1	0.33	3	0.2	0.33	3
Temperature	5	1	5	0.33	1	0.33	0.33	3
Soil pH	1	0.2	1	0.33	0.2	0.2	0.33	3
Rainfall	3	3	3	1	3	3	5	3
Drainage	0.33	1	5	0.33	1	0.2	3	0.33
Land covers	5	3	5	0.33	5	1	5	0.33
Altitude	3	3	3	0.2	0.33	0.2	1	0.33
Depth	0.33	0.3	0.33	0.33	3	3	3	1
sum	18.67	11.73	23.33	3.2	16.53	8.13	18	14

- The matrix was normalised so that the sums of all the columns would add up to 1.
- The values in each row were then averaged to get the corresponding ratings

Table 7: Normalised comparison matrix

	Texture	Temperature	Soil pH	Rainfall	Drainage	Landcover	Altitude	Depth	average
Texture	0.05	0.02	0.04	0.10	0.18	0.02	0.02	0.21	0.08
Temperature	0.27	0.09	0.21	0.10	0.06	0.04	0.02	0.21	0.13
Soil pH	0.05	0.02	0.04	0.10	0.01	0.02	0.02	0.21	0.06
Rainfall	0.16	0.26	0.13	0.31	0.18	0.37	0.28	0.21	0.24
Drainage	0.02	0.09	0.21	0.10	0.06	0.02	0.17	0.02	0.09
Land covers	0.27	0.26	0.21	0.10	0.30	0.12	0.28	0.02	0.2
Altitude	0.16	0.26	0.13	0.06	0.02	0.02	0.06	0.02	0.09
Depth	0.02	0.03	0.01	0.10	0.18	0.37	0.17	0.07	0.12

Sum	1	1	1	1	1	1	1	1	1

- The weights were then computed for each of the questionnaires, and the average weights from the 4 questionnaires taken as the final criteria weights.

Table 8: AHP weights computation

Factor	quest 1	quest 2	quest 3	quest 4	average	% weights
Texture	0.08	0.09	0.17	0.13	0.12	12
Temperature	0.13	0.12	0.03	0.11	0.1	9
pH	0.06	0.06	0.22	0.05	0.1	10
Rainfall	0.24	0.23	0.17	0.28	0.23	23
Drainage	0.09	0.09	0.12	0.09	0.1	10
Land cover	0.2	0.2	0.14	0.11	0.16	16
Altitude	0.09	0.09	0.06	0.12	0.09	9
Depth	0.12	0.12	0.1	0.09	0.11	11
sum	1	1	1	1	1	100

3.7.2 Re-sampling and re-classification

The vector datasets were first rasterised, for all the datasets to be in a uniform format and for the rest of the analysis that required raster datasets only to be possible. The datasets requiring rasterization were the soil datasets as they were initially feature classes.

Due to the varying resolutions of the datasets, all datasets were re-sampled with respect to one of the dataset's resolution, for them to all have a uniform resolution. A uniform resolution would ensure smoother results.

They were all resampled to the Land cover dataset, at 30m resolution.

Re-classification was then done for each dataset, which involved changing the values of the raster criteria to suit preference/importance values for a particular tree species, in preparation for weighted overlay.

The reclassification values from 1 to a maximum of 8 were used to show the different levels of preference for the sub-criteria, with 1 being the most preferred, and preference decreasing with the increasing numbers.

The re-classified temperature maps for all the three species are as in figures… These are a sample of the maps of all the reclassified datasets. A total of 24 reclassified raster datasets (8 for each species) were obtained. Figure 22 below represents this, showing the re-classified criteria maps of temperature for each of the 3 tree species

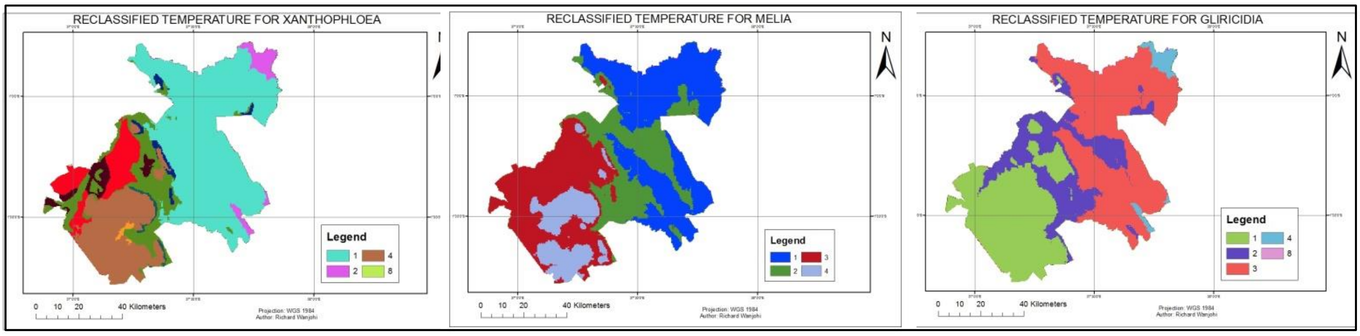

Figure 22: Re-classified temperature maps for the 3 tree species

3.7.3 Weighted overlay

This was used to overlay the several reclassified raster datasets for each tree species using a common measurement scale, weighing each according to its importance/ weight determined. It was done for each individual tree species suitability, and finally done on the suitability maps to determine the overall potential of afforestation. Figure 23 below illustrates the weighted overlay tool used in ArcGIS.

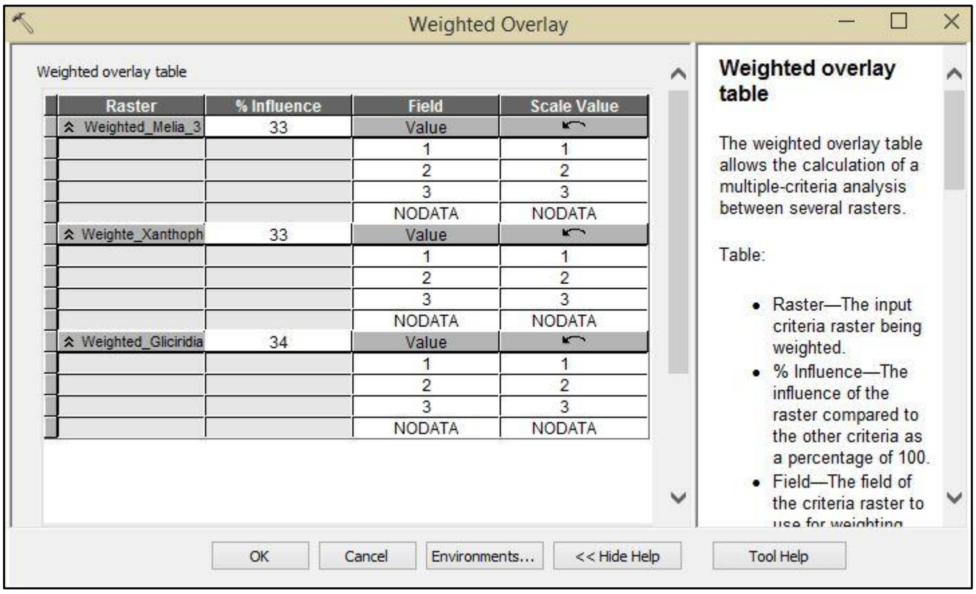

Figure 23: Weighted overlay tool in ArcGIS

CHAPTER FOUR: RESULTS AND ANALYSIS

4.1 Suitability areas for individual tree species

After the weighted overlay analysis was done for each species, the resulting suitability maps for each species were obtained.

4.1.1 Suitable afforestation areas for Acacia Xanthophloea

Figure 24 below shows the suitability of afforestation of Acacia Xanthophloea

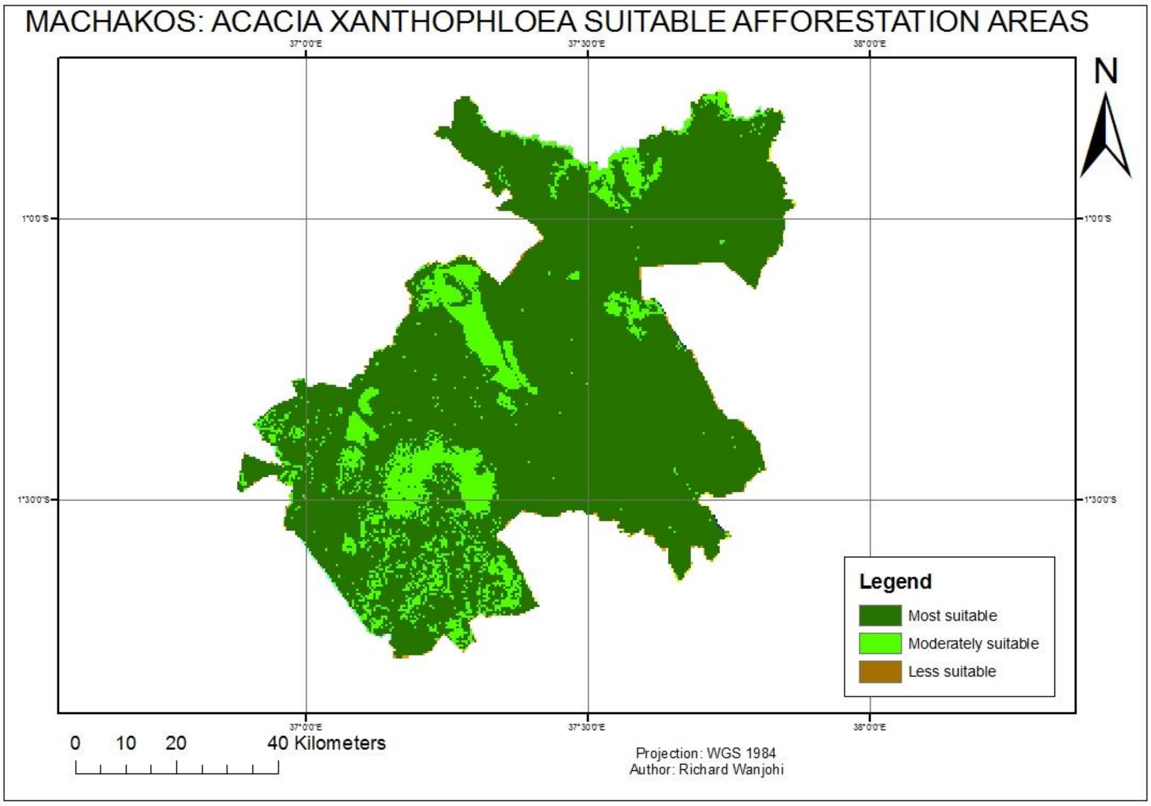

Figure 24: Suitability map for Acacia Xanthophloea

The weighted overlay for Acacia Xanthophloea produced two main suitability levels for the species within the whole county. These were the most suited and moderately suited regions. Their percentages and areas were as shown in table 9 below:

Table 9: Comparison of suitability classes for A. Xanthophloea

Suitability level	Percentage	Area(Ha)
Most suitable	86.2	513140
Moderately suitable	13.8	82150

4.1.2 Melia volkensii suitability

The suitability map for Melia Volkensii is as shown in figure 25 below:

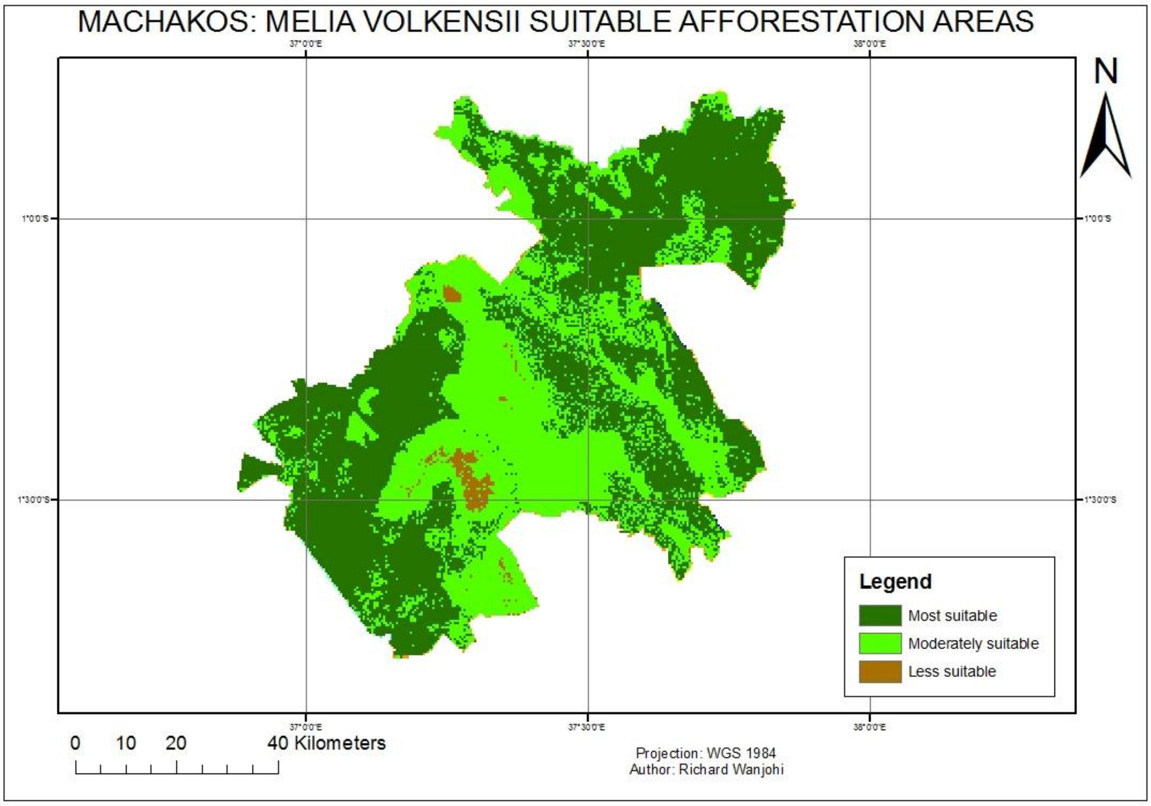

Figure 25: Suitability map for Melia Volkensii

Table 10 below shows the areas and ratios of the most suitable, moderately and less suitable areas for the species as gotten from the analysis.

Table 10: Comparison of suitability classes for M. Volkensii

Suitability level	Percentage	Area(Ha)
Most suitable	56.7	337529
Moderately suitable	42	250021
Less suitable	1.3	7740

4.1.3 Gliciridia sepium suitability

Table 11 below shows the comparison between suitability areas for the G. Sepium species as obtained from the map.

Table 11: Comparison of suitability classes for Gliciridia sepium

Suitability level	Percentage	Area(Ha)
Most suitable	20.9	124416
Moderately suitable	79	470279

Less suitable	0.1	595

The suitability map for the species is as shown in figure 26 below

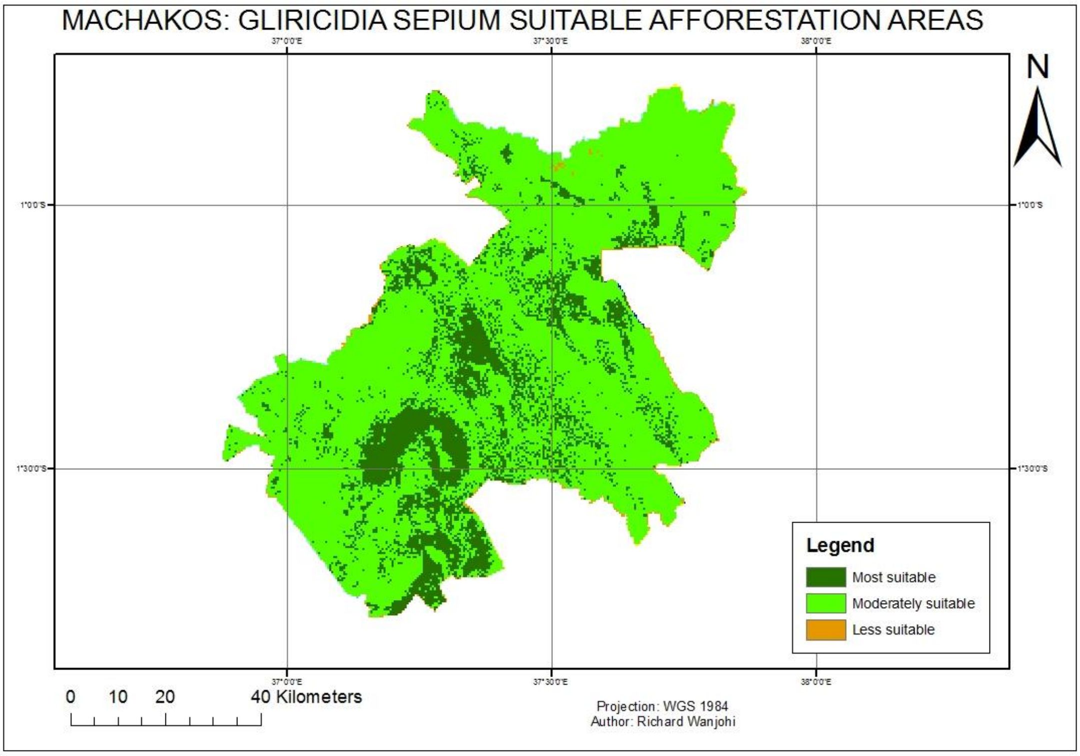

Figure 26: Gliciridia sepium suitability map

4.2 Comparison of each criteria's distribution with each species' suitability map

4.2.1 Rainfall

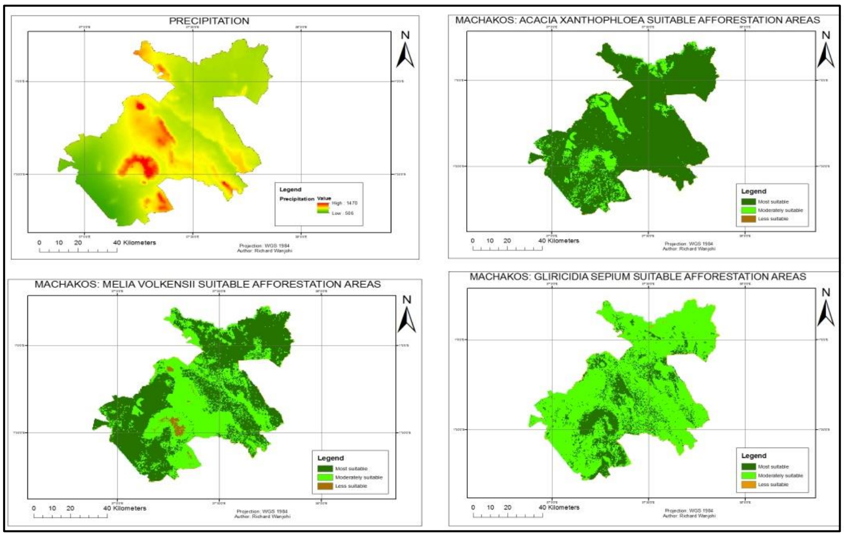

Figure 27: Comparison of species suitability with rainfall distribution

The Acacia species was seen to prefer the regions of lower precipitation more. The Melia species preferred the lower to medium (about 500mm to 1000mm per year) precipitation regions; those with higher precipitation being less preferred. The mostly preferred precipitation by the Gliciridia species was generally higher precipitation, as seen on figure 27 above.

4.2.2 Elevation

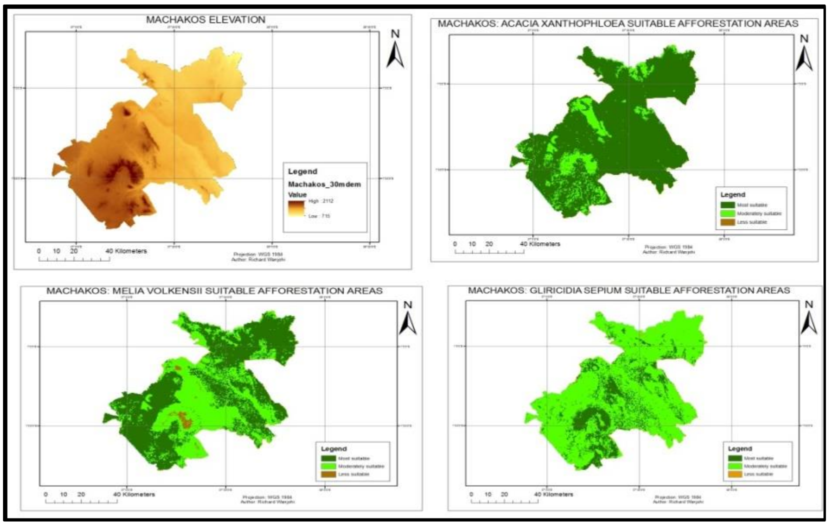

Figure 28: Comparison of species suitability with elevation

In comparison to elevation, the Acacia species was found to mostly prefer the lower to mid altitude regions, about 750m to 1500mabove sea level, when compared to the elevation map. The lower elevation regions were also preferred more by the Melia species. High altitude regions were mostly preferred by the Gliciridia species, as seen in figure 28 above.

4.2.3 Temperature

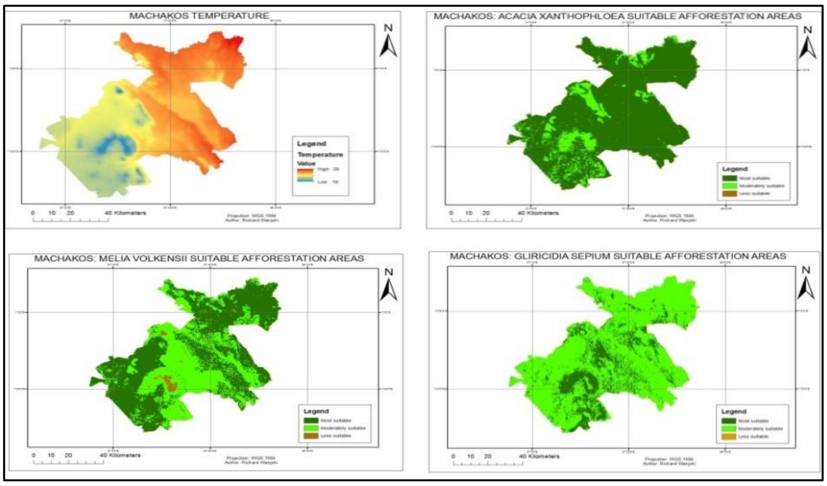

Figure 29: Comparison of species suitability with temperature

In comparison to temperature, the Acacia species was found to prefer all the temperature ranges within the study area. The Melia species was found to prefer the higher temperature zones. The Gliciridia species mostly preferred the lower temperature zones, around the central and highland parts of the map. This is illustrated in figure 29 above.

4.2.4 Soil pH

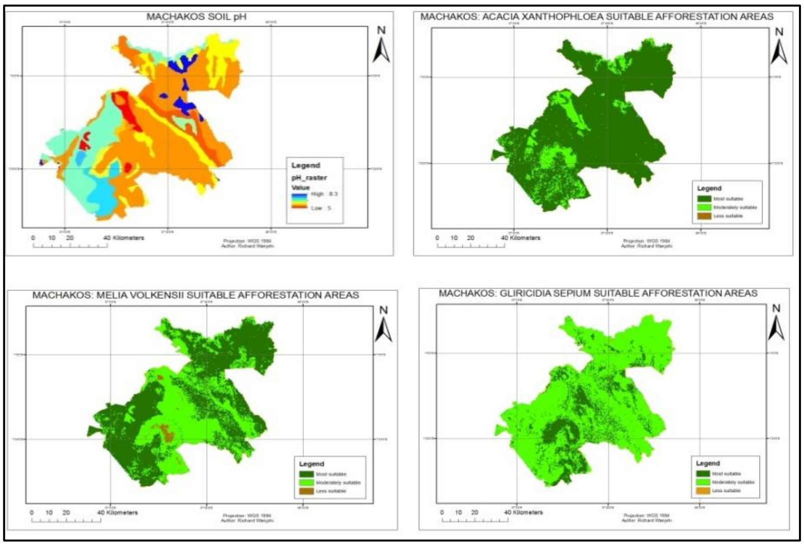

Figure 30: Comparison of species suitability with soil pH

The Acacia species was found to prefer a wide range of soil pH values, ranging from about 6 to 7.5. It however showed less preference for extremes of soil pH beyond the given range. The Melia species preferred regions with medium to high soil pH range, about 6 to 8. The soil pH mostly preferred by the Gliciridia species was low to medium, with values of about 5 to 6.5. This is illustrated in figure 30 above.

4.2.5 Soil depth

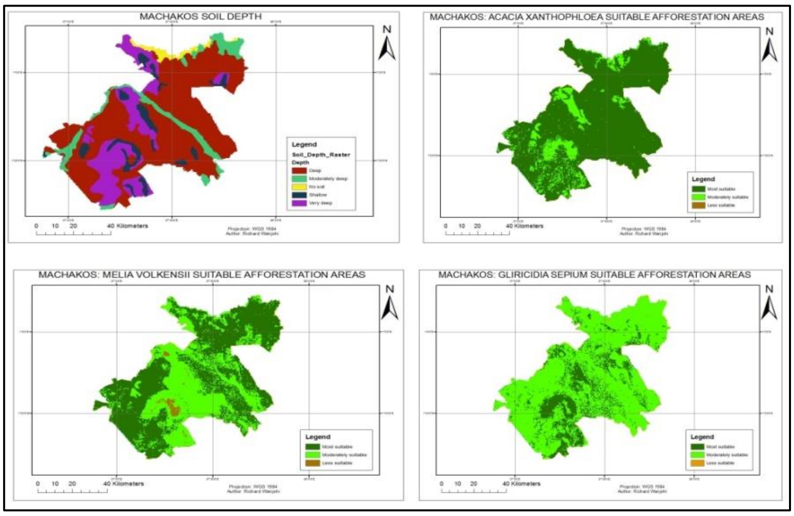

Figure 31: Comparison of species suitability with soil depth

A wide range of soil depth was preferred by the Acacia species, ranging from shallow to deep soils, with the very deep soils being less preferred. Deep and very deep soils were mostly preferred by the Melia species, with shallow soils being least preferred. The soil depth ranges in the region were all mostly preferred by the Gliciridia species, but with shallow soils being less preferred. This is as illustrated in figure 31 above.

4.2.6 Soil texture

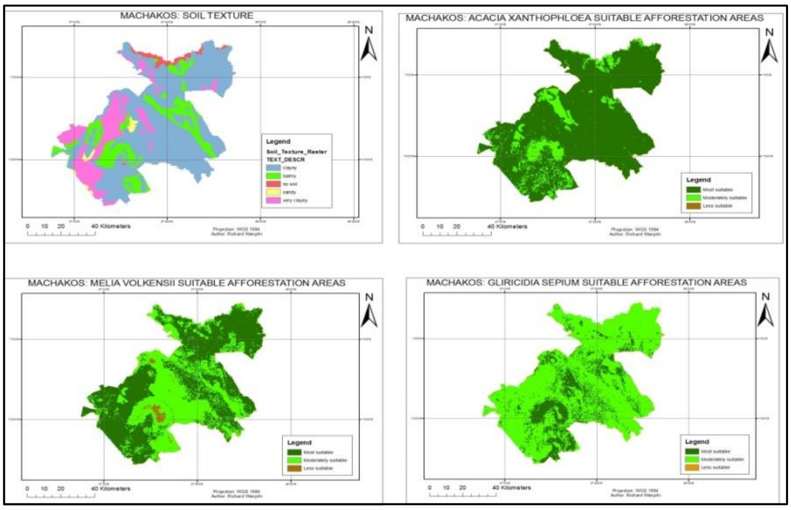

Figure 32: Comparison of species suitability with soil texture

The Acacia species was seen to prefer all soil textures, from sandy to clayey soils. It was also seen to prefer all the soil drainage levels in the area. All the soil textures from sandy to clayey were preferred by the Melia species. The soil texture most preferred by the Gliciridia species was loamy, with the other soil textures moderately preferred. Figure 32 above illustrates this.

4.2.7 Soil drainage

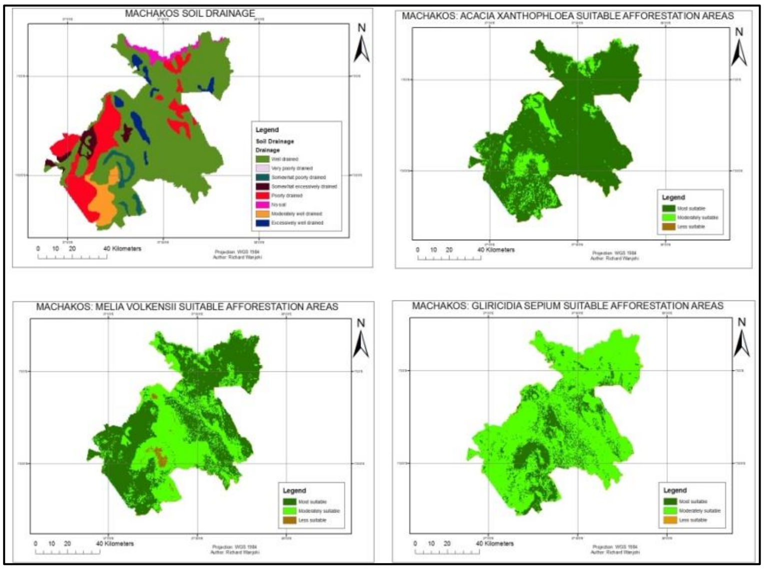

Figure 33: Comparison of species suitability with soil drainage

The Acacia species was seen to prefer all soil drainage levels. The Melia species also highly preferred all soil drainage levels, but excessively well drained soils were less preferred. The soil drainage mostly preferred by the Gliciridia species was excessively well drained to very well drained, with the well-drained drainage class being moderately preferred and poorly drained least preferred. Figure 33 above illustrates this.

4.2.8 Land covers

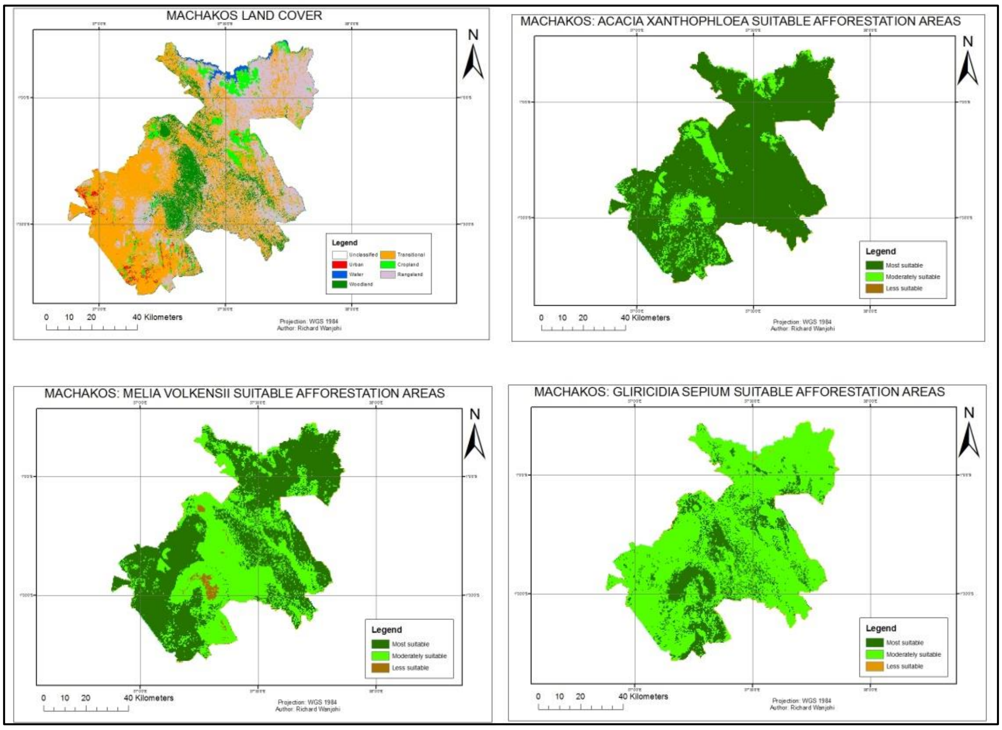

Figure 34: Comparison of species suitability with land covers

The land covers most preferred by the Acacia species were transitional land, range land and the lowland woodlands. The urban areas, cropland and water areas were preferred less. The land covers most preferred by the Melia species were transitional and rangeland, with woodlands and croplands being less preferred. The land covers most preferred by the Gliciridia species were woodland and cropland, as well as the rangelands in the higher altitude areas. This is illustrated in figure 34 above.

4.2.9 Agro-climatic zones

The Agro-climatic zones were not considered as a suitability criteria. However, the species suitability was compared to them, in order to show their most suitable agro-climatic zones. The Acacia species was found to have the potential to do well across all the agro-climatic zones III, IV and V of the county. The Melia species had its best potential in AC zone V, while the Gliciridia species best potential was in zones III and IV. These findings matched with the Agro-Climatic zoning of the species, considering the data availed by KEFRI and JIFPRO. This is illustrated in the figure below.

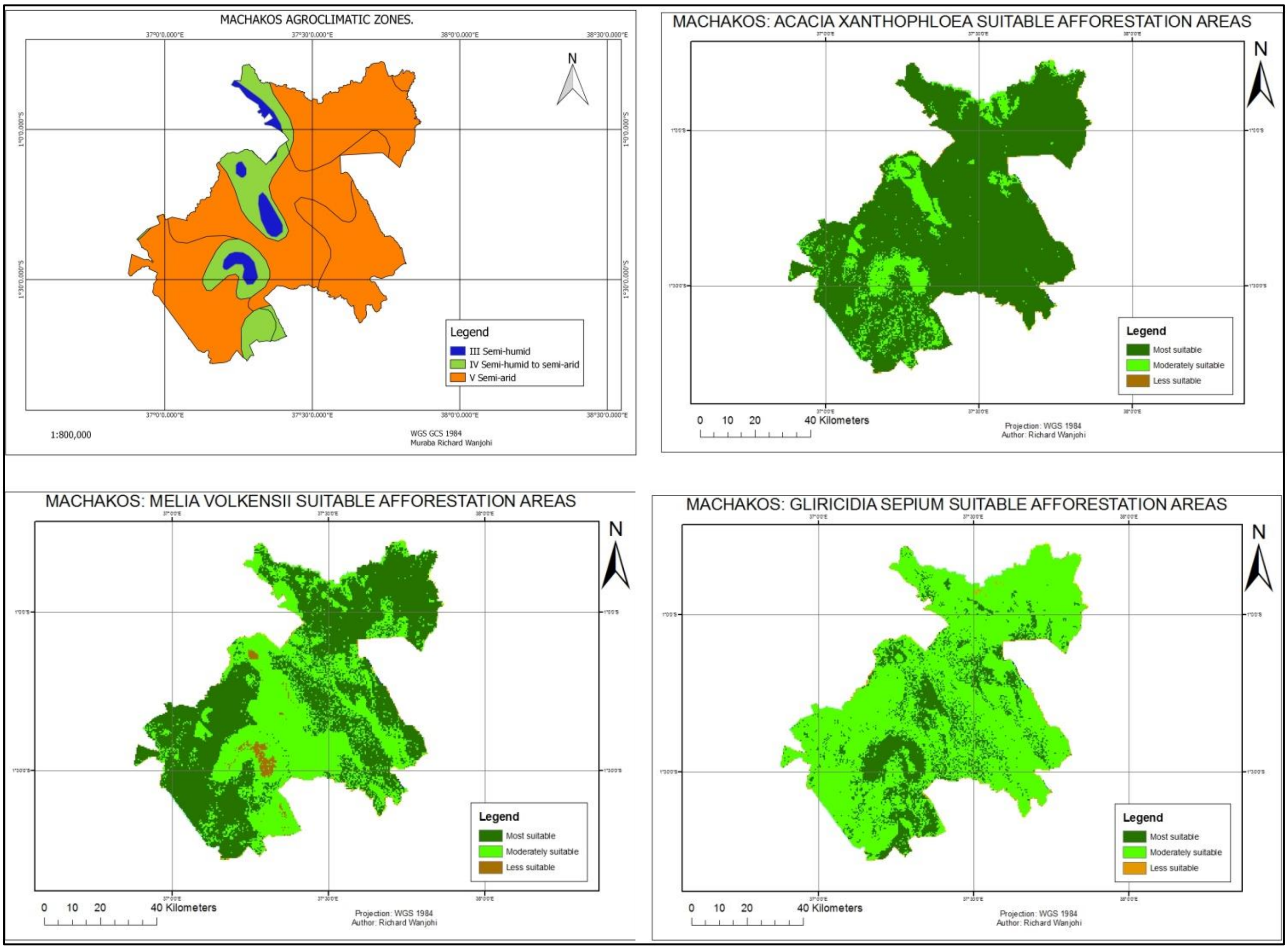

Figure 35: Comparison of species suitability to Agro-Climatic zones

4.3 Overall afforestation suitability and potential

The overall suitability and potential, determined by overlaying the suitability maps for each species with equal weights, was obtained, with the result as shown on the map in figure 36 below. The areas generated by the analysis were basically the most suitable and moderately suitable areas, in the percentages as shown in table 12 below.

Table 12: Overall afforestation potential

Suitability level	Percentage	Area(Ha)
Most suitable	64.6	384557
Moderately suitable	35.4	210733

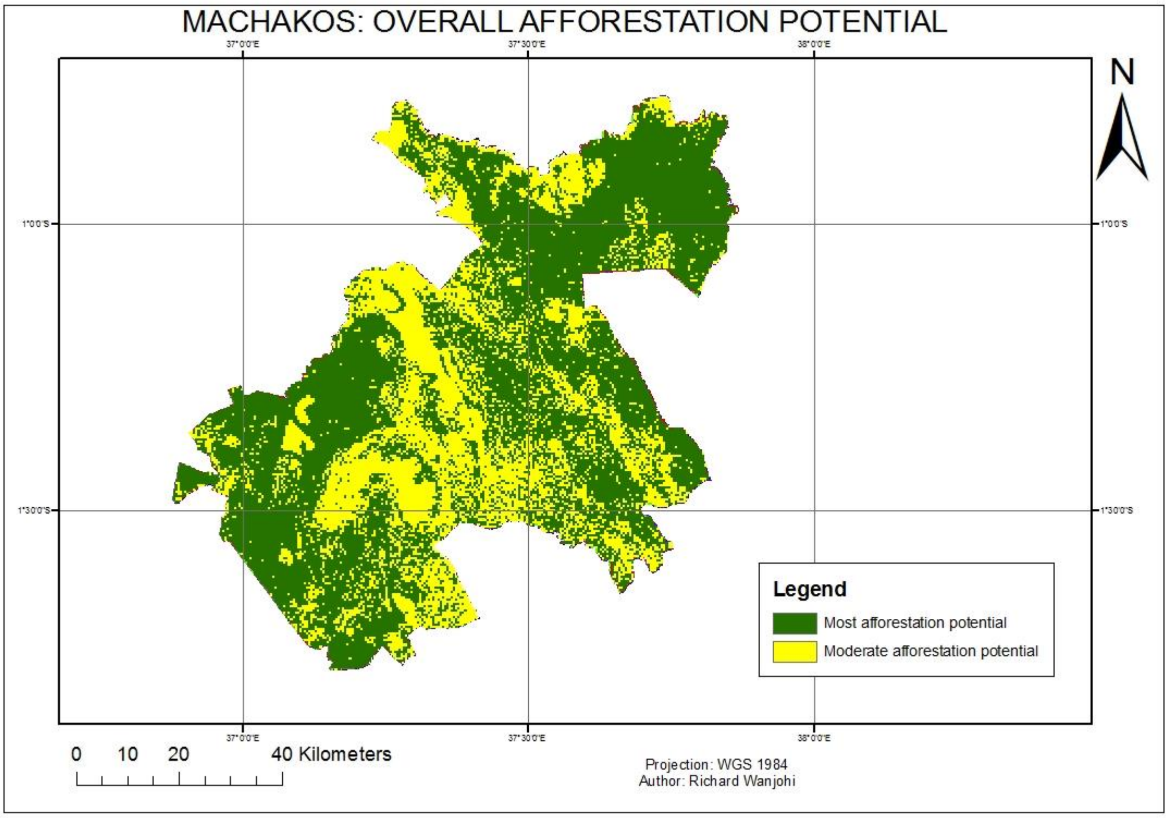

Figure 36: Map showing overall afforestation potential in Machakos for the 3 species

The overall suitability map was compared with the Agro-climatic zones map. This showed that agro-climatic zones IV and V had a high potential for afforestation. Figure 37 below illustrates this.

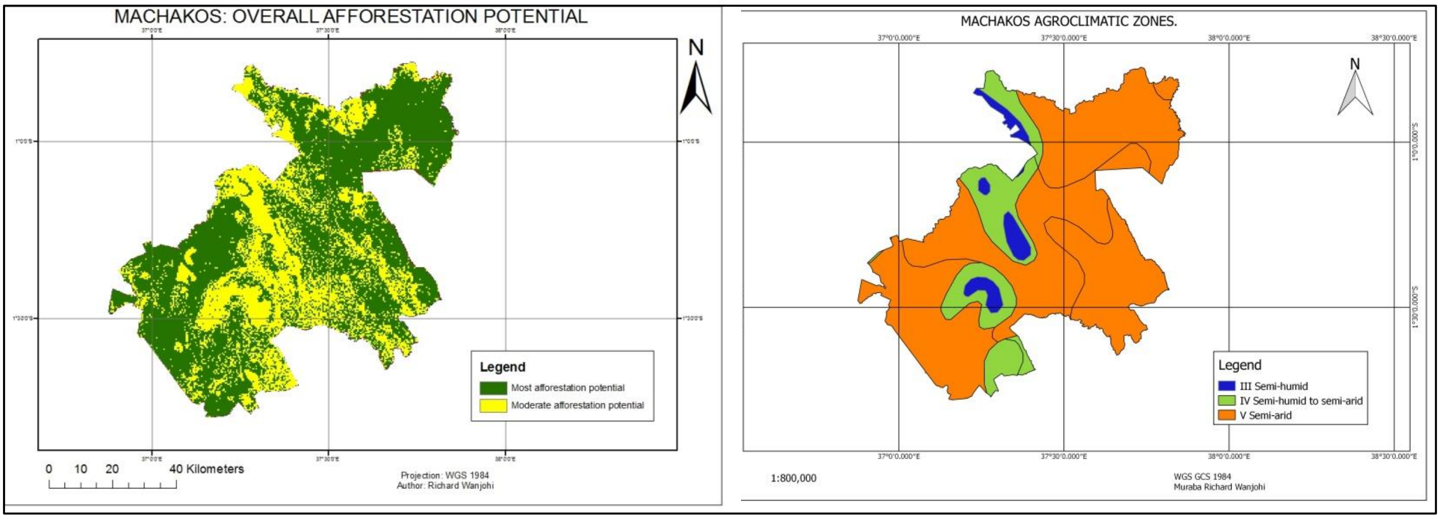

Figure 37: Overall afforestation potential comparison with Agro-climatic zones.

The suitability areas for each species were compared, tabulated and plotted, as illustrated in table 13 and figure 38 below.

Table 13: Comparison of suitability areas for all species and overall potential area

Species/ Area(Ha)	Acacia Xanthopholea	Melia Volkensii	Gliciridia sepium	Overall
Most suitable	513140	337529	124416	384557
Moderately suitable	82150	250021	470279	210733
Least suitable	0	7740	595	0

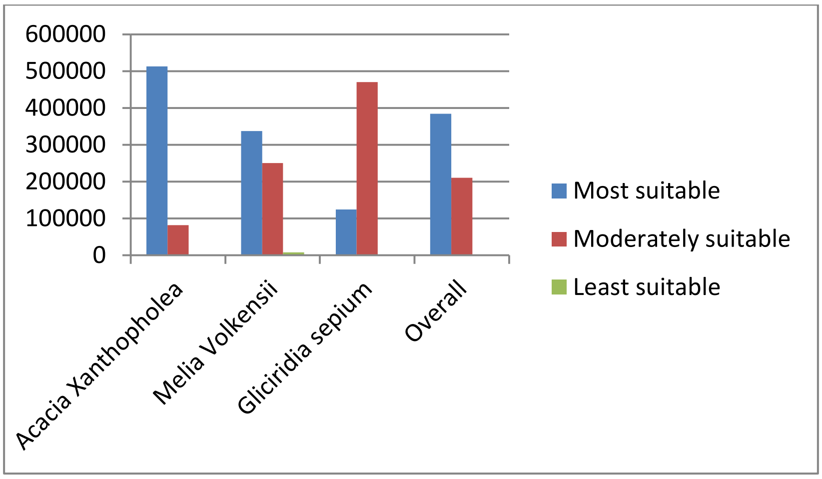

Figure 38: Chart showing suitability classes areas for each species and overall

As is visible from the chart, Acacia Xanthophloea had the largest most suitable area, with Gliciridia sepium having the least. Overall, the most suitable areas were more than the moderately suitable areas, while the less suitable areas are very minimal.

Thus, the results showed that there is a high afforestation potential for the 3 species within the study area, and this would reflect if more drylands tree species analysed, as they have largely similar characteristics. The area thus generally has a high potential for afforestation using drylands tree species.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The project work and analysis was successfully done and completed, with the objectives of the study being met. From the results, it was determined that Machakos county, being largely a semi-arid region, has a high potential for afforestation in these regions. As a result, it is possible and viable to conduct afforestation in semi-arid regions.

Moreover, it was determined that the Geospatial techniques of GIS and remote sensing, as well as multi-criteria decision making, can be successfully used to determine the potential and suitability of afforestation in a given area.

It was also determined that different drylands tree species could be successfully used for afforestation in the region, with different tree species being more suited for different regions, depending on the spatial distribution of the suitability criteria selected. Both indigenous and exotic tree species could be used, but indigenous species showed more potential for afforestation than the latter. Of the three tree species studied, the indigenous tree species, Acacia Xanthophloea and Melia Volkensii were found to be most suited.

The acacia species proved to be the most suited overall, with it having a potential of afforestation in the largest areas within the study area, and being suited to all the agro-climatic zones covering the region i.e. III, IV and IV. It could withstand the harsh semi-arid conditions, and also do well in the less harsh sub-humid regions of the county.

The Melia Volkensii species was also determined to be well suited for afforestation in the larger parts of the county, which are semi-arid, in agro-climatic zone V. It was found to be best suited to the low rainfall and high temperature regions that define a semi-arid region, and thus can be used successfully for afforestation in the study area and in other semi-arid regions of the country. However, from the results, it is less suited for areas with higher rainfall and altitude, and lower temperature.

Gliciridia sepium, a species exotic to the area, proved to be best suited to the areas with less harsh climatic conditions, i.e. the cooler and wetter regions, and higher altitude regions. It showed moderate to low potential in the regions with harsher conditions. It is thus a suitable afforestation species that can be considered for a sizeable area of the region.

Moreover, with the dominant land covers being found to be transitional and range land, the study area was thus determined to have large tracts available for afforestation of drylands tree species. Such land can be successfully used with minimal conflict of interests from the locals or the land owners.

5.2 Recommendations

Geospatial techniques of remote sensing, GIS and multi-criteria decision making should be considered for use, or continue being used, by agencies and parties involved in afforestation and its studies, such as the KFS and its country-wide branches, KEFRI, ICRAF, REDD, CDM and FAO. This is because the tools have proven to be powerful and very useful for this type of analysis.

The ongoing research work on forestry, including on tree species suited for different regions and their growth requirements, should continue being done by the organisations doing them, such as KEFRI and ICRAF. More data and findings on the tree species would be very helpful for future research studies.

Both indigenous and exotic tree species should continue being considered for afforestation in the area and the country at large, as both showed high potential for afforestation. Moreover, as the study was limited by time constraint, only 3 species were studied. It is thus recommended that in future, similar studies be done using many more tree species, which would be more beneficial.

The ongoing efforts by the government, government agencies and other organisations to sensitise the public on tree planting should continue and be intensified, in order to achieve the vision 2030 goal of 10% tree cover country-wide and for environmental conservation. This is also owing to the high potential for afforestation seen.

A challenge was encountered with the KMD rainfall and temperatures data, since for the study area, only data for one ground weather station was available. This was insufficient for use in the study as many points were required for surface interpolation, and thus satellite climate data had to be downloaded and used. It is thus recommended that data for more weather stations be available for all the KMD weather stations in the county and country wide, with the non-functional ones being renovated, to enhance and improve data provision for future studies.

However, owing to the high accuracy and correlation between the satellite and ground data, in cases where ground data is insufficient, satellite data may be successfully used as a substitute.

It is also recommended that the online shapefiles data on Kenyan soils be updated in sync with the complete data from the KENSOTER database by ISRIC, owing to the numerous gaps in some crucial soil characteristics in some regions, with the study area being largely affected.

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APPENDICES

APPENDIX I: Introductory Letter for Data Collection from KFS.

JOMO KENYATTA UNIVERSITY

OF

AGRICULTURE AND TECHNOLOGY

DEPARTMENT OF GEOMATIC ENGINEERING & GEOSPATIAL INFORMATION SYSTEMS (GEGIS)

P.O BOX 62000. CITY SQUARE, NAIROBI, 00200. KENYA.

Tel: (067) 52711, 52181-4. Fax: (067) 52164

gegis@jkuat.ac.ke

Our Ref: JKU/2/34/138/2 **6th October, 2015**

The Ecosystems Officer,
KENYA FOREST SERVICE – MACHAKOS
P.O. BOX 2-90100
MACHAKOS

Dear Sir/Madam,

RE: REQUEST FOR SUPPORT WITH RESEARCH PROJECT DATA

Muraba Richard Wanjohi Reg. No. EN281-0261/2010 is an undergraduate student at the Department of Geomatic Engineering & Geospatial Information Systems, JKUAT. He is currently carrying out his final year research project entitled "***Afforestation Potential and Suitability Analysis in Arid and Semi-arid Lands".***

To enable him to undertake this project successfully, we kindly request for your assistance with the data he requires. Your assistance is highly appreciated.

Eunice Nduati, For:
Dr. Thomas Ngigi.
Chairman, Department of Geomatic Engineering & Geospatial Information Systems (GEGIS)

JKUAT is ISO 9001:2008 Certified
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APPENDIX II: QUESTIONNAIRE FOR AHP

QUESTIONNAIRE ON ANALYTICAL HIERACHY PROCESS FOR SUITABLE AREAS FOR AFFORESTATION

Prepared by:

Muraba Richard Wanjohi, a 5TH year student of Geomatic Engineering and Geospatial Information Systems at Jomo Kenyatta University of Agriculture and Technology, Juja.

Introduction

The document is a questionnaire that will be useful for my final year project titled "Potential and Suitability analysis of afforestation in arid and semi-arid areas", case of Machakos county. It will be important in determining weights/ importance of factors to use in the Analytical Hierarchy Process (AHP), which I will be using for the suitability analysis.

Your assistance in filling it is very highly appreciated.

How to fill the questionnaire

A value 1,3,5,7 or 9 is assigned to the spaces (check boxes), to show the importance of a factor in comparison to the other factors. Each factor is eventually compared to every other factor.

If the factor on the left hand side is more important than that on the left hand side, then the check box on the left is filled with a value 1,3,5,7 or 9, depending on its weight or importance over the other, leaving the check box on the right blank. Likewise, if the factor on the right side of the table is more important, then the check box on the right is filled with a value 1,3,5,7 or 9, leaving the left check box blank.

If the factors are of equal importance, then a value of 1 is assigned to both check boxes to show equal importance of the factors.

Below are the importance/ weight levels for the analysis factors, represented by values 1,3,5,7 and 9.

1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very strong or demonstrated importance
9	Extreme Importance

An example on how to fill:

Soil		3	Water
	1	1	Rainfall
	5		Temperature

The questionnaire:

Factor 1	Left and right check boxes		Other factors
Mean Annual Rainfall			Mean Annual Temperature
			Soil pH
			Soil Texture(e.g. clayey, sandy, loamy)
			Soil Drainage/ Soil surface drainage
			Land cover(e.g. forests, bare land, farmland)
			Altitude/ Elevation
			Slope
			Soil depth
			Proximity/ Nearness to water bodies

Mean Annual Temperature			Soil pH
			Soil Texture(e.g. clayey, sandy, loamy)
			Soil Drainage/ Soil surface drainage
			Land cover(e.g. forests, bare land, farmland)
			Altitude/ Elevation
			Slope
			Soil depth
			Proximity to water bodies

Soil pH			Soil Texture(e.g. clayey, sandy, loamy)
			Soil Drainage/ Soil surface drainage
			Land cover(e.g. forests, bare land, farmland)
			Altitude/ Elevation
			Slope
			Soil depth
			Proximity to water bodies

Soil Texture			Soil Drainage/ Soil surface drainage
			Land cover(e.g. forests, bare land, farmland)
			Altitude/ Elevation
			Slope
			Soil depth
			Proximity to water bodies

Soil Drainage/ Soil surface drainage			Land cover(e.g. forests, bare land, farmland)
			Altitude/ Elevation
			Slope
			Soil depth
			Proximity to water bodies

Land cover			Altitude/ Elevation
			Slope
			Soil depth
			Proximity to water bodies

Altitude/ Elevation			Slope
			Soil depth
			Proximity to water bodies

Slope			Soil depth
			Proximity to water bodies

Soil Depth			Proximity to water bodies

Name (optional):………..

Occupation (optional):……

Date:………

Signature:…….