ASSESSMENT OF THE EXTENT OF USAGE AND QUALITY OF TIMBER AS A BUILDING MATERIAL IN KIRINYAGA COUNTY

JAMES MITHAMO MUTHIKE

MASTER OF SCIENCE

(Construction Engineering and Management)

JOMO KENYATTA UNIVERSITY OF

AGRICULTURE AND TECHNOLOGY

2016

Assessment of the extent of usage and quality of timber as a building material in Kirinyaga County

James Mithamo Muthike

A thesis submitted in partial fulfillment for the degree of Master of Science in Construction Engineering and Management in the Jomo Kenyatta University of Agriculture and Technology

2016

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature: --------------------------- Date: --------------------------------

James Mithamo Muthike

This thesis has been submitted for examination with our approval as university supervisors.

Signature: --------------------------- Date: --------------------------------

Prof. Christopher Kanali

JKUAT, Kenya

Signature: --------------------------- Date: --------------------------------

Eng. Charles Kabubo

JKUAT, Kenya.

DEDICATION

I dedicate this work to my beloved mum, Nancy M. Muthike, for her care, unconditional motherly love and selfless service even when circumstances would have dictated otherwise.

ACKNOWLEDGEMENT

This study has been possible as a result of input of many individuals. I am particularly grateful and intellectually indebted to my two supervisors Prof. Christopher Kanali (JKUAT) and Engineer Charles Kabubo (JKUAT) for their valuable guidance and mentorship during the entire study period. Dr.Joseph Githiomi (Director of Kenya Forestry Research) institute was very receptive to me when I approached him seeking access to use their facilities. He went out of his way not only to accept my request but also to provide me with his personal books. I thank him for his kindness to me. I am also grateful to members of staff of KEFRI and particularly Mr. Dominic Mikile (chief technologist) who offered me unwavering support and facilitated me to prepare and carry out the tests. I also thank University of Eldoret wood science students Irene Mwanisa and Nancy Ong'uti who also assisted me to prepare and test the specimens.

My sincere gratitude also goes to Dr. Henry Kibet Rotich (KEBS), Korero (KEBS) and Ben Ochieng (KEBS) all of whom assisted me in one way or another to complete this research study. This section would be incomplete without mentioning Dedan Kimathi University of Technology (DeKuT). Prof. Eng. P.N. Kioni, Prof. Muthakia and the members of the training committee who extended to me a scholarship to study this programme. I appreciate and feel indebted by your generosity. I thank my family members and especially my wife Nancy Mithamo for her patience and support during the entire study period. I finally thank God for his grace, love and mercies without which I could have despaired on the way.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BS: British Standards

BSI: British Standards Institution

DeKuT: Dedan KimathiUniversity of Technology

FAO: Food and Agriculture Organization

ISO: International Organization for Standardization.

JKUAT: JomoKenyattaUniversity of Agriculture and Technology

KEBS: Kenya Bureau of Standards

KEFRI: Kenya Forestry Research Institute

KFMP: Kenya Forestry Master Plan

MDG's: Millennium Development Goals

NCA: National Construction Authority

SMARTEC: Sustainable Materials Research Technology Centre

UNEP: United Nations Environmental Programme

UNFCCC: United NationsFramework Convention on Climate Change.

UNFF: United Nations Forum on Forests

ABSTRACT

Kenyan population has been steadily rising over the years which has in turn exerted pressure on available natural resources. As a result of increase, the demand of quality construction timber has outstripped supply. This shortage of quality construction timber constituted the problem to be addressed. The objective of this study was therefore to determine the extent of usage and assess the physical and structural strength of timber as a building material in Kirinyaga County. Descriptive cross-sectional design and experimental research designs were used to carry out this study. Under descriptive cros-sectional design, open ended questionaires were administerd to contractors, county forest officers, saw millers and timber yard owners to collect the desired information. Data was also collected through direct observation and interviews. Under experimental research design, tests on timber derived from selected tree species i.e *cordia Africana*, Eucalyptus, Cypress, *Grevilea robusta* and Pine were done so as to determine their mechanical properties. Non-probabilistic sampling methods were used. Results from this study show that 15% of land mass of the county is covered with trees. Unfortunately, the 15% tree cover does not translate to timber sufficiency as most of it is sold to neighbouring counties and other major towns. Apart from construction, wood is also extensively used as electricity transmission poles and wood fuel. The high moisture content percentage contained by timber in this region contributes significantly to lower mechanical strengths. Sixty-eight (68) percent of the sampled species had a moisture content of more than 20%. The findings show that there exists a correlation between increase in population and higher demand of timber. Exploration on use of bamboo, use of alternatives such as steel and composites and prudent use of available timber are some of the recommended measures to counter shortage of timber. For further research, it is recommended that a research on timber with moisture content of 12% and below be done. The scope should also be widened to cover species not done.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The latest statistics of the world population survey by United Nations, Department of Economic and Social affairs, Population Division (2015), indicates that the world population had reached 7.3 billion by mid-2015 with this figure being projected to reach 9.7 billion by the year 2050 and 11.2 billion by the year 2100. Data from Kenya National Bureau of Statistics (Facts and Figures, 2015) shows that the Kenyan population stood at about 42 million people. According to Kenya population and housing census report of 2009, Kirinyaga population stood at about 528 thousand thousand people.

The above stated statistics shows that there is a sustained increase in population as time elapses. Lusigi (1994) notes that with the increase in population, the pressure on the natural resources in many regions has continued to intensify. The forests in Kenya, like in other developing countries, have been declining rapidly thus adversely impacting biodiversity, the climate, rivers and streams, wildlife, and human population (Kimani, 2013). Forests are critical in development of any state since there are a wide range of benefits derived from forests. Steiner (2011) notes that "sustainable development is not a choice but an imperative and the only course possible in a 21st century world of rising populations and environmental risks. A transition to a green economy will happen, either by design or by default''. Forests do provide a foundation for our development. McAlpine(2011) notes that,"every single one of us has our physical, economic and spiritual health strongly tied to the health of our forest ecosystem.The people and our collective action is the key to a sustainable future".

Some of the benefits derived from proper management of our forests include mitigation of climate change. The forests also convert carbon dioxide into oxygen while still building biomass and acting as storage containers for carbon. They do store a quarter of all carbon on earth (more than all the carbon in the atmosphere), significantly mitigating greenhouse gas emissions (UNFCCC, 2010). Human kind also benefits from the ecosystem services which includes products such as clean drinking water and processes such as the decomposition of the wastes. These ecosystem services were categorized by the United Nations 2004 Millennium Assessment into four broad categories, i.e., provisioning (production of food and water), regulating (control of climate and disease), supporting (nutrient cycles and crop pollination) and cultural (spiritual and recreational benefits).

In many developing countries, more than 80% of total energy consumed comes from forests (Biodiversity synthesis, 2005). Over one third of the world's population (or 2.4 billion) relies on wood and other plant based fuels for cooking and heating (International Energy Agency, 2002). Forests cover one third of the earth's land mass performing vital functions around the world. These green lungs of the earth are disappearing at an alarming rate of approximately 13 million hectares per year for the period 1990-2005, (FAO, 2010). Kenya on its part had 3,640,000 hectares under forest in 1990 but this has declined to 3,504,000 hectares in 2000 and 3,422,000 hectares in 2005(Global Forest Resources Assessment, 2005). Kenya has one of the most lucrative timber markets in the great lakes region with supplies being sought from neighboring countries such as Tanzania, Uganda, Rwanda and the Congo (Sammy, 2007). Apart from Government gazetted forests being the source of timber, another source is the smallholder farms. In these farms, farmers grow trees either in woodlots or through agroforestry practices and then sell them to buyers who in turn cut and convert to timber.

Timber is a by product of trees and is one of the earliest materials used in building and still plays an important role in general building and particularly in flooring and roofing. If correctly used, it has extremely good durability. Timber is derived from diferent tree species. The botanical classification divides timber into hardwoods (Angiosperms) and softwoods Gymnosperms). Hardwoods are from broad- leaved trees most of which are deciduous and are used for furniture and fixtures. Softwoods on the other hand are from conferous trees and are most commonly used for construction elements and framing (Chudley *et al*, 2011). The advances in the field of adhesives and fabrication techniques combined with increased understanding of timber properties have enabled it to be used at quite high stress levels hence increasing enormously its potential as a material (Taylor, 2002). The building industry is one of the largest consumers of raw materials in the world today after food production and the guiding principle for the future should be a drastic reduction in the use of raw materials. Kenya's Vision 2030 blue print which was launched on October 2006 is hinged on three key pillars,i.e., economic, social and political. Under the social pillar, the country aims to be a nation living in a clean, secure and sustainable environment by 2030. The short term goal was to increase forest cover from 3 to 4% by the year 2012 and also lessen by half all environmental related diseases. Under the strategy, environmental conservation for better support to economic pillar flagship projects and for purposes of achieving Millennium Development Goals (MDG's) was to be undertaken. Further, under the same pillar, the vision for housing and urbanization was to be an adequately decently housed nation sustainable in an all-inclusive environment. The ultimate goal by the year 2012 was to increase the annual production of housing units from 35,000 annually to over 200,000. On the economic pillar, economy was to grow from 0.6% in 2002 and rise to a sustainable figure of 10% till the year 2030.

The need to grow the economy at a sustainable figure of 10%, the need to provide decent housing for the urban population coupled with population explosion has led to a more increased demand for timber. A survey conducted and reported in one of the dailies (Mutai, 2010) indicated that the country spends more than US $37.5 million annually on timber imports compared to US $ 62,000 in 1999 so as to meet the rising demand that stood at 38 million cubic metres annually. The quality aspect of timber is governed by a consideration of many factors that affect quality. These factors include density, rate of growth, moisture content, slope grain, knots, section size and creep. Quality control is necessary to check and monitor the production so as to lead to a product of consistently satisfactory standards. It is imperative to protect our natural forests and increase tree cover in our farmlands in an effort to secure the well being of the future generations. Benefits derived from conservation of forests and usage of forest products to mankind are enormous and infact formed the basis of carrying out this study.

Where strength and durability are key factors, timber is specified by either a strength class or a combination of timber species and strength grade. In addition to strength class or grade, the specification should also include lengths and cross-section sizes, surface finish or tolerance class, moisture content and any preservative or special treatments (Arthur , 2010). Kirinyaga County, which is the focus of this study, has a tree cover of 15% against that of Kenya which currently stands at 2% (Kirinyaga County Forest Office, 2012). Against this background, the County would have been self-sufficient with its timber requirements but one has to appreciate the fact that due to demand from other regions in the country, most of the timber from this county is sold to these regions. Further, the five tea factories in the region also consume a large amount of timber for their fuel in tea processing. From the collected data, each of the five factories consumes more than 20 tons of wood yearly. These factors coupled with an ever increasing population leaves the demand being higher than the supply and hence a shortage is experienced.

1.2 Statement of the Problem

The demand of construction timber in Nairobi and other major towns which neighbour Kirinyaga County has been fuelled by an improving economy as a result of economic strategies such as Vision 2030. According to Statistics (Population and Housing Census Report, 2010), the number of new buildings constructed in major urban centers has increased by about 150% over the past seven years from only 1,178 units completed in 2003 to a mammoth 2936 units completed in 2009. Kenyans also use a bigger chunk of forest products for other purposes other than construction works. For example, the projected wood demand in high and medium potential districts by the year 2020 are as follows: firewood – 15,593,000m^3, wood for charcoal - 10,972,000 m³ and poles – 2,153000 m³ against a total demand of 30,679,000 m³ (Kenya Forestry Master Plan, 1994).

In normal circumstances, the agroforestry systems/small holder timber farms together with the governments gazetted forest plantations supplement each other in provision of national timber needs. In Kenya, this scenario has not been the case since the banning of logging in the government forests in the year 2000. The aftermath of this ban has been over reliance of timber produced from smallholder and private farms which rarely meet the national timber demands. Importation of timber from our neighboring countries such as Tanzania, Rwanda, Uganda and as far as Congo has also supplemented what is available locally though at prohibitive costs.In Kirinyaga County, the current tree cover stands at 15%while that ofthe entire country stands at 2% (County forest office, 2012) against a global recommendation of 10%. Though the tree cover stands at 15%, most of the county's timber products are sold and consumed by other counties which possess a deficit. This scenario always leaves the demand being higher than the supply.

Checking through the timber yards, built up structures and carpentry and joinery workshops, there was evidence on limited use of sound structural timber for construction purposes. Camphor (*Ocotea usambaren*) and large-leafed cordia (*cordia africana*) and cypress are some of the species suitable for structural timber. The use of poor quality timber leads to reduced lifespan of the structure and additional renovation/replacement costs. Again, through cross checking on the timber yards and observation, there exists a trend of cutting immature trees. The consequence of use of this type of timber is to have an end product with reduced strength. The quantity of timber derived from these trees is small and hence reduced economic returns. The unavailability of quality timber for construction, the cutting of immature trees for conversion to timber and the demand of timber being higher than supply constitutes a problem which formed the basis of this study.

1.3 Objectives

1.3.1 General Objective

The general objective of this study is to assess the extent of usage and quality of timber as a construction material in Kirinyaga County.

1.3.2 Specific Objectives

1. To determine the extent of usage of timber as a construction material in Kirinyaga County.
2. To assess the physical and structural strength of timber as a construction material in Kirinyaga County.

1.4 Research Questions

1. Is there increased usage of timber in Kirinyaga County which has led to demand far much outstripping supply?
2. Does the timber harvested for construction within Kirinyaga County meet the required physical and structural specifications as specified by Kenya Bureau of Standards specifications?

1.5 Justification

The following reasons were used as the basis to justify carrying out of this study. To start with, there is an ever increasing population in Kirinyaga County, in Kenya and the world at large. A balance between demand and supply will create room for trees to mature which will further lead to quantitive and qualitative supply of the product. The quantitive and qualitative aspects brings about economic benefits for Kirinyaga residents on board and the entire country at large. The processing of immature trees is a phenomenon gaining root in Kirinyaga County partly due to dwindling economic returns from traditional cash crops such as coffee and tea coupled with lack of adequate knowledge on the economic benefits derived from processing mature trees.

With a high demand of sawn timber, the implication of this practice is a reduction in the volume of processing mature trees and consequently a compromise on the quality aspect. It cannot be gainsaid that qualitative timber products lead to durable structures which in turn saves on replacement/renovation and maintenance costs. The results of this study will be useful in enhancement of production of both quantitive and qualitative timber.

Secondly, to develop, Kenya requires a well-planned and thought out infrastructure in terms of rural and urban housing scheme as envisaged in the vision 2030. For this dream to come true, an increased demand of qualitative timber must be met and should be met in a sustainable manner so that we do not provide for the current generation by compromising the needs of the future generations. To achieve the vision, the people of Kirinyaga have an opportunity to satisfy the ready market. The study provides an in-depth analysis of the extent of usage of timber and its availability within the region and hence can be used to provide a road map on what needs to be done to satisfy timber demands within the county and at national level.

Finally, the tests on mechanical strengths revealed the structural strength of timber. Also, the visual inspection to check the timber defects showed the occurrence of common timber defects. The results of this study will be useful in making informed decisions in regard to structural performance of the timber processed from trees in Kirinyaga County.

1.6 Scope of the Study

This research study has been carried out at Kirinyaga County. The focus of the study was on the extent of usage, quality and structural performances of timbers derived from the county. On the extent of usage, issues of demand versus supply were critically analysed through literature review and also through the data collected in the field. The availability of timber for construction purposes was also dealt with through data collected from contractors, saw millers, timber yard owners and county forest officers. The method of data collection was through questionnaires and observation.

In regard to quality and structural performances, various mechanical strengths of defect free timber were tested. These tests included static bending, shear strength, janka hardness, moisture content and compressive strength. Also, through visual inspection, occurrences of various timber defects were identified. Timber processed from five tree species which was readily available in the market were; Cypress, Eucalyptus, Pine, *Grevillea robusta* and *Cordial Africana*.

1.7 Limitations

The study limited itself to available timber species and testing facilities. Species such as *cordia Africana*, eucalyptus, Cypress, Pine and *Grevillea robusta* were investigated. The test procedures and testing machines/apparatus for some of the properties such as slope of the grain and creep were not readily available in some institutions such as KEFRI and KEBS. Further, samples were taken at specific major locations in an effort to reduce costs. Those stations were; Kagumo town in Kirinyaga Central Constituency, Sagana town in Kirinyaga West Constituency, Kianyaga town in Kirinyaga East Constituency and Ngurubani town in Kirinyaga South Constituency.

CHAPTER TWO

LITERATURE REVIEW

2.1 Extent of Usage of Timber as a Construction Material

2.1.1 Demand of Timber for Construction

Timber is product of wood. Wood is a renewable, durable and versatile material that has been used for millennia all over the world (Dawes, 2009), Wood and wood based products have for a long time had a wide variety of applications ranging from construction and furniture making to paper production and heating. Worldwide, the demand for wood, especially fuelwood has been on the increase and demand is higher than supply, for example, Owoyeni *et al.* (2010) notes that the demand for wood for various purposes has put serious pressure on Nigeria's forest.

In Kenya the demand of sawn wood is projected to grow from 203,000 m^3 in 1990 to 262,800 m^3 in 2020 (Kenya's Forestry Master Plan, 1994). According to Kenya Forest Policy – Revised on 20th February 2014, Ministry of Environment, Water and Natural Resources, a key challenge facing the wood products sub-sector is unsustainable extraction which exceeds production, leading to degradation of forests particularly in community and private lands. Other challenges include inefficient conversion, low value addition methods leading to wastage and thereby exacerbating the unsustainable wood supply scenario.

Since 2002, Kenya has taken major steps in terms of economic growth rate. Under the Vision2030 strategy, there are major infrastructural projects outlined under the economic and social pillars. Among them is the provision of decent housing for the urban population. These infrastructural projects require timber as a construction material and hence this is a trigger factor for a higher demand of the material. Other factors which contribute to timber shortage are the conditions of production which have changed as a result of increased greenhouse effect, thinner ozone layer and effects of acid rain. The effects of greenhouse gasses in the atmosphere are global warming, climate change, ozone layer depletion, sea level rise and adverse effects on biodiversity. Acid rain causes stunted growth on trees and consequently death of forests. The demand of housing in Nairobi and other major towns has led to an increase of construction projects forcing the country to turn to Democratic Republic of Congo (DRC) for timber supplies. The shortage has contributed to negative effects such as price increases (Mutai, 2010).

The pressure on the natural resources in many regions has continued to intensify as a result of increase in population (Lusigi, 1994).The high rate of declining of forests in Kenya just like in other developing countries has impacted negatively on biodiversity, the climate, rivers and streams, wildlife, and human population in the following ways; Forests play an important role in regulating the Earth's temperature and weather patterns by storing large quantities of carbon and water. Forests also act as habitats for many species and these species are often unable to live in habitats that remain after forests are depleted. The rate of forest loss in Kenya was about 15,000 hectares per year (Ngigi & Tateishi, 2004). In 1990, Kenya had 3,640,000 hectares under forests with this figure declining to 3,504,000 in 2000 and 3,422,000 hectares in 2005 (Global Forest Resources Assessment, 2005).This rapid deforestation is as a result of increased demand for agricultural land due to increase in human population combined with a growing per capita consumption, widespread poverty and ways of forest management (Global Forest Resources Assessment, 2005).

Construction materials need to be sustainable. Timber as a construction material will only be sustainable if it is drawn from a source that is renewable so that it is replaced fast or faster as it is used and does so in an acceptable time span. For this to be true, part of a cycle will have to be formed. Many materials do not meet these constraints but timber does provided the total tree stock is constant such that wood is harvested at the same rate as it is grown. Unfortunately this is not the case today because wood is harvested (or simply burned) much faster than it is replaced, hence making it a diminishing resource. It is also cut, dried and chemically treated and transported all with some non-renewable consequences. To ensure sustainability of current timber usage as a construction material without serious future implications, Taylor (2002) advances the concept of "GREEN HIERARCHY". In this concept, terms such as reduce, re-use, recycle, recover and dispose are addressed. On the concept of reduce, the argument is about the overall reduction of the usage of the resource itself which is in conflict with the welfare of humanity and therefore seen by many as unrealistic.

The use of the term, reduce, would therefore focus more on achievement of lower wastage rates in production while maintaining all round improvement. Currently in Kirinyaga County, and the Nation of Kenya at large, the concept of reduction in timber usage can only be counter productive; the reason being because the economy is steadily growing and requires the timber resource for use as a construction material in construction industry.To apply the concept of reduce, other alternative materials to replace timber have to be found. An example of these materials would be composites. Sangeeta *et al.* (2009) notes that composites are emerging with an increasing role in building materials to replace timber, steel, aluminum, concrete etc. These are used for prefabricated, portable and modular buildings as well as exterior cladding panels. They also find extensive applications in shuttering supports, special architectural features imparting aesthetic appearance, ergonomics, large signage's etc. Composites have a longer life, low maintenance, corrosion resistance and their light weight nature have proven attractive in many low stress applications .

Re-use is a concept that places emphasis on re-use of the already used materials. Over the years, timber for making formwork has been re used, however, timber is susceptible to breakages during dismantling and therefore its reusability is limited to a certain period. Recycle, is a concept used to imply conversion of the previous material into some other form, usually by production of a lower grade. It is the reprocessing of recovered materials at the end of product life and returning them into the use stream. Recycling has far-reaching environmental and social benefits (Michael, 2009). Most of the materials can be recycled, with metals, plastics and paper being the most recycled materials in Kenya. The problem with the recycled materials is that they normally face competition from the virgin products and therefore their prices are relatively lower. One of the challenges with recycling is the capacity to make some profits from the business. Recycling is the way to go now and in future, this is because recycling especially in paper products will allow room for the newly planted tree seedlings time to mature and be harvested and hence bridge timber shortage. This has to be done in an economical way and without affecting the end product adversely.

Recover is another term used to refer to energy recovery from materials with limited recycling options.There is the to need save on the energy cost for transporting waste materials with low recycling end product. The energy cost to transport might turn out to be higher or equivalent to the profits to be realised after sales hence un economical in the long run besides other environmental hazards that are associated with transportation.The solution to this problem is to incinerate the waste products. Timber would pose very little or no challenge in terms of environmental hazards. The waste products from timber can be used as fuel (Taylor, 2002).

Disposing off increases the burden of landfills and should come in as a last result.Timber need not be disposed of since it has more other uses such as being used as firewood or being burnt into charcoal for cooking and heating purposes. Timber has over the years been used as railway sleepers and in other application areas such as the construction industry but with time it deteriorates and needs replacement. The use of softwood timber sleepers is limited to more lightly secondary rail netwoks because they do not offer resistance to gauge spreading and spike hole enlargement. In addition, softwood sleepers are not effective in transmitting the loads to the ballast as the hardwood timber sleepers do. Currently the problems associated with hardwood timber include being very expensive, less available and being of inferior quality compared to timber previously available. There is also the environmental concern over the use and disposal of chemically impregnated sleepers. Due to the above stated problems, many railway industries are searching for alternative viable construction materials (Manalo *et al.*, 2010).

Amongst research studies on the extent of timber usage within Mt Kenya region is one done by Sammy Carsan titled, ‘Sustainable Farm Timber for Smallholder Cropping Systems’. The study mainly featured on smallholder cropping systems (a case study for the Meru county). In Kirinyaga County,there are atleast six Government owned forests namely, Kangaita, Castle, Kathandeini, Njukiini, Murinduko and Kamuruana. These forests are further categorized as either Natural forests, Plantation forests, Bamboo forests, Bushland/Grassland or Kenya Forest Tea Zone (Misonge, 2012). Through this study,the area in hectares or acreage will be determined so as to assess the contribution of the forests towards provision of timber as a construction material. Other systems such as private owned forests, smallholder timber farming and agroforestry systems need to be brought on board to see the clear picture. Through this study, this gap will be addressed.

2.1.2 Use of Timber as a Construction Material

Tomas (2014) notes that in the context of the modern society where forests are being depleted at a faster rate and availability of wood increasingly becoming scarce, research has been undertaken which has established and demonstrated that bamboo could be a viable substitute of wood and several other traditional materials for housing and building construction sector and several infrastructure works.

Timber remains an important construction material because it is versatile, that is, it has a wide range of applications. Timber has diversity in the sense that it is derived from a variety of species and also posseses aesthetic properties. It is arguably one among the original building materials (Arthur, 2007). Approximately a third of annual worldwide timber harvest is used in construction and the rest is consumed for paper production, as fuel, or as wasted during processing. A wide range of products are manufactured from wood material, ranging in size from small to large timber sections and thin laminates through chips and shavings down to wood fibres.Timber has a wide range of application in many construction areas such as flooring, joinery, pile foundations, pole construction, a variety of boards, roofing materials, among others. It is a renewable resource and an environmentally acceptable material which uses less energy in its production compared to other construction materials such as steel, cement and concrete. Some timber products can be manufactured from reconstituted and waste wood. Examples of these products include finger – jointed floor boards, laminates and medium fibreboard (Arthur, 2007).

The usage of timber and steel depends on their availability and management as a key constituent to a construction project success (Korde *et al.*, 2005). The specific cultural elements such as architecture, construction type and techniques play an essential role in selection and utilization of building materials (Fewings, 2005). For successful completion of complex and large construction projects, there is the need for economic and social stimulus for developing material alternatives in order to address resource constraints for complex and large construction projects.The economic and social stimulus are categorized under external factors outside the organization but have either a positive or negative impact on the performance of a project. Under economic stimulus, there is the need for materials availability and under social stimulus, there are issues such as resources procurement, client consultation, competitors, subcontractors and altitude of the members of the public towards the project all of which affect the performance of the project especially in the planning stages (Belassi & Tukel, 1996).

2.2 Quality of Timber Used for Construction

2.2.1 Structural Qualities

Where particular visual properties are required, the specification of timber for each use may involve defining whether it is a hardwood or softwood. For general purposes where strength and durability are key factors, timber is specified by either strength class, or a combination of timber species and strength grade. Specification may also be specified by lengths and cross- sectional sizes, surface finish or tolerance class, moisture content and any preservative or special treatments (Arthur, 2007).

In European countries, the European strength class system is defined by the European standard (EN 338) and covers 9 softwood classes with characteristic bending strength between 14 and 40 MPa, and 6 hardwood classes with bending strength between 30 and 70 MPa (Hans, 2001). Apart from strength grading, which is either done visually or through a machine, there are other factors that affect the strength of timber and they include density, moisture content, slope of grain, knots, section size and creep among others (Taylor, 2002).

The rate of growth is a factor to be considered in visual stress grading and this is because in rapid growth of softwoods, the proportion of sapwood tends to increase but the situation is much less in hardwoods. Ring porous hardwoods, such as mahogany, can be denser and stronger as aresult of increased growth rates (Taylor, 2002). Growth rings consists of a lighter and a darker part. The strength of timber is negatively affected by the growth rings in the transversal (cross) direction. Large annual growth rings means that the timber will have a low density and consequently lower strength (Hans, 2001). The growth rate and timber strength is established by the width of the growth rings the optimum being around five rings per centimeter for softwoods and three rings for hardwoods depending on the species (Arthur, 2007).Trees grown in diferent climatic zones exhibit diferent growth rates, diferent strength characteristics and diferent growth patterns. Geldenhuys (2005) notes that there is absence of clearly identifiable annual growth rings in tropical species to determine the age and growth rates of trees compared with clear rings in many temperate tree species, However, Further research by Grundy (2006) has also shown that some tropical and sub tropical species are capable of producing growth rings which correlate with age.

A study by Perera *et al,*.(2011) in Sri lanka which is in a tropical climatic zone indicates that Larsen (1972) proposed and was supported by subsequent studies that accelerated growth rates induced by improved forest management practices may result in wood of inferior quality. Moisture content has an effect on mechanical properties of timber. The reduction of moisture content from that of the green state to a value generally between 25-30% for most species has no effect on mechanical properties of timber but a further reduction causes a marked increase in most of the properties such as bending strength, stiffness, shearing strength and resistance to indentation. The degree of increase depends on the property. Moisture content in the region of 15% would cause a strength increase of about 40% higher than in saturated state (Taylor, 2002). Moisture content is either determined gravimetrically or by an electric moisture meter. The electric moisture meter is faster but not so accurate (Hans, 2001).

The tensile strength of timber is affected by the slope ofgrain with a rapid drop of strength as the slope of grain increases. Equation (2.1) is used in determination of timber strength with the grain angle as the grain angle increases from 0°- 90°. In the equation, N is the estimated strength at GA of θ, P is the mean strength G II θ=0°),

Q is the mean strength G⊥ (θ= 90°) and θ= GA in degrees. GA is the grain angle

(Rakesh Gupta *et al*, 2012)

$$N = \sqrt{P^2 Cos^2\theta + \theta^2 Sin^2\theta} \qquad (2.1)$$

The drop of strength as the slope of grain increases also increases the risk of shear failure. The deviation of fibre direction is normally as a result of inaccurate sawing or due to irregular growth of the tree. When measured parallel to the grain, the tensile strength of most softwoods is in the regon of 100N/mm² when tested dry (Taylor, 2002). Wood is generally weak in tension when loaded perpendicular to grain and thus the mechanical properties for wood loaded in tension parallel to grain and for wood loaded in tension perpendicular to grain differ substantially. According to a study by AYDIN *et al.*,(2007), the bending strengths of two clear specimens of softwood timber (Fir and Pine) were 53.3 MPa and 56.8 MPa, respectively.

Sloping grain is considered under the category of conversion defects to both hardwoods and softwoods. A 10% slope of grain reduces the bending strength by about 20% (Taylor, 2002). Further, as the slope of the grain increases, there is a proportionate reduction in bending strength with a range of 4% at 1 in 25 to 19% at 1in 10. British Standards (BS 5756:2007) limits the slope of grain in visual strength graded structural tropical hardwoods (HS) to 1 in 11. Beach, Oak, Sweet chestnut, Meranti, Lauan, Elm and American Mahogany account for 50% of hardwoods used in the United Kingdom. Also, half of hardwoods used in UK come from temperate forests in North America and Europe including Britain. British Standards (BS 4978:2007) also limits the slope of grain in visual strength graded softwoods (HS) to 1 in 6 for the general structural grade (GS) and 1 in 10 for the special structural grade (SS). In this category are Pine (European red wood) and Spruce (European white wood imported from Europe (Arthur, 2007).

Knots do distort growth rings in the trunk and are responsible for strength reduction because the cambium layer is discontinuous and the knots tend to contract, often falling out of thin sections such as boards. The effect of knots on strength also depends on their position in the section being generally more serious in tensile areas than compression areas.Smaller timber sections give higher strength on average.Plate 2.1 shows various types of knots and their positions.



Plate 2.1: Types of timber knots and their positions.

Equation (2.2) is used as an approximate guide in determination of timber strength. In this equation, σ_1 is strength of timber at section depth h, and σ_2 is strength of timber at section depth 200mm.

$$\sigma_1 = \sigma_2 [\frac{200}{h}]^{0.4} \quad (2.2)$$

Creep is a time-dependent strain resulting from sustained stress. Wood used in construction shows notable creep behaviour under sustained loads which is known to have significant effects on safety and service ability of wood structures over their lifetime. Investigations have shown that the level of applied loads, moisture content and temperature are the most critical factors in creep behaviour (SHEN, 1995).

2.2.2 Other Timber Qualities

The quality of timber is affected by other factors such as classification, conversion, defects, moisture content and seasoning. Commercial timbers are either classified as hardwoods or softwoods. Under microscopic investigation, softwoods show only one type of cell while hardwoods have a more complex cell structure, these cells or tracheids gives strength to the tree (Arthur, 2007). Many hardwoods are generally durable and some may last for centuries without use of preservatives. They grow slowly and may not mature for 100 years or more.They are relatively expensive and their use is restricted to applications calling for high strength, hardness or durability (Taylor, 2002). Softwoods generally come from trees with needle-like leaves (conifers) and they are evergreen. Preservatives are applied to this type of timber to increase durability (Erdogan,2002). Some of the problems associated to softwoods is warping and shrinking. They are suitable for framing and subflooring. Examples include Fir and Pine (Black, 2004).

Softwoods grow at arelatively faster rate compared to hardwoods and they produce timber of low density which is easily worked and of fairly low strength. At 30 years, Softwood trees could be felled for processing to timber. They are relatively cheap and used in all forms of construction. Conversion is the process of cutting up logs before seasoning and the method of cutting individual logs should be a compromise between that which results in the most economical use of timber and that which results in the most desirable timber properties (Taylor, 2002).

The felled timber is normally unworkabe and unusable because of the inherent moisture content in it. According to an article, “Moisture in Timber’’ (2014) as contained in the Technical Data Sheet issued by Timber Queensland, in a green off sawn timber, the moisture content may be as low as 40% but can be as high as 180%. If timber is allowed to remain so, then it becomes prone to shrinkage, distortion and the effects of fungal growths. Natural (air) seasoning and kiln seasoning are the two methods used to reduce the moisture content to between 12 and 20% (Chudley *et al.*, 2011). The moisture content is expressed as the weight of water in the timber as a percentage of the weight of the dry timber.

Equation (2.3) is used for determining the moisture content percentage. In this equation W represents moisture contentas a percentage, Kn^1denotes dry weight of specimen and Kn^2 the wet weight of the specimen. Under normal atmospheric conditions, timber is a very resilient, durable and a robust construction material. It has been used for thousands of years. However, the weakness of both hardwoods and softwoods is their source as a food for plant growths in the form of fungi and to certain species of insect, which weaken their structure and durability (Chudley *et al.*, 2011).

$$W = \frac{(Kn^2 - Kn^1)}{Kn^1} X\ 100\% \qquad (2.3)$$

2.3 Structural Performances of Timber for Construction

2.3.1. Attributes for Structural Performance

The mechanical properties of products generally depend upon two main factors, i.e., the density of the product and the fibre direction in the final product. Timber being an anisotropic material, its strength properties is heavily dependent on the orientation of stress in relation to grain direction. Different tests must therefore be applied to describe fully the mechanical properties of timber. BS 373(1995) describes methods of testing small, clear specimens of timber which should normally be 20 mm square sections. Through a study carried out by Githiomi *et al.* (2001), information was gathered on the most viable commercial trees in Mt Kenya region and tests conducted to determine their strength values when timber is dry. The tests included compressive strength, shear strength, and hardness test. Moisture content was also determined as a percentage.The test samples were; camphor (*octea usambaren*), rose gum (*eucalyptus grandis*), large-leafed cordia (*cordia africana*), cypress (*cupressus* *lustanica*), grevillea (*grevillea robusta*), croton (*croton megalocarpus*) and pine (*pinus patula*).

2.3.2 Tests Carried Out in Reference to Timber

The following are the tests carried out in reference to timber, tensile strength, shear strength, bending strength, hardness strength and compressive strength.

(a) Tensile Strength

The tensile strength of timber is much higher than its compressive strength when measured parallel to grain. Compression causes buckling of the fibres. Failure in tension is normally due to shear failure between fibres or cells. Resistance to indentation (hardness of timber) is another important property because it affects indentation and flooring. For dry softwoods, a load of 3kN may be required to press a steel ball of 11.3mm diameter into a timber to a depth equal to its radius whereas for dry hardwoods such as oak, may give twice this load. Resistance to identation is of importance when timbers are joined together, and also in timber to be used for such purposes as sports goods, bearing blocks among others. This property, i.e., resistance to indentation does not include any measure of resistance to abrasion (Taylor, 2002).

(b) Bending Strength

The maximum bending strength (equivalent fibre stress in maximum load) is a measure of maximum stress which timber can momentarily sustain when loaded slowly and continuously as a beam. It is of primary importance in timbers subjected to transverse bending. Bending stresses are commonly applied to timber in service. The flexural strength as measured by modulus of rapture is intermediate between tensile and compressive strength.The bending strength of most dry softwoods is typically in the region of $70N/mm^2$ in the short term (Taylor, 2002). Stiffness as determined by modulus of elasticity is of importance in determining the deflection of a beam under load, the greater the stiffness, the less the deflection. For many uses, stiffness is an essential property. Energy consumed to total fracture is a measure of ability of the timber to absorb energy and is, therefore, of particular importance where timbers are subjected to considerable bending under heavy loads such as shunting poles, wheel spokes amongst others. This property is closely allied to the toughness of timber (Taylor,2002).

(c) Hardness

The standard method of determining resistance to suddenly applied load (impact) is to drop a weight from increasing heights onto a beam supported near the ends, the height of a drop at which the beam breaks is a measure of the property; an alternative method is to measure the energy absorbed in fracturing by a single blow. The third method is to use toughness test, in this, a test piece 250mm long and 16mm square, freely supported over a span of 200mm is broken by a single blow centrally applied by a machine of the pendulum type. The energy absorbed by the test piece during fracture, calculated from the angle of swing of the pendulum before and after impact, is taken as measure of toughness of timber.

(d) Shear Strength

Shear strength property is a measure of resistance of timber when the forces acting on it tend to make one part slide over another in a direction parallel to that of the grain. It is important in beams where the depth is large in relation to the length and in timber fastened by bolts or other forms of connection. The shear strength of timber parallel to the grain is low, i.e., about 11N/mm^2 for dry softwoods (Taylor,2002).

(e) Compressive Strength

The maximum compressive strength parallel to grain is a test carried out to measure the ability of timber to withstand loads applied on the end grain and is of importance where use as short columns or props is contemplated. Moisture content also has an effect on mechanical properties of timber. The strength of clear timber rises approximately linearly as moisture content decreases from the fiber saturation point and may increase 3-fold when the oven-dry state is reached. At moisture contents of around 15%, the strength would be approximately 40% higher than that of saturated state, depending on the type of wood (AYDIN, 2007). The degree of the increase depends on the property, the species and the final moisture content. Most timbers show an increase of over 100% in compressive strength on seasoning from green state to equilibrium moisture content state (Taylor,2002).

2.3.3 Strength Grading

Strength grading is the measurement or estimation of the strength of individual members which allows each piece to be used to its maximum efficiency. It is either done visually (a slow and skilled process) or through a grading machine to test flexural rigidity. In visual strength grading, each piece of timber is inspected for distortions, growth ring size and slope grain, and then checked against the permissible limits for the number and severity of the natural defects such as knots, waney-edge and fissures. Timber is then assigned to a grade and stamped accordingly. For softwoods, timber is assessed as special structural grade (SS), general structural grade (GS) or reject. For hardwoods, timber is assessed as heavy structural temperate hardwood or general structural temperate hardwood or reject(Arthur, 2007). In Kenya, Only one method of grading softwood timber for structural use is specified. This method is visual stress grading although the possibility of stress grading is not ruled out through approved techniques. The specification is contained in the standard document KS 02-771:1991. In this Standard, the permissible sizes of characteristics in two visual stress grades of timber, which are named general structural grade (GS) and special structural grade (SS), are specified. Visual grades for laminating timber viz, grade LA and grade LB, are also specified.

In machine testing, timber is moved through a series of rollers and the machine measures either the load required to produce a fixed deflection or the deflection produced by a standard load. The measurement of stiffness is then related to timber strength and therefore a grading standard. Acording to BS EN 338: 2003, the strength classes are defined as C14 to C50 and D18 to D70 where the prefix Crefers to softwoods (coniferous) and D tohardwoods (deciduous). The number refers to characteristic bending strength in MPa. Other specifications include values for density and a wide range of strength and stiffness properties, all based on sample test values without taking into consideration of any safety factors to be included in the design process.

After determining strength properties, it is also important to determine the working stress. Working stress is also referred to as the safe stress. It is only possible to determine the working stress if the proportional limit, the yield point and the ultimate strength of a material is known. The ultimate strength is usually taken as the basis for determining the working stress of a material. The ratio presented in Equation (2.4) or Equation (2.5) is used for determining the ultimate working stress. In this equation σ_w denotes working stress, $\sigma\gamma\cdot\rho$represents yield stress while σ_u represents the ultimate strength of the material. n andn_1 are costants called factors of safety (Timoshenko, 2002).

$$\sigma_w = \frac{\sigma_y \rho}{n} \tag{2.4}$$

$$\sigma_w = \frac{\sigma_u}{n^1} \tag{2.5}$$

2.3.4 Quality Control

In construction, quality control is concerned with montoring of the results of a specific project to determine if it complies with relevant quality standards and identifying ways to eliminate the cause of unsatisfying performance contract documents. The contract documents define a constructed facility considered acceptable under the applicable regulatory codes and standards of professional practice, in terms of it's reliability, the ease with which maintenance and repairs can be performed, the durability of it's materials and operating systems, and the life safety provided for it's user (Lakshmi, 2015).

Quality control is a process of checking and monitoring of production which leads to a product of consistently satisfactory standards and documentary evidence of all quality control procedures is required. Quality control is also concerned with the saving of cost through prevention of production of substandard work which may have to be redone.The hallmark of a good quality control system is that every aspect of the process of production should be inspected with special attention given to those stages that have a greater risk of producing faults or where the consequences of faults are more serious. Product assessment is an essential part of any quality control process. It is independent of acceptance testing (Taylor, 2002).

In the construction process, the safety and functions of a construction project together with environment and socio economic development are determined by the performance and quality of the building. Many countries through their concerned ministries have set up departments which are responsible for testing and application of construction materials. In Kenya, under the Ministry of Transport and Infrastracture, a department known as Material Testing and Research Department has been set up and charged with the responsibility of testing engineering and non-engineering materials for building and construction industries. Again in Kenya, under the Ministry of Land, Housing and Urban Development there is the Appropriate Building Materials and Technology (ABMT) programme. This in essence refers to building processes, materials and tools that are cost effective, safe, innovative, green/environmentally friendly as well as acceptable to the climate, socio-economic conditions and natural resources of an area. The Government through the Ministry of Land, Housing and Urban Development, has set up ABMT centers in all provincial headquarters. Among the services the ABMT centers provide is the testing, quality control and maintenance of standards.

Several areas can be considered in terms of quality control (i.e., quality control of construction materials, structural quality, aesthetic quality, functional quality and economic quality) but for the purpose of this study only structural quality aspect of construction materials is considered. Standards are designed to encourage, promote use of materials or products of high quality and to provide a means of distinguishing such items from other similar but of inferior quality. A mark of quality is usually placed on the product as an indication of approval by the standards authority. The standards are produced by committees which normally represent points of view of all parties with interest in the production of the materials, users, researchers, professional bodies and government institutions. They do state specified levels of performance which can be achieved at a reasonable cost by the manufacturer (Taylor, 2002). The main bodies which oversee both national and international standards for building materials are Kenya Bureau of Standards (KEBS), British Standards Institution (BSI) and International Organization for Standardization (ISO).

2.4 Summary of Literature Review and Research Gaps

Research worldwide has shown that there exists pressure on forests and that demand of wood and wood based products continues to intensify. For example in Nigeria, Owoyeni *et al.* (2010) notes that the demand for wood for various purposes has put serious pressure on Nigeria's forest. Nationally, Kenya's Forestry Master Plan (1994) projects demand of sawn wood as 203,000 m^3in 1990 to 262, 800 m^3 in 2020.

A steady rise in population every year (The 2009 Kenya population and housing census) is one among the many factors that have contributed to a high demand of construction timber in Kenya.This demand has often led to shortage of construction timber. This shortage is responsiblefor the high rate in declining of forests in Kenya. To reverse the trend and ensure materials sustainability (in this case construction timber). Taylor (2002) has advanced concepts such as reduce,re-use, recycle andrecover.

According to Kirinyaga County Forestry Annual Report (2012), research has shown that tree cover currently stands at 15% against national tree cover of 2%. The recommended global tree cover is at 10%. The 15% tree cover has in essence not translated into timber sufficiency and therefore demand continues to outstrip supply.

There has not been a study done to explain this sceario and hence forms one of the research gaps to be addressed by this study.

Timber has remained a useful construction material over the years because of its versatility, diversity and aesthetic properties. It has a wide range of applications including flooring, joinery, pile foundations, pole construction, a variety of boards and roofing materials among others. In the context of modern society where forests are being depleted at a faster rate, availability of wood is increasingly becoming scarce and research which has been undertaken has established and demonstrated bamboo could be a viable substitute of wood. Apart from the use of bamboo, other measures undertaken to ensure future sustainability of timber as a resource includes use of composites and application of Taylor's concept of green hierarchy, i.e., reduce, re-use, recycle and recover.

For structural purposes, specification involves defining the timber as either hardwood or softwood. Timber is also specified in terms of strength class and strength grade where strength and durability are key factors. The other factors that affect the strength of timber include density, moisture content, slope of grain, knots, section size and creep among others (Arthur, 2007). From literature review, it has been established that there exists no findings on the factors affecting the structural strength on species within Kirinyaga County save for a study carried out by Githiomi *et al.*,(2001) covering generally Nyeri, Thika, Nakuru and Kiambu regions but not Kirinyaga. There was therefore the need to study Kirinyaga region and this constituted a research gap to be addressed by this study.

The mechanical properties of timber are determined through testing of small, clear specimens of timber which are normally 20mm square sections. These tests include compressive strength, shear strength, static bending and hardness test. A previous study done by Githiomi *et al.*(2001) only addressed some particular types of tree species such as *acacia decurens, cassipourea malosana among others.*On physical properties, the study by Githiomi *et al.*, (2001) did not touch on them and how they affect quality and structural strength of timber. These properties include conversion, defects, rate of growth and seasoning. This aspect also constitutes a research gap to be addressed by this study.Quality control is also critical in ensuring production of consistently satisfactory standards. It is a process of checking and monitoring of production. The two main bodies which oversee both national and international standards for building materials in Kenya are Kenya Bureau of Standards (KEBS) and International Organization for Standardardization(ISO). Figure 2.1 shows a model of the conceptual framework of the study.

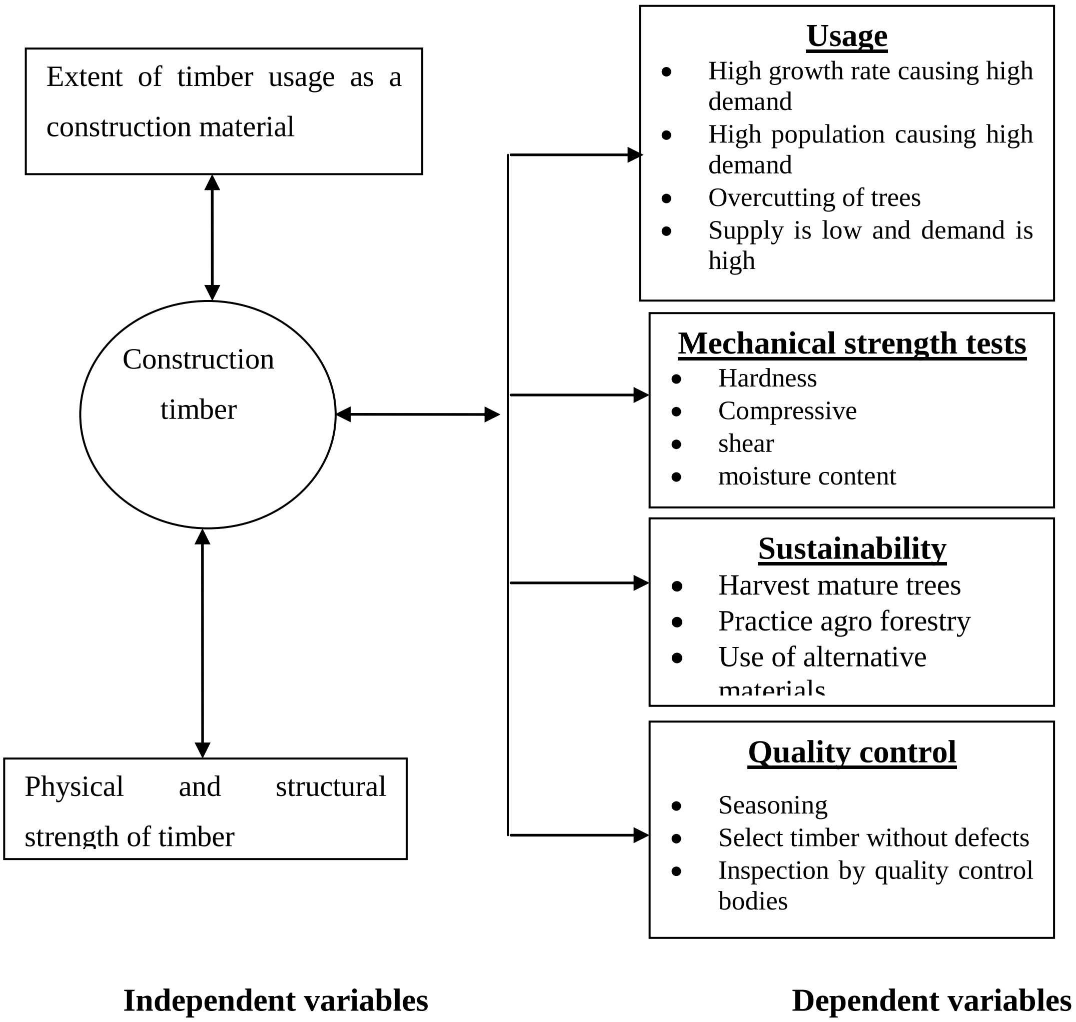

Figure 2.1: Conceptual framework of the study.

The study is hinged on four major key pillars. These pillars include; extent of timber usage, structural strength, sustainability and quality control. Consruction timber is at the centre of the model because it is the central focus in relation to the key pillars and therefore the main arrows points towards the centre. Under the extent of timber usage, supply of timber is low compared to its demand which is high. The demand is high as a result of factors such as increase in population every year and high economic growth rate among others. Sustainability is affected negatively by deforestation and can be improved through measures such as provision of alternatives such as composites,harvesting mature trees, use of concepts such as reduce, recycle and recover.

The structural strength of timber is basically determined through testing of various mechanical strengths. The tests which which are ordinarily carried out include compressive strength, static bending, shear strength, hardness and moisture content percentages. Under quality control, the study focusses on main bodies empowered to carry out standardization such as KEBS, BSI and ISO. Careful selection of test samples is required to avoid timber with imperfections. Extension services and government policies to control planting and harvesting are critical in ensuring harvesting of mature trees which will further lead to production of high quality timber. Seasoning before use is another factor of importance in controlling quality.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction to Reasearch Design

Research design is a blueprint for the collection, measurement and analysis of data and aims at combining relevance to the research purpose with economy in procedure. It is a conceptual structure within which research is conducted (Kothari, 2004). Descriptive cross-sectional and Experimental research designs were adopted for this study.

3.2 Research Design

3.2.1 Research Design to Determine the Extent of Timber Usage

In order to determine the extent of usage of timber as a construction material in Kirinyaga County, descriptive cross-sectional design was used. In this study, questionaires were administered to various participants with a view to get their responses. Other data was gathered through observation. The data gathered was both quantitative and qualitative. Quantitative in the sense that percentages were calculated to clearly show such attributes like which tree species were commonly used for construction timber requirements. It was also qualitative since the administered questionnaires dealt on quality aspects such as methods of timber preservation, tree age factor, measures taken by county forest officers to ensure quality and seasoning methods undertaken. In consideration of the information given above, it was justified to use descriptive, cross sectional design as a research design in an effort to determine the extent of timber usage.

3.2.2 Research Design used in Determing the Structural Strength of Timber

Experimental research design was used to assess the structural strength of timber as a construction material for most common tree species in Kirinyaga County.To determine various timber strength characteristics such as compressive strength, shear strength, hardness andstatic bending, laboratory testswere carried out. A minimum of six (6) test samples of each tree species sampled from different locations of the county were prepared for use. Te location of Kirinyaga County in Kenya is presented in Figure 3.1 while the corresponding constituencies are shown in Figure3.2.

Figure 3.1: Kenya map showing location of Kirinyaga County

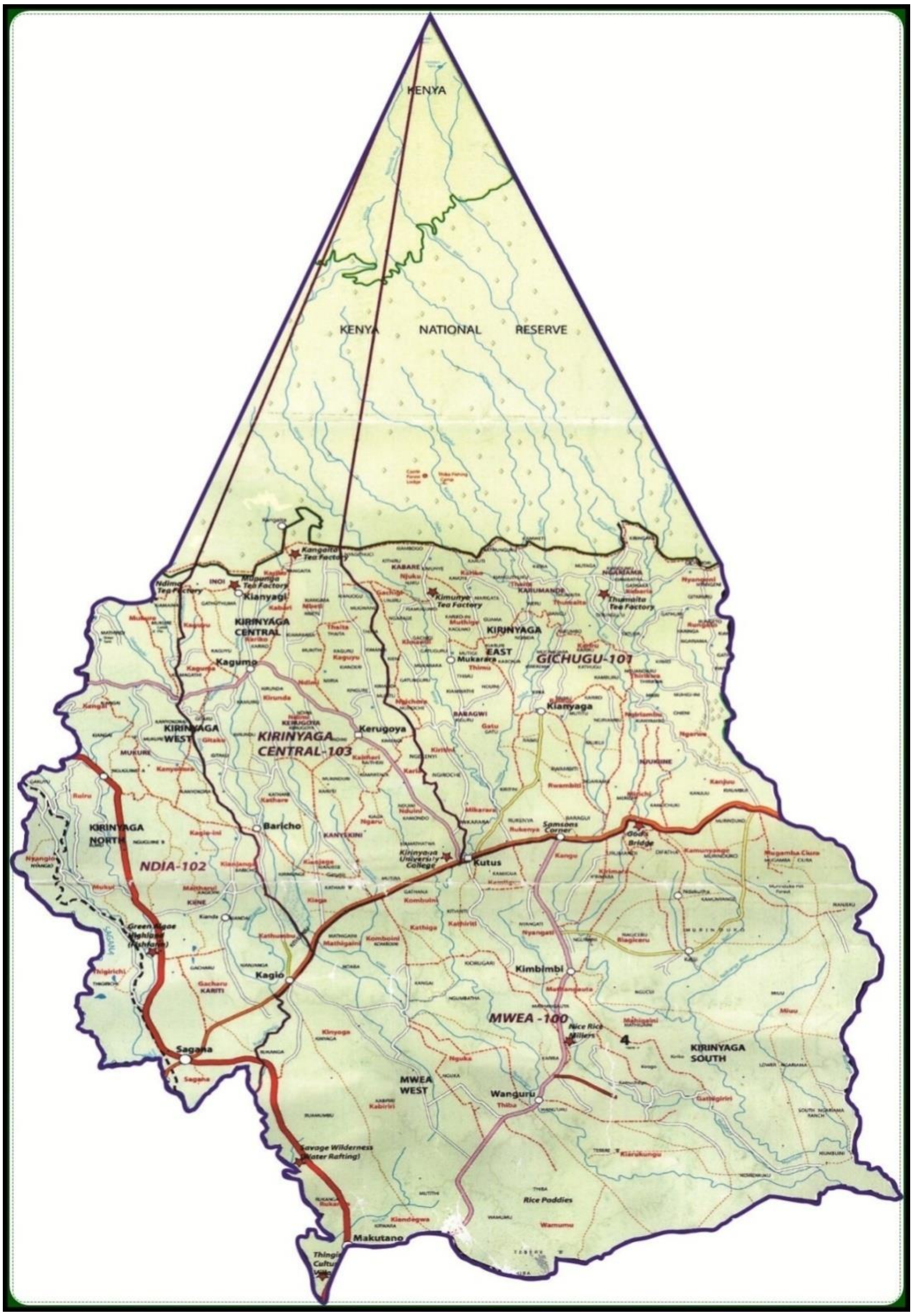

Figure 3.2: Constituencies of Kirinyaga County.

3.3 Target Population

The initial plan was to target quite a large number of species to be studied both in the hardwood and softwood category. The target population for the study was made up of the following groups: builders, saw millers, timber yard owners and government forest officers. The choice of this target population was because the group comprised of the end users, timber handlers and those entrusted with taking care of trees as a resource. From the target population, information was sought on the the availability of timber in terms of tree species and timber samples were taken for testing of mechanical properties. Figure 3.2 shows the constituencies from which the sampling was done. The four constituencies making up Kirinyaga County are: Kirinyaga Central, Kirinyaga West, Kirinyaga East and Kirinyaga South.

On data collection, the initial plan was to target quite a large number of species to be studied both in the hardwood and softwood category but on the ground, this was not possible.as a result of absence of some species especially the hardwoods in the market. In the hardwood category, the commonly found species were *Cordia africana* and *Eucalyptus grandis* while in the softwood category, the common types were *Grevillea robusta*,pine and Cypress. Figure 3.3 shows a schematic diagram of how the research process was carried out.

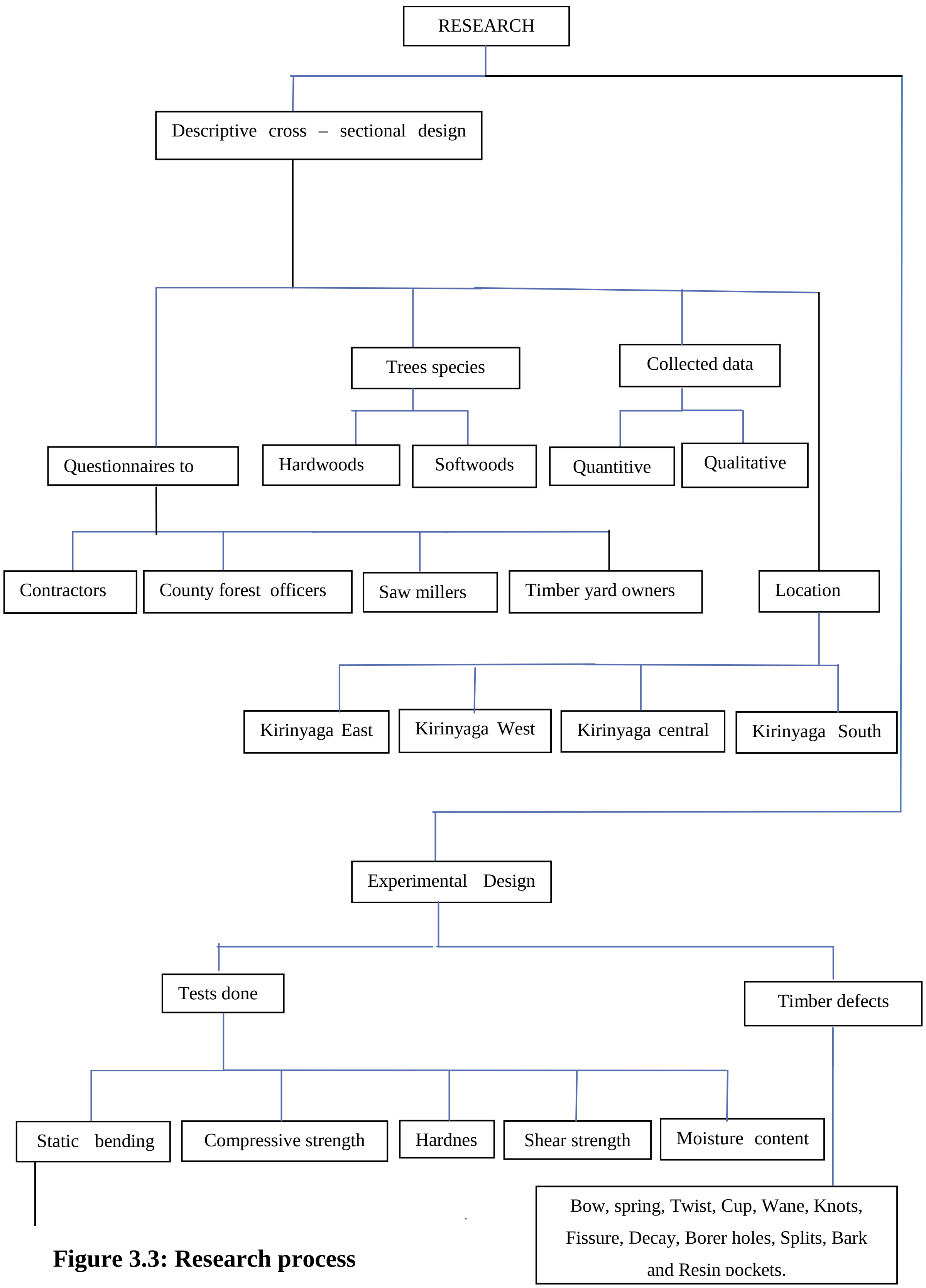

Figure 3.3: Research process

3.4 Sampling Frame

Purposive sampling method was used for this study. The need to capture both hardwoods and softwoods categories , timber without defects and samples from specific stations informed the choice of the method. Further, the population (in this case sawn timber) being large and workforce also contributed to the choice of the method.To determine the extent of usage, Workshops and timber yards in major towns namely Kagumo in Kirinyaga Central, Kianyaga in Kirinyaga East, Kagio in Kirinyaga West and Ngurubani in Kirinyaga South were sampled. Public buildings, residential buildings and a few farm structures were also sampled. For experimental purposes, timber derived from the following types of tree species were sampled, *Cordia africana*, *Eucalyptus grandis*, Cypress, *Grevillea robusta* and Pine. Tables 3.1-3.5 shows the list of all the Contractors, Saw millers, County forest officers and Timber yard owners interviewed directly and through questionnaires on matters pertaining to timber usage and quality.

Table 3.1: Registered contractors interviewed in Kerugoya town

S/No	Reg. No	Company name	Class	No
1	1919/B/0214	Digial Spares and Electronics co ltd	Building works	8
2	3829/B/0214	Jimro Enterprisees ltd	Building works	4
3	3860/B/0214	Jobec Ventures	Building works	8
4	3970/B/0214	Josak G.Contractors	Building works	7
5	8823/B/0214	Tonilo Builders	Building works	7
6	9038/B/0214	Umeme Contractors ltd	Building works	6
7	1362/B/0214	Cherith investments co.	Building works	7
8	1771/B/0214	Davega enterprises ltd	Building works	7
9	12231/B/0914	Harikrishna Hardware ltd	Building works	3

In the table: S/No -serial number; Reg. No -registration number;No–NCA registration class category

Table 3 2: Non-registered contractors interviewed

S/No	Contractors	No
1	James Gitogo of Kiamiciri (Kirinyaga East Constituency)	1
2	John Njagi of Gatuto (Kirinyaga West Constituency)	1
3	Enoch Gicanga of Kimunye (Kirinyaga East Constituency)	1
4	James Mbogo of Kutus (Kirinyaga South Constituency)	1
5	Johnson Kariithi of Kimunye (Kirinyaga East Constituency)	1

Table 3.3: Saw millers interviewed

S/No	Saw millers	No
1	Kutus saw mills Ltd (Kutus)	1
2	Kamugi saw mills Ltd(Kutus)	1
3	Ushidi saw mills Ltd(Kerugoya)	1

Table 3.4: County forest officers interviewed

S/No	County forest officers	No
1	County forest officer-Kirinyaga central	1
2	County forest officer-Kirinyaga east	1
3	County forest officer-Kirinyaga west	1
4	County forest officer-Kirinyaga south	1
5	County forest officer – Castle forest	1

Table 3.5: Timber yard owners interviewed

S/No	Timber yard owners	No
1	Gitaritimber yard – Kutus	1
2	Wabusara timber yard – Sagana	1
3	Douglas Githaiga timber yard – Sagana	1
4	Waima timber yard – Ngurubani	1
5	Sanyo timber yard – Kagio	1
6	Mwireri timber yard – Kagumo	1
7	Rose Pauline Wanjiku timber yard- Kianyaga	1
8	Midtown timber yard – Kagio	1

3.5..Sampling Technique and Sample Size

In this study, the sampling unit was Kirinyaga County which was zoned into four blocks (i.e., Central, West, East and South). The sampling sites in these zones were Kagumo and Kerugoya towns in Kirinyaga Central Constituency, Kagio and Sagana towns in Kirinyaga West (Ndia) Constituency, Kianyaga town in Kirinyaga East (Gichugu) Constituency and Ngurubani town in Kirinyaga South (Mwea) Constituency. These towns were chosen because they are the largest in the County.

To achieve objective two , that is , on the physical and structural strength of timber, five sample specimens of eucalyptus, *grevillea robusta*, pine, *cordia africana* and cypress of were prepared for testing various mechanical properties. The tree species were chosen based on their availability at that time.Samples free from timber defects were chosen. In order to determine the extent of usage of timber, purposive sampling method was used. This method is based on the concept of non- random sampling. In this method, the items are deliberately selected by the researcher. The method could be prone to bias element but it has the advantage of saving time and budget costs. To achieve tolerably reliable results and minimize bias, samples were carefully selected in four distinct locations of the four constituencies in the County at points where there is high concentration of each timber species.

3.6 Data Collection Instruments

Data for this study has been generated from information acquired as feedback from questionnaires which were administered to contractors, timber yard owners, saw millers and government forest officers. The administered questions were open ended to enable the respondents give their views. Few questions as low as six for each category were administered. The other method adopted to generate information was carrying out scientific tests.These tests were done at KEFRI. The instruments/machines used to carry out the tests included the universal testing machine, an oven , a thicknesser machine and a digital weighing machine. Plates 3.1 - 3.5 show views of the universal testing testing machine, an oven in its opened position, an oven in its closed position,a digital weighing scale and a thicknesser machine, respectively.

Plate 3.1: Front view of the universal testing machine.

Plate 3.2: Front view of the oven in its opened position.

Plate 3.3: Front view of the oven in its closed position.

Plate 3.4: A view of a weighing scale used to measure weight of specimens in grammes.

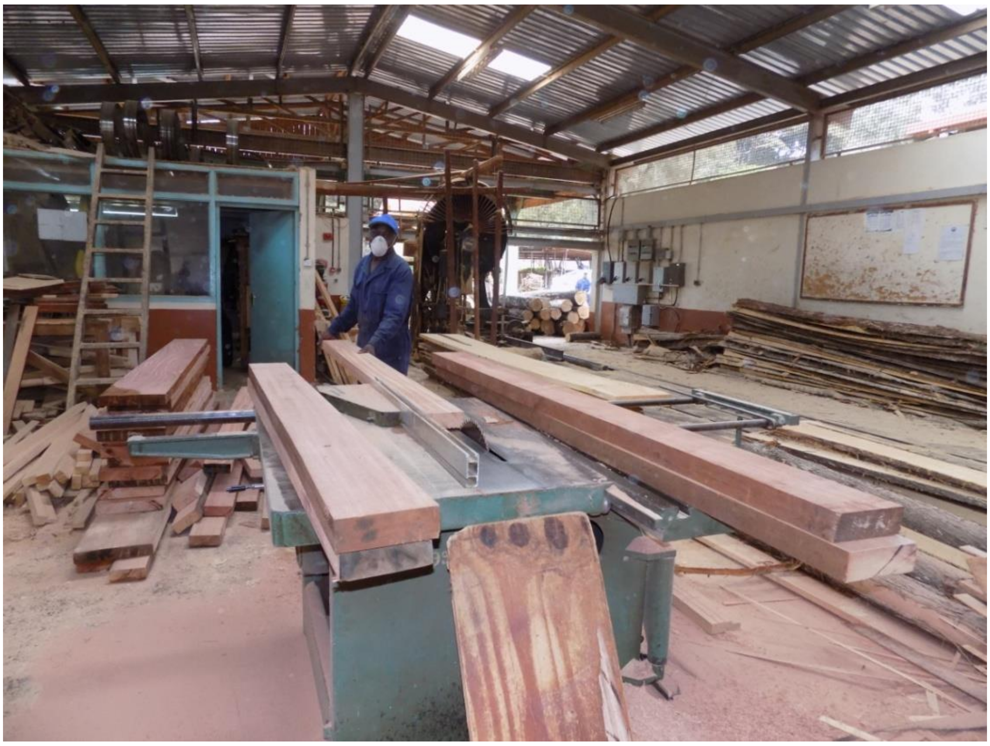

Plate 3.5: View of a thickneser machine.

3.7 Data Collection Procedure

3.7.1 Extent of Timber Usage

To collect data on the extent of timber usage, structured questionnaires with open ended questions were prepared and dispatched to four different respondent groups which included timber yard owners, contractors, saw millers and government forest officers. The questionaires are attached in Appendix 2 of this report. The tree species studied included *Cordia africana* and *Eucalyptus* in the hardwoods category and *Grevillea robusta*, Pine and Cypress in the softwoods category.The type of data to be collected touched on demand/supply trends, preference on usage between timber and other construction materials such as steel, the most commonly used timber species and why, sources of timber, licensing of timber business and both National and International policy guidelines regarding timber. The respondents gave feedback through report writing and useful information was received. Scanty information was received from Saw millers owing to the fact that very few saw mills are available in the region.

3.7.2 Quality and Structural Strength of Timber

For quality and Structural Strength, tests were carried out to determine mechanical properties of various timber species sampled. The universal strength testing machine at KEFRI (Karura) was used to carry out the tests. In this case, sample sizes of 20x20x20 mm were used to determine shear strengths of various sample species. The following is a test procedure for testing shear strength.

(a) Shear strength

Procedure and apparatus set up for testing shear strength.

- ❖ Twelve 20mm cube clear specimens of the particular piece of timber to be tested were prepared in the carpentry and joinery workshop. Six pieces were tested on the radial side (parallel to grains) while the other six were tested on the tangential side (perpendicular to the grains).Refernce was made to BS 373 and KS 02-982: PART6:1990 as the testing standards.
- ❖ The compression platewas attached to the underside of the moving cross-head of the machine and the shearing tool fitted on the machine table.
- ❖ The specimen to be tested was slotted on one end of the shearing tool where the loading will be applied.
- ❖ The load was then applied continuously throught the test at cross-head motion rate of 0.6 mm per minute. After testing, the maximum load was recorded. The type of shearing failure is either true shearing or oblique.
- ❖ The test measurements were recorded in data sheet form TL/M3.

Plate 3.6: View of the compression plate and the shearing tool attached to the underside of the machine.

Plate 3.7: View of the shearing tool and the platen.

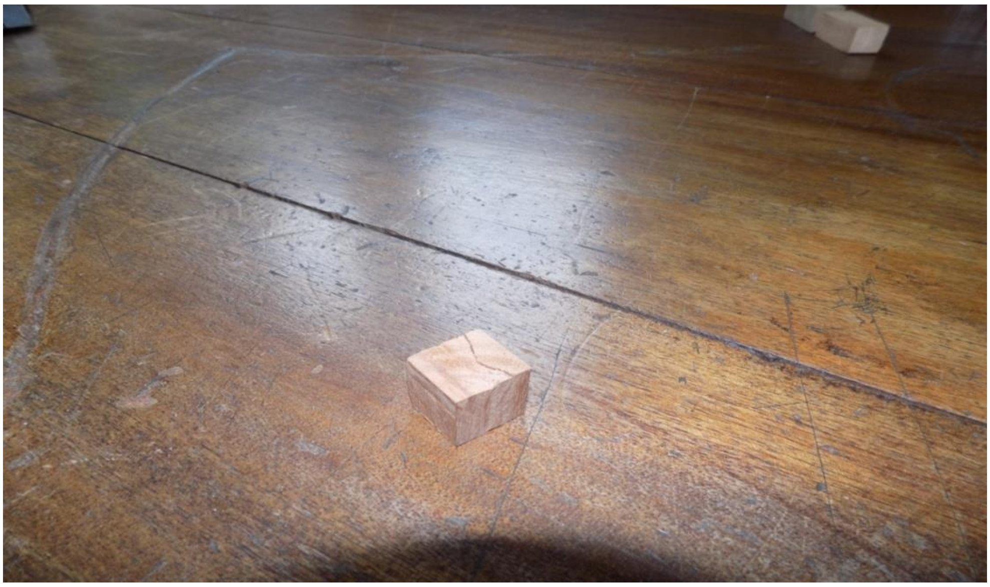

Plate 3.8: View of the specimen after testing showing true shearing mode of failure.

(b) Janka Hardness

Sample sizes of 20x20x100 mm were used to test janka hardness.The following is a test procedure for testing hardness.

Procedure and apparatus set up for testing hardness.

- Six pieces of 20x20x100 mm clear specimen of the particular piece of timber to be tested were prepared in the carpentry and joinery workshop. The Janka identation tool was fitted on the underside of the moving cross-head of the universal testing machine and the specimen holder to the machine table.Reference was made to BS 373 and KS 02-982: PART 9:1990 as the testing standards

- The specimen to be tested was pressed firmly between two blocks of timber making a composite block. The two timber blocks should preferably be of the same species as the test specimen.
- The load was the continuously applied at cross-head motion rate of 6.4 mm per minute and was removed immediately the bell sound.
- Two identations are made, one on the radial face and the other on the tangential face. The specimen is placed in holder such that the identation is 20mm from end and not closer than 30mm to the other identation. The maximum load for each identation is recorded.

Plate 3.9: View of janka identation tool and the specimen holder fitted on the moving cross-head of the universal testing machine.

Plate 3.10: View of the identing tool and the sample holder.

❖

Plate 3.11: View of the sample after the test showing identation.

(c) Compressive strength

Sample sizes of 20x20x60 mm were used to test compressive strength.The following is a test procedure and apparatus set up for compressive strength.

Procedure and apparatus set up for testing compressive strength

❖ Six pieces of 20x20x60 mm clear specimens of the particular piece of timber to be tested were prepared in the carpentry and joinery workshop. The specimen were prepared to have the end faces truly parallel to each other and at right angles to the long axis. Refernce was made to BS 373 and KS 02-982: PART 3:1990 as the testing standards.

❖ The compression platen was fitted on the underside of the moving cross-head of the machine while the specimen was held by the compression cage assembled on the machine table.

❖ The load was then applied continuously throughout the test at a rate of 0.6 mm per minute cross –head motion. When the test is complete, the maximum load is recorded and failure sketched.

❖ The test measurements were recorded on the data sheet form TL/M1.

Plate 3.12: View of compression platen with specimen held by compression cage fitted on underside of moving cross-head of machine.

Plate 3.13: View of the compression cage and the compression platen.

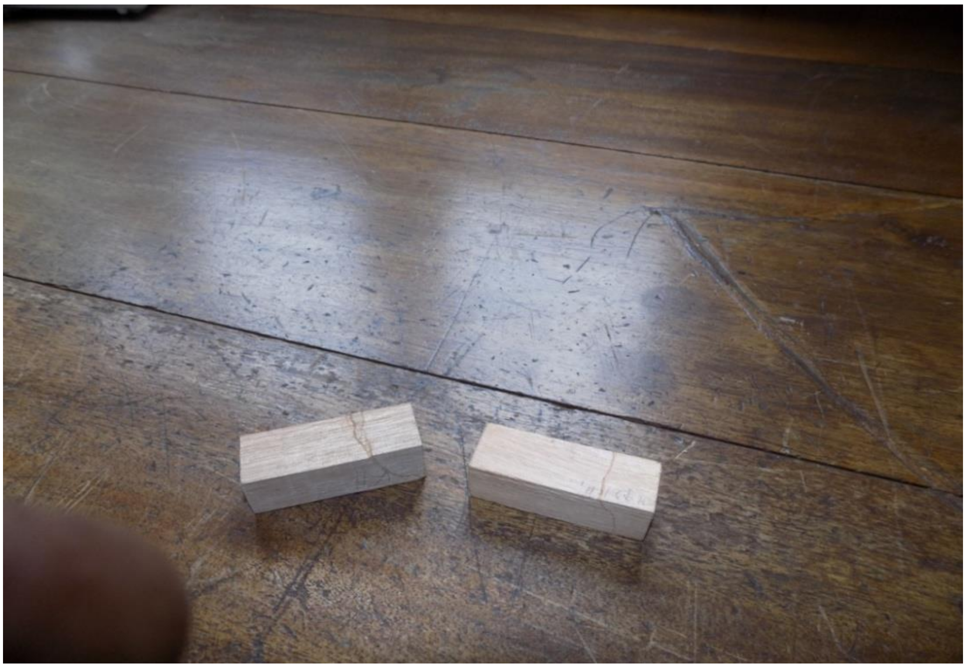

Plate 3.14: Samples showing modes of failure after the test.

(d) Static bending

Sample sizes of 20x20x300 mm were also used to test static bending.

Procedure and apparatus set up for testing static bending

❖ Six pieces of 20x20x300 mm clear specimens of the particular piece of timber to be tested were prepared. After dimensions and weights are taken, three small nails are driven perpendicular to one tangential face in the neutral plane at the centre and 140mm from the centre. Refernce was made to BS 373 and KS 02-982: PART 4:1990 as the testing standards.

❖ Two accessories to the machie are used i.e., Bending knee and the trunion supports. Others are the deflection yoke and the dial gauge (deflectometer).

❖ The bending knee is attached to the underside of the moving cross-head and trunion supports fitted on the machine table. The cross-head is lowered sufficiently to near touching the specimen, then the deflection yoke supported on the end nails is adjusted to measure deflection of the centre point of the neutral axis.

❖ a small load is apllied to facilitate initial reading of the deflectometer. The load is continuously applied at a rate of cross-head motion of 1mm per minute. The load is read at predetermined deflection intervals.

❖ At the end of the test, the maximum load is recorded and failure sketched. The test measurements are recorded on the data sheet form TL/M4.

Plate 3.15: View of the Bending Knee and Trunion Supports attached at underside of moving cross- head of machine.

Plate 3.16:View of the Bending Knee and the Trunion Supports.

Plate 3.17: View of the specimen after the test showing the failure mode.

(e) Moisture Content

❖ To arrive at the moisture content percentages, an oven drying machine and digital weighing scale were used. The test samples were each weighed and their weight in grammes taken and recorded.This is the wet weight of the samples.The test samples were then placed inside the oven drying machine chamber and dried at a temperature of 103ºC for about three days. After drying, the samples were then removed and weighed again to get the dry weight in grammes. With the two types of weight, the formula for arriving at the moisture content percentage was therefore applied. Reference was made to BS 373 and KS 02-982: PART 1:1990 as the testing standards.

Plate 3.18 shows pictorial views of the samples used for testing shear strength, compresssive strength and janka hardness, respectively.

Plate 3.18: Pictorial views of samples used for testing shear strength, compresssive strength and janka hardness.

Equation (3.1) was used to determine compressive strength.As adapted from BS373 (1995), the ratio presented in equation (3.1) is used in testing compressive strength. In this equation, L is maximum load in newtons, A is cross-section area in mm^2 while C.S is compressive strength of timber in N/mm^2.

$$C.S = \frac{L}{A} \times 1000 \qquad (3.1)$$

Again, as adapted from BS 373(1995):

$$MOE = \frac{P^1(280)^3 X\, 1000}{4ebd^3} \qquad (3.2)$$

The ratio presented in equation (3.2) is used to determine the Modulus of elasticity (MOE) where p^1 is the maximum load in Kilonewtons at the proportional limit read from the curve, eis the extension in millimetres at p^1 , b is the width in millimetres of the specimen that has been tested while d isthe depth in millimetres of the specimen that has been tested.

The extension (E) is the reading in millimetres where deflection at proportional limit occurs.

$$MOR = \frac{3 \text{ x max load x } 280 \text{ x } 1000}{2bd^2} \qquad (3.3)$$

The ratio in equation (3.3) is used to determine the modulus of rapture (MOR) where b is the width in millimetres of the specimen that has been tested and d is the depth in millimetres of the specimen that has been tested.

$$W = \frac{(Kn_2 - Kn_1)}{Kn_1} x\ 100\% \qquad (3.4)$$

To determine moisture content,an oven drying machine was used to dry the wet samples. By the use of a digital weighing scale, the wet weight of samples measured in grammes was taken and later the oven dry weight of samples (after drying) was taken. The ratio in equation (3.4) shows how to arrive at moisture content percentage (W) in which Kn_1 is dry weight of specimen and Kn_2 is wet weight of the specimen.

Data received from publications, reports and journals was used to reinforce data received from the above mentioned methods.

3.8 Data Processing and Analysis

To determine the extent of timber usage, questionnaires were administered to specific groups. The data obtained through questionnaires was cross checked to determine whether it contained errors or omissions. The statistical package for social sciences (SPSS, Version 18) was used to analyze the data. Answers from specific questions but from different respondents were classified into groups.The raw data on the extent of timber usage is in Appendix 3: Sections 1-4. To assess the quality and structural strength of timber derived from most common tree species, data collected through experimentation was tabulated and analyzed through the use of tables and figures so as to determine various aspects of the specimen. These aspects include: compressive strength, moisture content, hardness, static bending and shear strength. This data is inAppendix 3-Section 5.

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Extent of Usage of Timber as a Construction Material

4.1.1 Saw mills

Table 4.1 shows the result of the number of saw mills in operation and those that have closed down in any of the four constituencies of Kirinyaga County. The results show that there are a few saw mills operating in this County. Out of the four constituencies sampled, two existing saw mills had literally closed down as a result of lack of trees for conversion to timber while two are in operation.The two in operation produces approximately 150 - 200 tons of sawn timber per month. Some of the former saw mills had resulted to operating as small timber yards sourcing sawn timber directly from small-holder farmers. In this County, most of the timber is split and sawn to required sizes through the use of tractor mounted splitting blades and hand operated power saws. The owners of the tractors and power saws are flexible enough to reach the location of the small quantities of trees available.

Table 4.1: Number of Saw Mills in Operation in Kirinyaga County

Constituency	Town	N_1	N_2
Kirinyaga Central	Kagumo	0	0
Kirinyaga Central	Kerugoya	0	0
Kirinyaga West	Sagana	0	0
Kirinyaga East	Kianyaga	0	0
Kirinyaga South	Ngurubani	0	0
Kirinyaga East	Kutus	2	2

In the table: N_1- number of saw mills in operation; N_2 - number of closed saw mills

The government ban on logging has contributed to unavailability of economical volumes of trees for conversion to timber. The ban also meant that only small quantities of trees could be released from the government forests after they have reached maturity/harvesting age (County Forest Officers Coordinators Reports, 2013).

4.1.2. Influence of Population on Timber Demand

Population increase every year without a direct proportional increase in the natural resources (in this case trees) has been cited as a major problem resulting to the demand of timber being higher than supply. Figures 4.1and 4.2 correlate population increase and a projected supply and demand of timber for Kirinyaga and National Goverments respectively.

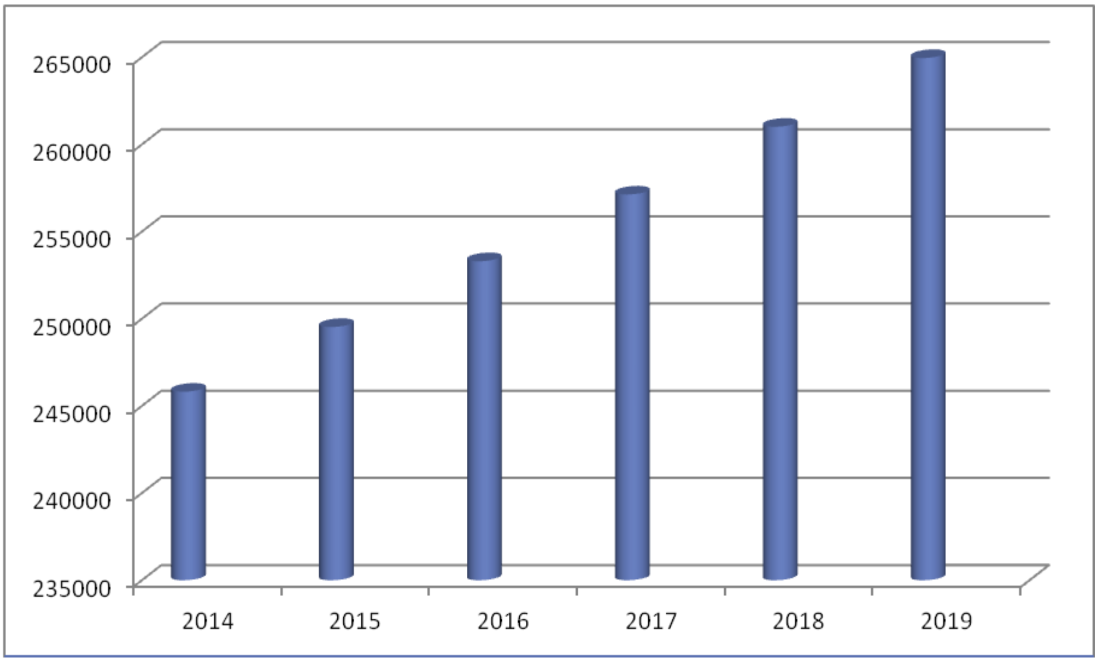

Figure 4.1: Projected increase in population for Kirinyaga County between 2014 and 2019. (Source: KenyaCensus Report, 2009).

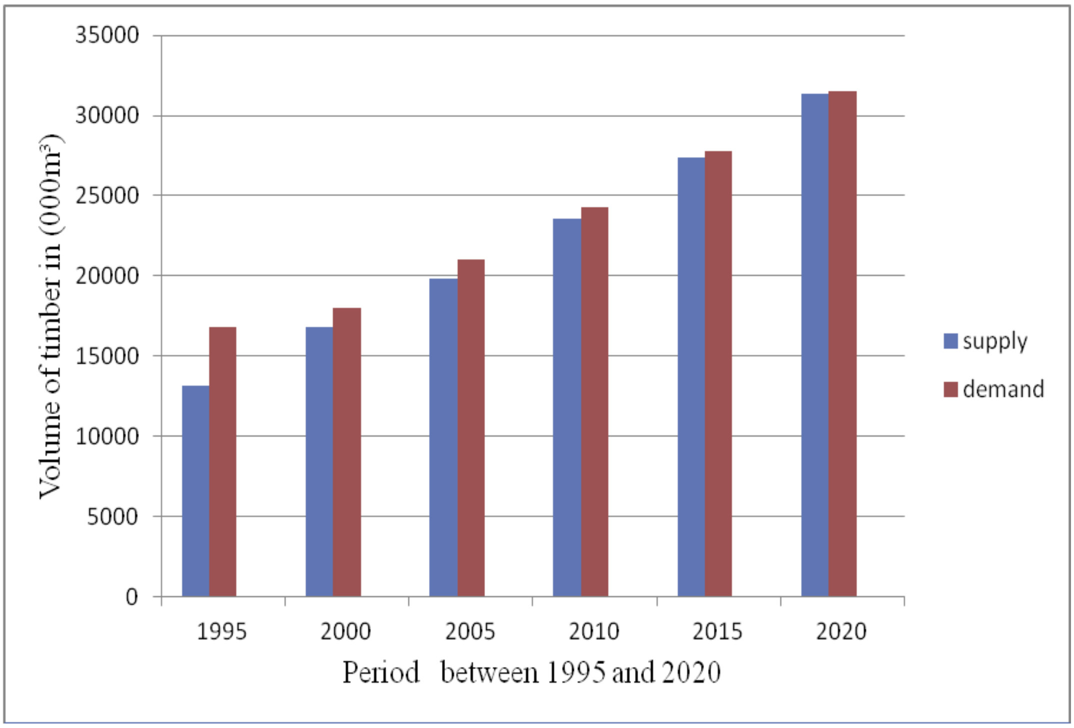

Figure 4.2: Projected supply and demand of timber in Kenya (in 000m³) within the period 1995 and 2020.(Source: Kenya Forestry Master Plan, 1994).

From the results in Figure 4.1, it is evident that the population of Kirinyaga County has been steadily rising from an approximate figure of 245000 people in 2014 to a projected figure of an approximate figure of 264000 people in 2019.The increase in population as seen in Figure 4.1 above automatically calls for an increase in supply of natural resources to be utilized by the bigger population. Figure 4.2 above explains the concepts of supply and demand of timber nationally between the period 1995 and 2020. From the statistics as seen inFigure 4.2 above, both supply and demand have been rising steadily every year but demand always outstripping supply in each year. No data was obtained for Kirinyaga County and it is expected demand versus supply for Kirinyaga would follow a pattern similar to that of national government. Results from County Forest Office (2012) indicates that the county could have been self sufficient with its timber requirements but selling off sawn timber to the neighbouring counties and major towns in the country always leaves the demand higher than supply.

4.1.3 Response from Timber Yard Owners

From the results of questionnaire for timber yard owners,the most common softwoods bought and sold were *Grevillea robusta,* Cypress and Pine while on the hardwood category, Eucalyptus was the common species bought and sold.

(a) Annual timber sales

The study established that 100% of the timber yard owners sold more than 20 tons of *Grevillea robusta* per year.This is attributable to the fact that *Grevillea robusta* grows faster and does well in agroforestry systems compared to other species. Fifty (50) percent of the timber yard owners also bought and sold more than 20 tons of Eucalyptus while the other 50% bought and sold between 6 and 10 tons of Eucalyptus per year. Eucalyptus, like *Grevillea robusta* also does well in agroforestry systems and is easily available in both smallholder farms as well as in government gazetted forests. For Pine, 50% of the timber yard owners bought and sold more than 20 tons of Pine, 37.5% bought and sold between 6 and 10 tons of Pine annually while the remaining 12.5% never bought or sold any Pine. In Kirinyaga County, Pine is commonly found in government gazetted forests especially the Mt. Kenya forest and therefore it is not very common in smallholder farms.All the respondents said they did not sell Camphor *or Cordia africana* within the year. The two species which are hardwoods are commonly found within the government gazetted forests. There exists government restrictions on harvesting, transportation and usage of the hardwood species.

(b) Sales to various departments

Through the study,it was established that timber is sold to contractors, individuals, furniture makers, schools, coffee factories and government departments. Further,75% of the Timber yard owners sells more than 50% of their timber to contractors, 62.5% sells between 0-25% of their timber to individuals, a 100% sells between 0-25% of their timber to Kenya Power. Kenya Power mostly uses timber poles which are normally treated and supplied by specific suppliers. A hundrend (100) percent of timber yard owners also sells 0-25% of their timber to government departments. Government departments use a big chunk of timber but it should be noted that most departments use tendering systems to award contracts to contractors who in turn execute projects on their behalf. Twenty five (25) percent of the respondents also sold 26-50% of their timber to furniture makers. The reason for this low percentage is the fact that some furniture makers may source their timber directly from suppliers or saw millers instead of sourcing from timber yard owners.Through the study, it was established that timber bought from timber yards is used in the following ways: making scaffolds, roofing, making floor boards such as T&G boards, formwork construction, furniture making, finishes such as doors, windows, wardrobes and sometimes as firewood.

(c) Timber availability

The study established that softwood timber is the most commonly available while hardwood timber is not readily available. A big chunk of the available timber is further sold to neighbouring county's and hence the demand always surpasses the supply. A small percentage of timber i.e, 0-25% is bought from other county's such as Nyeri County. The timber bought from neighbouring counties comprises of the species not common in Kirinyaga County such as the Pine. Apart from construction, timber is also used for other purposes such as fencing poles, firewood, wooden boxes, railway sleepers and wood pallets.

4.1.4 Response from Contractors on Timber Usage

From the questionnaires administered to contractors, fourteen out of twenty responded. This represents a 70% of response rate. Figure 4.3 shows the response rate on the preference of usage of either steel or timber by the contractors for construction purposes.

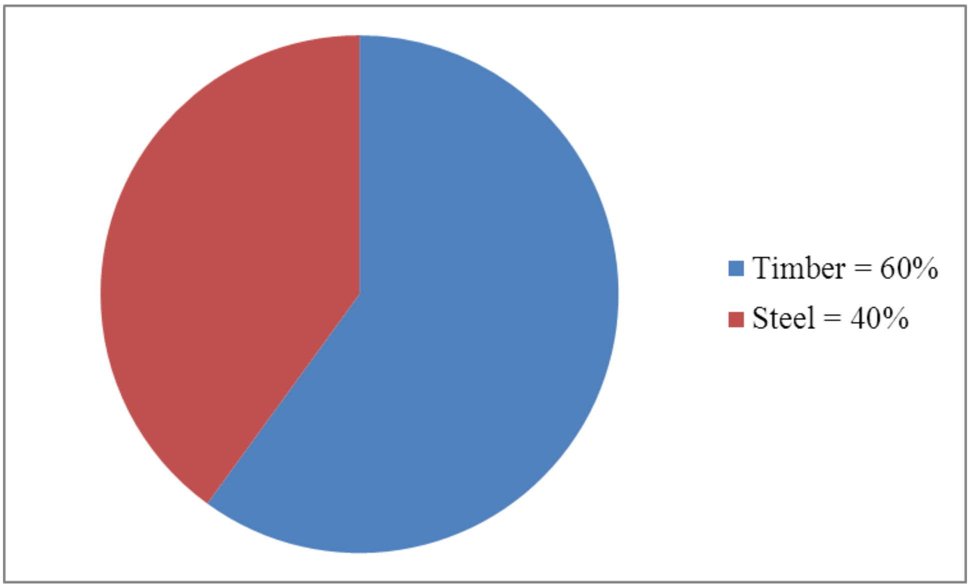

Figure 4.3: Response rate on preference of timber and steel usage.

From the results of this study, Sixty (60) percent of the population prefer using timber to other materials such as steel. The reasons given for a higher preference of timber to steel usage includes , timber is economical compared to steel, flexibility in terms of modification into various shapes and reusability aspects. This trend is attributable to relatively low cost of specific types of timber and its easy reusability aspect.

4.1.5 Response from CountyForest Officers on Timber Usage

From the questions which were administered to County Forest Officers, 62.5% responded. Table 4.2 shows questionare results from the County Forest Officers. Question one sought to investigate whether the county was self-sufficient with its timber requirements. Fourty (40) percent of the respondents indicated the county was self-sufficient. Another 25% indicated relative self-sufficiency while the other 35% indicated that the county was not self-sufficient with its timber requirements. Question two dealt on the most commonly used timber species and the reason behind it. A hundrend (100) percent of the respondents cited *grevillea robusta* as the most commonly used timber species. *Grevillea robusta* being a softwood, has a high growth rate, it is cheaper than hardwoods, does well in almost all parts of the county and has excellent agroforestry aspects compared to other species. These are some of the aspects that made it the most commonly preferred tree species.

Table 4.2:Questionaire results of County Forest Officers

County sufficiency in timber requirements	Commonly used timber species	Ensuring future timber demand does not outstrip supply	Ensuring timber used is of high quality	National and international guidelines on timber production and usage
Self sufficient = 40%	Grevillea robusta = 100%	sensitization	planting trees of high quality such as Eucalyptus	permit to cut trees a requirement
Relatively self sufficient = 25%	Eucalyptus=60%	establishment of demonstration plots	enhancing proper seasoning	Approvalgiven by county forest officers.
Not self sufficient = 35%	Cordia africana = 0%	support to schools tree planting programme	harvesting of mature trees	planting trees phenotypically and genotypically
-	Cypress=0%	ensuring maximum utilization of available timber	providing good quality seeds	enhancing proper seasoning
-	Pine = 0%	provision of extension services	advice to farmers on spacing and pruning,	approval given by county forest officers.

In question three, the enquiry was on the steps taken by the county forest office to ensure demand of timber does not outstrip supply. Some of the steps the office is undertaking include continuous sensitization of the farmers on problems associated with lack of trees, establishment of demonstration plots for the farmers to get first-hand information and rehabilitation of degraded sites using indigenous trees. In agroforestry system, crops and trees farming is done together. The office has undertaken to support this system by issuing farmers with tree seedlings friendly to crops. Some of the measures being implemented by the county forest office to ensure demand of timber does not outstrip supply include establishment of woodlots, support to schools tree planting programme and ensuring maximum utilization of available timber. Other measures undertaken include provision of extension services, capacity building to people in rice growing areas, encouraging farmers to engage in other income generating activities instead of selling their trees immaturely, promotion of farm forestry, proper plantation management in gazetted forests in accordance to technical notes, planting trees on trust lands, promotion of private commercial tree planting, sensitization and promotion of efficient energy saving jikos and strict adherence to vision 2030 by ensuring forest cover of 10% is attained.

Question four touched on quality and sought to investigate the steps being taken by the county forest office to ensure timber used for construction is of high quality.Five out of eight respondents responded. This was a 62.5% response rate. They said that the office was enhancing and promoting planting trees which produce high quality timber such as eucalyptus, allowing and enhancing proper seasoning through seminar and workshop training, harvesting of fully mature trees that have reached rotational age and providing good quality seeds to farmers which are procured from Kenya forestry research institute by the Kenya forest service.

Other steps being undertaken include giving advice to farmers in regard to best spacing and timely pruning, provision of advice to farmers on technical management of plantation forest, encouraging growing of high value tree species such as the clonal which are fast growing and diversification of growing trees and forest products, e.g., growing of bamboo to supplement timber in construction. Domestication of high quality timber trees in private farms and visiting farmers to advise them on the best practices in regard to tree management such as spacing, pruning, and thinning of woodlots were also cited as major steps to enhance quality.

Through this research, it was noted that more than 60% of construction timber in the market was derived from softwoods.The slow growth rate of hardwoods, ban on logging in government gazetted natural forests and overprocessing of trees in smallholder farms are among the contributing factors to a higher usage of softwoods. In question five, information was sought in reference to whether there were national and international guidelines that regulate timber production and usage to ensure quality timber sustainability. The response rate was 62.5%.The respondents said that at national level, permits and authority to cut trees was a requirement and that chiefs have to recommend while approval is given by county forest officers. In this way, there is regulation of trees harvesting to allow sustainability. They also said that policies do exist based on planting of trees phenotypically and genotypically but the problem lies on farmers who buy seedlings from any vendor and plant tree wildlings from their farms. The other cited national policy is that of increasing tree cover to 10% as recommended internationally and as one of the vision 2030 flagship projects. Save for the county annual reports which only emphasize on the forest management and extension services work to increase tree cover as one of the means to achieve vision 2030, no records were found indicating that research has ever been done in this county to determine the extent of timber usage as a construction material.

Timber is widely used in construction and also used for other purposes which makes it an important natural resource. Practical and sustainable steps need to be taken to save this resource for use by the current and future generations. The government needs to come up with policies to safeguard its prudent use and increase its availability to counter higher demand. In an effort to achieve this, the government has undertaken forest rehabilitation, protection and management of plantations of the four main forest stations in Kirinyaga County. These stations include Kangaita, Castle, Kathandeini and Njukiini. Kamuruana and Murinduko are isolated but attached to Kangaita and Njukiini forests respectively. Figure 4.4 shows the percentage acreage of government forests in terms of type and category.The total gazetted forest area in Kirinyaga County is 30867.02 hectares.

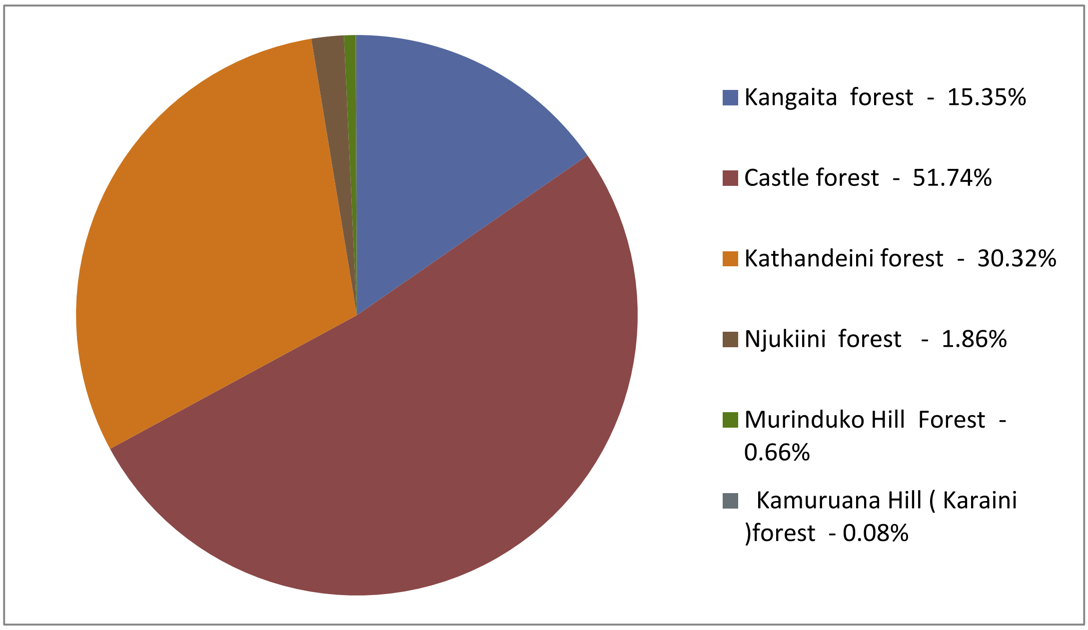

Figure 4.4: Percentage acreage of government gazetted forests in the fourconstituencies in Kirinyaga County. (Source: Kirinyaga County Forestry Annual Report , 2012)

Kangaita forest borders Mt Kenya forest in Kirinyaga Central Constituency. It is located in the well-endowed highlands which has a favorable climate for both the indigenous and exotic forest plantations. Castle forest also borders Mt Kenya forest in Kirinyaga East Constituency. It is also on the wetlands well-endowed with a favorable climate and that is the reason it accounts for more than half of the county's forest cover. Kathandeini forest is in Kirinyaga East Constituency and borders Mt Kenya forest and Embu county. It comprises of both the exotic and indigenous trees.Njukiini forest is also in Kirinyaga East Constituency but on the relatively dry lower parts of the Constituency. It is situated about 2 kilometers from Mwea-Embu road. It is surrounded by arable farmlands on all sides and hence prone toto illegal logging. Murinduko hill forest is in Kirinyaga South Constituency. This constituency is on the lower parts of Kirinyaga which are relatively dry throughout the year and receives minimal rainfall. It is also about 5 kilometers drive from Mwea–Embu road. The forest is a combination of both the indigenous and exotic trees. The exotic trees are an effort of the forest rehabilitation by the government. It is also surrounded by arable farmlands and hence there is no room for extension. Kamuruana hill forest is also in Kirinyaga Central Constituency and borders arable farmlands therefore there is little room for extension.

Figure 4.5 also shows percentage acreage in hectares of different types of forests in Kirinyaga county. This shows clearly the effort being put in place by the government to rehabilitate our forests in an effort to boost productivity.

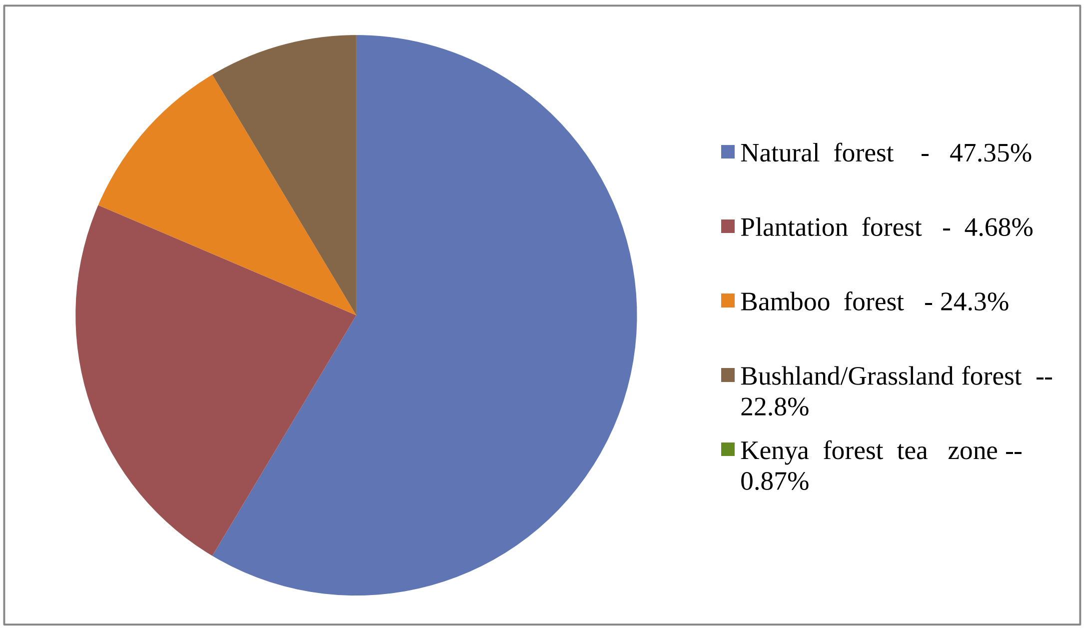

Figure 4.5: Percentage acreage of the government gazetted forests by category.(Source - Kirinyaga County Forestry Annual Report, 2012).

Natural forests cover 47.35% of the total forest area which is almost a half. This is as result of government intervention otherwise the percentage could have been lower as a result of exploitation. Plantation forest accounts for only 4.68%. The plantation mainly covers the exotic trees and it is planted by Kenya forestry service in an effort to rehabilitate our forests and thereby increase our tree cover. All bamboo and bush land forest also occur naturally. Kenya tea zone accounts for only 0.87% of the total forest area. The Kenya forest tea zone was initially part of Mt Kenya and was curved to form the current Nyayo tea zones replicated all over Kenya in tea growing areas.

To the intended objective of increasing tree cover and sustain the same, the government also needs to deal with some of the challenges facing forests management and its sustainability. These challenges include; forest fires, trees and seedlings being damaged by antelopes and elephants, damage by insects such as cutworms and army worms. Fungi and other pathogens also affect the trees and seedlings.Also, to achieve the recommended 10% tree cover, farm forestry has been much emphasized in extension work. Many farmers have been earning their living through the sale of their farm produce with an estimated Ksh79, 363,650 being realized. These earnings are realized from the sale of timber, transmission poles, posts, firewood, and sale of seedlings (Kirinyaga County Forestry Annual Report, 2012).Rapid deforestation, failure to use natural resources sustainably, poverty and poor methods of information dissemination are some of the root causes of higher demand of timber compared to its supply. However, due to increased sensitization, good government policies in place coupled together with increased global awareness, this trend is likely to be reversed in the near future.

4.1.6 Response from Kenya Power on Timber Usage

Question one touched on the question of whether Kenya Power uses other types of poles for transmission of power other than timber poles. Results show that timber poles accounts for 79%, concrete poles accounts for 20% while steel poles accounts for 1% of the poles. From these results, it is clear that timber remains a prefered construction material. From the results of this study, it was established that

Eucalyptus globules (Blue gum) was the most widely used. Information obtained from the Manager in charge of Kirinyaga County indicates that Kenya Power does not buy and treat the timber poles but instead relies on suppliers who buy from any part of the country, treat and then sell to the company. An example of these plants is the Line power Enterprises Ltd Plant located at Kwa V in Kirinyaga county. Plate 4.1 shows a pictorial view of a section of the plant.

Plate 4.1: Line power Enterprises Ltd Plant at Kwa V in Kirinyaga County.

Concrete poles are used for high power transmission lines carrying 33000 (33 kv) while timber poles are used for medium power transmission lines carrying 11000 (11 kv) and 240 volts. Some of the advantages of using concrete poles compared to timber poles is that concrete poles are durable and that they are also used in water logged areas. They are also used in towns so as to avoid regular replacing during maintenance periods which normally disturbs the consumers. Concrete poles also have an advantage in that they donot require preservative treatment and are impervious to weather. One of the disposal methods adopted by Kenya Power for the replaced timber poles is through selling off to the company's staff. The staff then uses or sells off to the members of the public who use it as fencing material or as firewood.

Another method by the Kenya Power to dispose off replaced timber poles is to re-use them for other minor transimission works where upgrade is being done before the poles lifespan is spent. On the question of timber poles availability, the company usually faces some constraints in acquiring only when the demand surges, i.e, when the company asks for the poles at a shorter notice. To ensure future sustainability of trees as a resource, the company undertakes corporate social responsibility (CSR) through afforestation and water towers preservation in conjunction with Kengen company.

4.1.7 Response from Tea Factory Production Managers on Timber Usage

Tea in Kirinyaga County is processed using either wood or furnace fuels. Results show that wood is the preferred option and the reason is that wood is cheaper than furnace oils. Wood also lowers the cost of production and is also environmentally friendly. Out of the five tea factories found in Kirinyaga County, all of them preferred using wood as their source of fuel.All the factories in the county, namely, Ndima tea factory in Kirinyaga West Constituency, Kangaita tea facory in Kirinyaga West Constituency, Mununga tea factory in Kirinyaga Central Constituency, Kimunye tea factory in Kirinyaga East Constituency and Thumaita tea factory in Kirinyaga East Constituency uses more than 20 tons of wood peryear. Forexample, Thumaita tea factory uses approximately 32,400 tons of woood per year.Kangaita tea factory used small quantitiesof furnace oils of between 0 to 5tons per year in addition to wood fuel. The types of tree species out of which wood is harvested are *grevilea robusta*, Eucalyptus, Cypress and Pine. Small quantities of fruit bearing trees such as Mango and Avocado are also used by the factories but on condition that the supplier produces a permit allowing them to harvest. The source of wood is from smallholder farms and Government gazetted forests.

The measures undertaken by the management boards of tea factories to ensure long term sustainability of trees as a resource include establishing of tree nurseries within the factory premises so as to sell the tree seedlings to farmers, neighbours and wood suppliers at subsidized prices. Some factories sell the tree seedlings at Kenya Shillings 1 per tree seedling. Factories also buy large tracts of land as much as 100 acres to plant their own forests for harvesting wood in future. Another measure undertaken by factories is to reduce consumption of wood at the point of use.The reduction is applied at the boiler by improving the boiler efficieny through the use of advanced boilers and improving on the existing boilers by fitting on the pre-heaters. Companies are also involved with the conservation efforts such as tree planting in public open lands and schools.

4.1.8 Response from Urban Household Dwellerson Cooking fuels Usage

Results of this study show that 11 out of the 50 sampled population in urban households used wood as a source of cooking fuel. This translates to 22% of the population. The rented apartments usually do not have open places to construct fireplaces and hence the low score of wood usage in urban households.Charcoal also remained an important source of cooking fuel for many urban hosehold dwellers albeit in small quantities. Out of the 50 sampled respondents, only 2 out of the 50 sampled respondents did not use charcoal as cooking fuel. This represents 4% of the population. Further, all those who used charcoal, each used less than 5 tons per year.

Among the sources of fuel used by urban household dwellers, gas is a preferred souce of fuel. The reasons advanced for its preference are that gas is quicker and economical compared to the other sources of fuel. Gas is also hygienic because it does not produce black smoke like in case of charcoal and firewood. Out of the 50 respondents sampled, only 14 did not use gas as their source of fuel. This represents 28% of the population. The 72% who used gas, used less than 5 tons of gas per year. Electricity was not used as source of cooking fuel but for other purposes such as heating water, lighting, ironing and for electrical appliances such as television sets and radios.

4.1.9 Response from Rural Household Dwellers on Cooking Fuels Usage

From the results, wood was a very popular source of fuel for rural household dwellers with a 100% of the sampled population preferring to use wood as a cooking fuel. The range of usage in tonnage per year is between 1.2 and 6. Twenty eight(28)% of the respondents used between 5-10 tons per year while the remaining 72 % used between 0-5tons per year. The high rate of wood usage is attributable to wood availability in the rural set up.Most of the rural household dwellers also used charcoal for cooking but in small quantities. Out of the 50 sampled population , 31 used charcoal. This represents 62% of the population. Each of those who used charcoal, used less than 5 tons per year. It was also established through these results that 22 out of the 50 sampled population used gas as a source of cooking fuel. This represents 44% of the population. Each of those who used gas, used less than 5 tons per year.A hundrend (100) percent of the entire population never used electricity for cooking except for other uses such as lighting, ironing and refrigeration. The reasons given for not using electricity for cooking was that it was expensive compared to other sources and for others there was no electricity in their homes.

4.1.10 Response from Furniture Makers on Timber Usage

On the question of the most widely used timber between hardwoods and softwoods, out of the 30 respondents surveyed, 27 of them said softwoods were readily available and commonly used. This represents 90%. Hardwoods take longer to mature than softwoods and most of them are normally found on the government gazetted forests. Other factors that have affected availability of hardwoods is the ban on logging and the many licencing procedures imposed to cut, transport and sell timber. The permits by area Chief, County government and Kenya Forestry Service are a requirement.The furniture makers source the timber for making furniture directly from farmers, saw mills and timber yards.

4.2 Assessment of Quality of Timber Used for Construction

4.2.1 Tree species

Species from different locations were sampled to get a true representative of the timber used as a construction material. The most common timber species sampled were *Grevillea robusta*, Cypress, *Cordia africana*, Eucalyptus and Pine. These samples were sourced from the four constituencies of Kirinyaga County, namely, Kirinyaga West, Kirinyaga Central, Kirinyaga East and Kirinyaga South constituencies.Generally hardwoods have a much higher compressive, static bending and shear strengths than softwoods and hence would make them the preferred choice for construction purposes.

From the results as shown in Table 4.3 above,hardwoods are in low supply in the region owing to the fact that they are mainly sourced from the government gazetted forests of which logging has been banned. *Cordia africana* and Eucalyptus are some of the hardwood species which can be seen in privately owned farms but also in very low quantities. *Cordia africana* type is grown in small quantities by farmers in their farms but not as a commercial activity. Over and above what was sampled, other timber species especially in the softwood category are used for timber requirements.An example of these types includes the avocado and mango trees.

4.2.2 Strength Characteristics of Timber and Moisture Content

Various strength tests of various sampled timber species were carried out to determine their strength characteristics. These tests included determination of static hardness, shearing stress parallel to grain, ultimate strength in static bending, compression perpendicular to grain and the moisture content. These tests were carried out at KEFRI with a view to correlate the results with what is generally recommended strength qualities ofconstruction timber.

a) Compressive Strength

Compressive forces in a material induce shear stresses and tensile strain leading to tensile stresses. Shear or tensile failure may result depending on the type of the material, shape of the specimen or the loading arrangement. Table 4.3 presents results of compressive strengths of the tree species at different mean moisture contents. Generally, timber in its green state has a lower compressive strength than when in its dry state. The test samples were sourced directly from the market to showcase the true mechanical characteristics of construction timber in use.To test compressivestrength ,BS373 (1995) standards was used as reference. The ratio in equation 4.0 was used. In this equation, L is maximum load in newtons, A is the cross-section area in mm² while C.S is compressive strength of timber in N/mm².

$$C.S = \frac{L}{A} x\ 1000 \qquad (4.0)$$

Table 4.3: Mean compressive strengths and mean moisture content for green timber

S/No	Specimen code	Mean.compressive strength, N/mm²	Mean moisture content(%)
1	Euc	35.1	54.0
2	Cord	34.9	16.8
3	Cyp	33.9	18.6
4	Gre	32.7	49.8
5	ES	50.1	56.4
6	PS	17.6	16.0
7	DN	23.6	18.6
8	DK	31.0	98.4
9	GN	20.7	104.3
10	NE	28.9	82.5
11	CS	21.6	54.4
12	DS	23.9	15.0
13	GS	25.6	100.4
14	GK	23.3	54.6
15	EK	45.8	26.8
16	CN	31.6	57.7

In the table: 1. Euc, Eucalyptus from Kagumo town (Kirinyaga central); Cord, *Cordia africana* from Kagumo town (Kirinyaga central); Cyp, Cypress from Kagumo town (Kirinyaga central); Gre, *Grevillea robusta* from Kagumo town (Kirinyaga central); ES, Eucalyptus from Sagana town (Kirinyaga west); PS, Pine from Sagana town (Kirinyaga west); DN, *Cordia africana* from Ngurubani town (Kirinyaga south); DK, *Cordia africana* from Kianyaga town (Kirinyaga east); GN, Grevillea from Ngurubani town (Kirinyaga south); NE, Eucalyptus from Ngurubani town (Kirinyaga south); CS, Cypress from Sagana town (Kirinyaga west); DS, *Cordia africana* from Sagana town (Kirinyaga west); GS, *Grevillea robusta* from Sagana town (Kirinyaga west); GK, *Grevillea robusta* from Kianyaga town (Kirinyaga east); EK, Eucalyptus from Kianyaga town (Kirinyaga east); CN, Cypress from Ngurubani town (Kirinyaga south).

Githiomi *et al*., (2001) found that *Eucalyptus Saligna* at a moisture content of 91.0% had a compressive strength of 39.9 N/mm² and 62.9N/mm² in its seasoned state, i.e., 12% moisture content. The same species, i.e.,(from Kirinyaga Central) had a compressive strength of 35.1N/mm^2 at a moisture content of 54.0%. *Cordia africana* had a compressive strength of 53.9 N/mm² in dry state i.e, at a moisture content of 12%. The same species from Kirinyaga Central attained a compressive strength of 34.9 N/mm² at a moisture content of 16.8 %. Cypress (*cupressus macrocarpa*) had a compressive strength of 43.1 N/mm² at a moisture content of 9.75% while the same species from Kirinyaga south had a compressive strength of 31.6 N/mm² at a moisture content of 57.7%. *Grevillea robusta* achieved a compressive strength of 28.0 N/mm² in green state, i.e.,122.7% moisture content while the same species from Kirinyaga E ast had a compressive strength of 23.3N/mm² at a moisture content of 54.6%. Pine (*pinus patula*) had a compressive strength of 68.9 N/mm² in dry state i.e., at a moisture content of 12% while the same species sourced from Kirinyaga West had a compressive strength of 17.6N/mm^{2}at a moisture content of 16.0%.

Taylor (2002) quotes compressive strengths of most softwoods when tested after seasoning i.e, 12% moisture content at 40N/mm².Out of the five tree species commonly used for sawn timber, three were softwoods representing 60%. The quality of construction timber in terms of strength partly depends on tree species with hardwoods having a much higher strength compared to softwoods. Among the strength tests carried out is the compressive strength. The compressive strengths of timber vary depending with the moisture content at the time of testing. Timber with high moisture will record a lower compressive strength than a similar sample in its dry state. In this study, sampled specieswere tested using the moisture content they had at that time. Sixty two (62.5) percent of all the sample species tested had moisture content above 30%. These species are: Eucalyptus from Kagumo town, *Grevillea robusta* from Kagumo town); Eucalyptus from Sagana town,*Cordia africana* from Kianyaga town, Grevillea from Ngurubani town, Eucalyptus from Ngurubani town, Cypress from Sagana town, *Grevillea robusta* from Sagana town, *Grevillea robusta* from Kianyaga town, Cypress from Ngurubani town. Thirty seven and a half(37.5) % of the rest had moisture content of below 30% and they are the following:*Cordia africana* from Kagumo town, Cypress from Kagumo town, Pine from Sagana town, *Cordia africana* from Ngurubani town, *Cordia africana* from Sagana town and Eucalyptus from Kianyaga town.Sixty eight(68) % of all the tested samples of timber had a moisture content of more than 20%.

Timber with moisture content above 20% is prone to shrinkage, distortion and fungal growth. This type of timber is also unworkable (Chudley *et al.*, 2011). High moisture content percentages also affects negatively the compressive strength and almost all other mechanical properties such as static bending and shear strength. Timber for construction purposes with high moisture content needs to be seasoned for it to have the appropriate moisture content for use. Depending on the atmospheric conditions, timber will equilibrate to certain moisture content. An advantage of reducing the water content to below 20% level is arresting of any incidence of fungal decay which commences above the level of 20% moisture content. Seasoned timber has the ability to resist fungal attack, it is stronger, is lighter compared to unseasoned timber and therefore it is easier to handle/transport. It is also easier to work with, glue, paint and preserve. As stated earlier in literature review, a moisture content of below 25% causes a marked increase in most of mechanical properties such as compressive strength, bending strength, shearing strength, among others.From the results (Table 4.4), a sample of Eucalyptus from Kagumo town had a moisture content of 54% with a compressive strength of 35.1 N/mm^2 while the same species from Kianyaga town had a moisture content of 26.8% with a compressive strength of 45.8 N/mm^2.

The high levels of high moisture content of most species experienced in this county and the fact that timber is immediately used as soon as it is sawn shows that the quality of the timber used is greatly compromised. For the purpose of this study, samples of well seasoned timber i.e, at a moisture content of 12% were not tested because the aim of the study was to report the quality aspect of timber within this county as it is used.

b) Hardness

Janka hardness test is a test that measures the hardness of timber, i.e, resistance of timber to identation. In this test, the load in kN required to press a steel ball 11.3mm diameter into a timber to a depth equal to its radius is measured. Table 4.4 shows the results of the mean loads required to cause identation when measured separately along the tangential and radial sides of the tested samples and also at various initial moisture contents. In this test, the mean load to cause indentation along the tangential side and the one along the radial side were calculated. From the results of this test and the results of a study carried out by Githiomi *et al*. (2001), a comparison can be made. For example, when *Cordia africana* was tested at 12% moisture content, it required 2.2kN on the radial side and 2.4 kN on the tangential side to cause indentation while the same species from Kirinyaga Central required 2.61kN on tangential side and 2.62kN on radial side, respectively, at a moisture content of 18.0%. Results by Githiomi *et al.* (2001) indicate that *eucalyptus saligna* required 8.78kN on the radial side and 9.34kN on the tangential side to cause indentation when tested at a moisture content of 12% while the same species from Kirinyaga East required 3.38kN on tangential side and 3.17kN on radial side, respectively, at moisture content of 27.76%. Again, results by Githiomi *et al.* (2001) indicate that pine panister required a load of 2.70kN on the radial side and 4.01 kN on the tangential side to cause indentation when tested at a moisture content of 12% while the same species from Kirinyaga West showed that a load of 1.7kN both on the tangential and radial sides, respectively, was required at a moisture content of 18.0%.

Table 4.4: Mean loads to cause indentation for various initial moisture contents of the species tested

S/No	Specimen code	Mean load on tangential(kN)	Mean load on radial(kN)	Mean moisture content (%)
1	EUC	3.8	3.3	57.8
2	GRE	3.0	2.8	49.1
3	CYP	2.0	2.0	18.6
4	CORD	2.6	2.6	18.0
5	GK	2.9	2.8	59.9
6	GN	2.4	2.2	109.7
7	PS	1.66	1.7	18.0
8	GS	2.9	2.9	97.0
9	NE	2.3	2.5	91.7
10	CS	2.0	1.9	64.1
11	EK	3.4	3.2	27.8
12	DK	2.6	3.0	115.2
13	DN	0.9	1.1	21.0
14	ES	3.8	3.6	47.4
15	DS	1.9	1.7	17.2
16	CN	2.3	2.1	45.7

Hardness test is done to measure the resistance of a sample of wood to denting and wear. It measures the force which is required to embed an 11.3mm steel ball into a wood to half the balls diameter. This type of test is commonly used to determine species suitability to flooring. For the purposes of this test, reference was made from KEFRI and KEBS. In KEFRI, the testing manual has been adapted from (BS 373, 1995) and provides for testing procedure, calculation of results and expression of results in Newton as a unit of measurement.

Taylor (2002) notes that the load required for typical dry softwoods to cause identation is approximately 3kN while for hardwoods it could be twice this figure. From the results in (Table 4.4) above, about 88% of all the softwood species tested posted a load of less than 3kN on tangential side while 100% of all softwood species tested posted a load of less than 3kN on radial side to cause identation. For the category of hardwoods, all the tested samples posted a load of less than 6kN which could be ideal as suggested by Taylor. Figure 4.6 shows result of the mean loads required to cause identation in kilonewtons(kN) both on the tangential and radial sides for two sets of tests, one carried out by Githiomi *et al.* (2001) on cypress(*cupressus macrocarpa)* with a moisture content of 10.29% and the other set is for this study with a moisture content of 64.1%. The test result data for this study is derived from table 4.4 whose sample specimen was sourced from Sagana town. The test results showed that an average load of 2.0and 1.9kN was required to cause identation for the tangential and radial sides, respectively. The sample size was six.

The test result data for the study by Githiomi *et al.* (2001) is derived from tests on sample specimens sourced from Mt Kenya region. The test results showed that an average load of 3.505 and 3.108kN was required to cause identation for the tangential and radial sides, respectively. The sample size was18. It is instructive from the results that the timber containing high moisture content percentage required less load to cause identation than the one with lower moisture content percentage. Figure 4.6 shows a comparison of mean loads to cause identation of two test results, i.e., one with a moisture content of 10.29% and the other 64.1%.

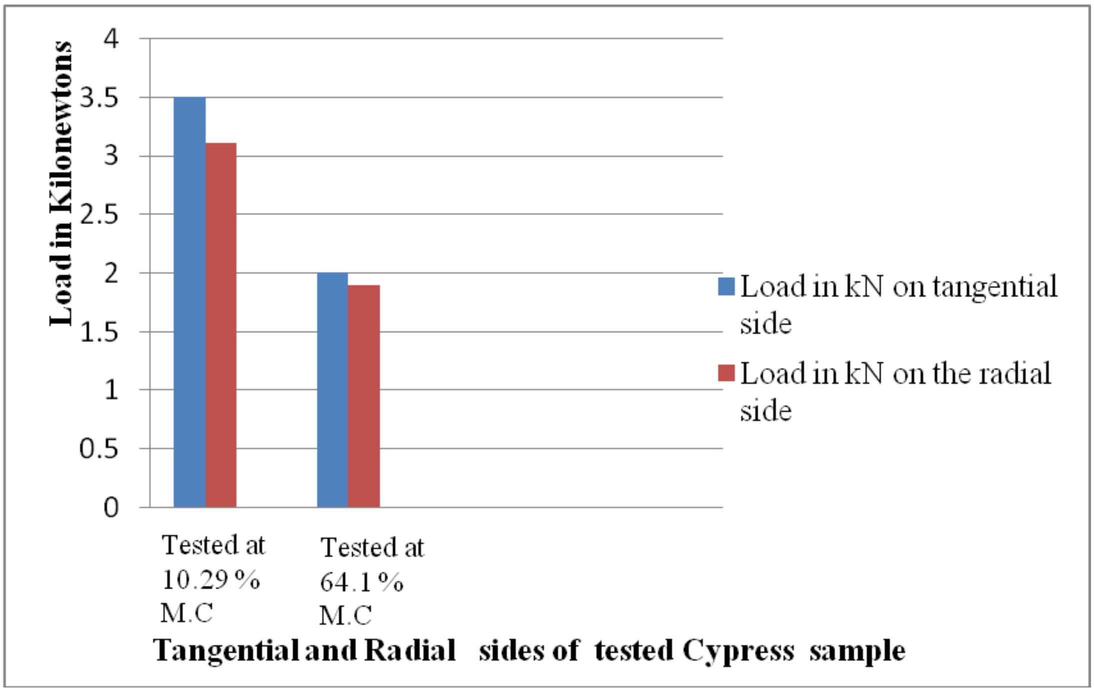

Figure 4.6: Acomparison of mean loads to cause identation with a moisture content of 10.29% and 64.1% of cypress(cupressus macrocarpa).

c) Static Bending

Bending tests can be carried out on simple beams constructed of different materials to determine their behaviour under the loading. The ductility value of a material can be described as the ability of the material to suffer plastic deformation while stilll being able to resist applied loading. The more ductile a material, the more it is said to have the ability to deform under applied loading (Case, 1999).Woods are visco-elastic solids and on loading, they show an immediate elastic deformation followed by a further slow creep or "delayed'' elasticity (Ashby, 2006). Table 4.5 presents the results of the mean load (P_1), the extension (e), the modulus of elasticity (e) and modulus of rapture (MOR) of all tested samples.

Table 4.5: Test results for mean load , extension, modulus of elasticity and modulus of rapture

Specimen code	P_1(kN)	e(mm)	E (N/mm²)	MOR (N/mm²)
GRE	0.89	3	30413	73.33
EUC	1.03	3.08	35443	76.72
CORD	0.72	3.08	24810	65.01
CYP	0.76	3.5	26125	62.74
CN	0.81	3.33	27897	77.75
DK	0.84	4.08	28698	68.25
GN	0.72	4.17	21248	49.79
CS	0.64	5.08	21781	46.81
EK	1.26	3.25	43047	91.79
NE	0.95	3.08	32414	66.59
DN	0.79	3.83	27040	51.01
PS	0.72	3.9	24833	52.08
ES	1.42	3.25	48820	104.13
GK	0.74	4.08	25268	48.65
DS	0.66	3.1	22467	48.48
GS	0.84	4.3	28812	59.41

In the table: 1. Euc, Eucalyptus from Kagumo town (Kirinyaga central); Cord, *Cordia africana* from Kagumo town (Kirinyaga central); Cyp, Cypress from Kagumo town (Kirinyaga central); Gre, *Grevillea robusta* from Kagumo town (Kirinyaga central); ES, Eucalyptus from Sagana town (Kirinyaga west); PS, Pine from Sagana town (Kirinya west); DN, *Cordia africana* from Ngurubani town (Kirinyaga south); DK, *Cordia africana* from Kianyaga town (Kirinyaga East); GN, Grevillea from Ngurubani town (Kirinyaga south); NE, Eucalyptus from Ngurubani town (Kirinyaga south); CS, Cypress from Sagana town (Kirinyaga west); DS, *Cordia africana* from Sagana town (Kirinyaga west); GS, *Grevillea robusta* from

Sagana town (Kirinyaga west); GK, *Grevillea robusta* from Kianyaga town (Kirinyaga east); EK, Eucalyptus from Kianyaga town (Kirinyaga east); CN, Cypress from Ngurubani town (Kirinyaga south).

To arrive at values in Table 4.5 above, i.e.,P_1(kN), e (mm), E (N/mm²) and MOR (N/mm²), a load deflection curve was drawn with x-axis denoting the deflection in millimetres and y- axis denoting load in kilonewtons. From the table, P_1 is the maximum load in kilonewtons applied to cause shear at the proportional limit and it is directly read from the curve. Note that e is the extension which is the reading in millimetres where deflection at proportional limit occurs measured in millimetres. MOE is the modulus of elasticity.

The ratio, E = $\frac{P^1(280)^3 X\,1000}{4ebd^3}$is used to determine the Modulus ofelasticity (e) where p^1

is the maximum load in Kilonewtons at the proportional limit read from the curve, e is the extension in millimetres at p^1 , b is the width in millimetres of the specimen that has been tested while d is the depth in millimetres of the specimen that has been tested.

MOR is the modulus of rapture., the ratio, MOR = $\frac{3 \text{ x max load x } 280 \text{ x } 1000}{2bd^2}$, is used to

determine the modulus of rapture (MOR) where b is the width in millimetres of the specimen that has been tested and d is the depth in millimetres of the specimen that has been tested.The values of modulus of rapture (flexural strength) MOR of most seasoned softwoods is normally in the region of 70N/mm². Out of the sixteen tested samples, eleven of them had MOR’s of less than 70 N/mm² which translates to about 69%.

Static bending is of primary importance in timbers subjected to transverse bending and in most seasoned softwood timber,it is typically in the region of 70N/mm² (Taylor, 2002). Results of Githiomi *et al.,* shows that *grevillea robusta* in its green state had an MOR of 55N/mm² and MOE of 8.853x10³N/mm² while those from this study shows that *grevillea robusta* from Sagana town had an MOR of 59.41N/mm² and an MOE of 28.812x10³ N/mm². Further, results of Githiomi *et al* shows that pine (*pinus patula*) in its green state had an MOR of 20.817N/mm² and MOE of 4.483x10³N/mm² while those from this study shows that pine (*pinus patula*) from Sagana town had an MOR of 52.08N/mm² and an MOE of 24.833x10³N/mm². For static bending, there was no records in Kirinyaga County to show that such a study was ever carried out. The high percentage of moisture content in timber contributes to abnormal timber defects such as fungal decay, brittle heart, distortion among others which ultimately reduces strength considerably.

d) Shear Strength

Table 4.6 presents results of the shear tests. Sample sizes of 20x20x20 mm clear specimens of various tree species were tested using the universal testing machine. The shear strength is either tested parallel to the grain (along the radial lines) or tested perpendicular to the grains (along the tangential lines). The shear strength of timber tested parallel to the grain is low. It is about 11N/mm² for seasoned softwoods. When the same timber is tested perpendicular to the grains, the shearing strength is high (Taylor, 2002). In this study,the maximum load to cause shear was measured both along the tangential and radial sides of the test samples respectively. Ordinarily, it would have been expected that since shear strength is normally high along the tangential side, all the results obtained for all species could have shown a higher load to cause shear on tangential side than on the radial side but this was not the case. The variances that existed in terms of moisture content percentages during the time of testing is a factor that could have caused the differences.

Table 4.6: Shear test results

Specimen code	Mean initial weight	Shear strength (N/mm²) on tangential	Shear strength (N/mm²) on radial	Mean oven dry weight
CN	5.9	12.0	9.6	3.7
DK	7.1	8.8	11.6	3.9
GN	7.5	7.8	6.1	3.9
CS	5.5	9.6	9.0	3.5
EK	6.4	12.5	9.5	5.0
NE	7.1	9.3	8.8	4.0
DN	3.5	7.2	7.6	2.9
PS	4.1	9.4	9.6	7.0
ES	8.1	10.7	11.7	5.5
GK	6.5	8.8	9.7	4.4
DS	3.5	8.3	8.4	3.1
GS	8.1	9.3	10.4	4.3

In the table: ES, Eucalyptus from Sagana town (Kirinyaga west); PS, Pine from Sagana town (Kirinyaga west); DN, *Cordia africana* from Ngurubani town (Kirinyaga south); DK, *Cordia africana* from Kianyaga town (Kirinyaga east); GN, Grevillea from Ngurubani town (Kirinyaga south); NE, Eucalyptus from Ngurubani town (Kirinyaga south); CS, Cypress from Sagana town (Kirinyaga west); DS, *Cordia africana* from Sagana town (Kirinyaga west); GS, *Grevillea robusta* from Sagana town (Kirinyaga west); GK, *Grevillea robusta* from Kianyaga town (Kirinyaga east); EK, Eucalyptus from Kianyaga town (Kirinyaga east); CN, Cypress from Ngurubani town (Kirinyaga south).

The results in Figure 4.7 shows two test results of the shear strengths of *Eucalyptus saligna*. The first set shows results of Githiomi *et al.* (2001) while the second set show results of this study.

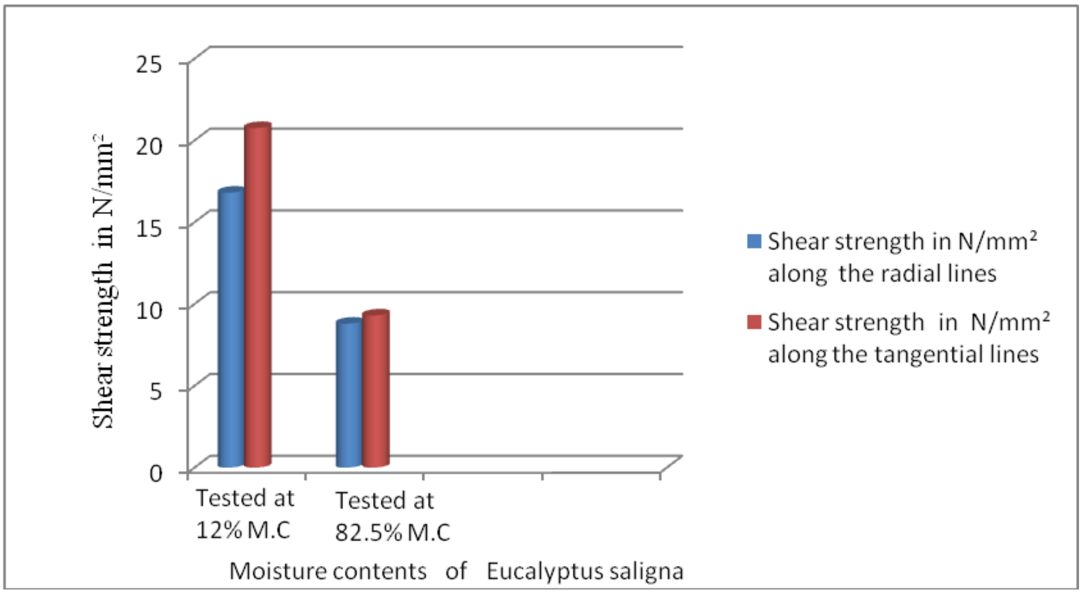

Figure 4.7: A comparison of shear test results in N/mm² with a moisture content of 12% and 82.5% of Eucalyptus saligna.

The species *Eucalyptus saligna* tested by Githiomi *et al.*is dominantly grown in highlands between 1200 and 2400 metres above the sea level. This particular one was sourced from Muguga in Kiambu County. Its shear strength measured along the tangential side was 20.76 N/mm² while its shear strength measured along the radial side was 16.81 N/mm². The moisture content during the time of testing was 12% and the sample size was 52.

The species *Eucalyptus saligna* from which the results of this study are derived is dominantly grown in highlands between 1200 and 2400 metres above the sea level. This particular one was sourced from Ngurubani in Kirinyaga County with the results data of its shear strength documented in table 4.6 of this report. It is shear strength measured along the tangential side was 9.3N/mm² while its shear strength measured along the radial side was 8.8 N/mm². The moisture content duringthe time of testing was 82.5% and the sample size was 6. Clearly as seen from results, the test results from the sample with a high moisture content % has lower shear strength values.

e) Moisture content and its influence on structural strength of timber

Table 4.7 shows the results of mean moisture content percentages of all the samples tested. Six samples of each tree species were weighed in wet basis, oven dried, weighed when dry and then an average calculated to arrive at mean moisture content percentage. Equation 3.4 was used in calculation of moisture content percentage. From the results of the study, it is noted that a 100% of the timber used in the county had a moisture content of more than the recommended 12%. About 0.06% of some species from different locations registered moisture contents of more than 100%. When a tree is felled, it contains a very large amount of water.This moisture exists as either free water that is contained as liquid in the pores or as bound water that is trapped within the cell walls. Taylor (2002) notes that green timber contains large quantities of moisture, typical average figures for softwoods being 130% (sapwood) and 60% (heartwood). When tested dry, the compressive strength of most softwoods is about 40N/mm² (Taylor, 2002). Generally, higher moisture content considerably affects negatively other mechanical properties of timber.

Table 4.7: Mean moisture contents

S/no	Specimen code	Mean moisture content %
1	Euc	54.0
2	Cord	16.9
3	Cyp	18.6
4	Gre	49.8
5	ES	56.4
6	PS	16.0
7	DN1	18.6
8	DK	98.4
9	GN	104.3
10	NE	82.5
11	CS	54.4
12	DS	15.0
13	GS	100.4
14	GK	54.6
15	EK	26.8
16	CN	57.7

In the table: 4.7. Euc, Eucalyptus from Kagumo town (Kirinyaga central); Cord, *Cordia africana* from Kagumo town (Kirinyaga central); Cyp, Cypress from Kagumo town (Kirinyaga central); Gre, *Grevillea robusta* from Kagumo town (Kirinyaga central); ES, Eucalyptus from Sagana town (Kirinyaga west); PS, Pine from Sagana town (Kirinyaga west); DN, *Cordia africana* from Ngurubani town (Kirinyaga south); DK, Cordia Africana from Kianyaga town (Kirinyaga east); GN, Grevillea from Ngurubani town (Kirinyaga south); NE, Eucalyptus from Ngurubani town (Kirinyaga south); CS, Cypress from Sagana town (Kirinyaga west); DS, *Cordia africana* from Sagana town (Kirinyaga west); GS, *Grevillea robusta* from Sagana town (Kirinyaga west); GK, *Grevillea robusta* from Kianyaga town (Kirinyaga east); EK, Eucalyptus from Kianyaga town (Kirinyaga east); CN, Cypress from Ngurubani town (Kirinyaga south).

From the test results of this study, it is established that an increase in moisture content may not always lead to a reduction in compressive strength. As evidenced by the results of eucalyptus from Sagana town which showed a higher moisture content and a higher compressive strength than eucalyptus from Kagumo town as shown in Table 4.4. The results show that the strength characteristics of a particular species is not necessarily affected by one aspect but a combination of other factors which could come into play.Figure 4.8 pesents an explanation of how higher moisture content percentages affects negatively various mechanical properties such as the compressive strength of *grevillea robusta* sampled from four stations namely Kagumo town, Kianyagatown, Sagana town and Ngurubani town. The data for Figure 4.8 is derived from Table 4.4 of this report.

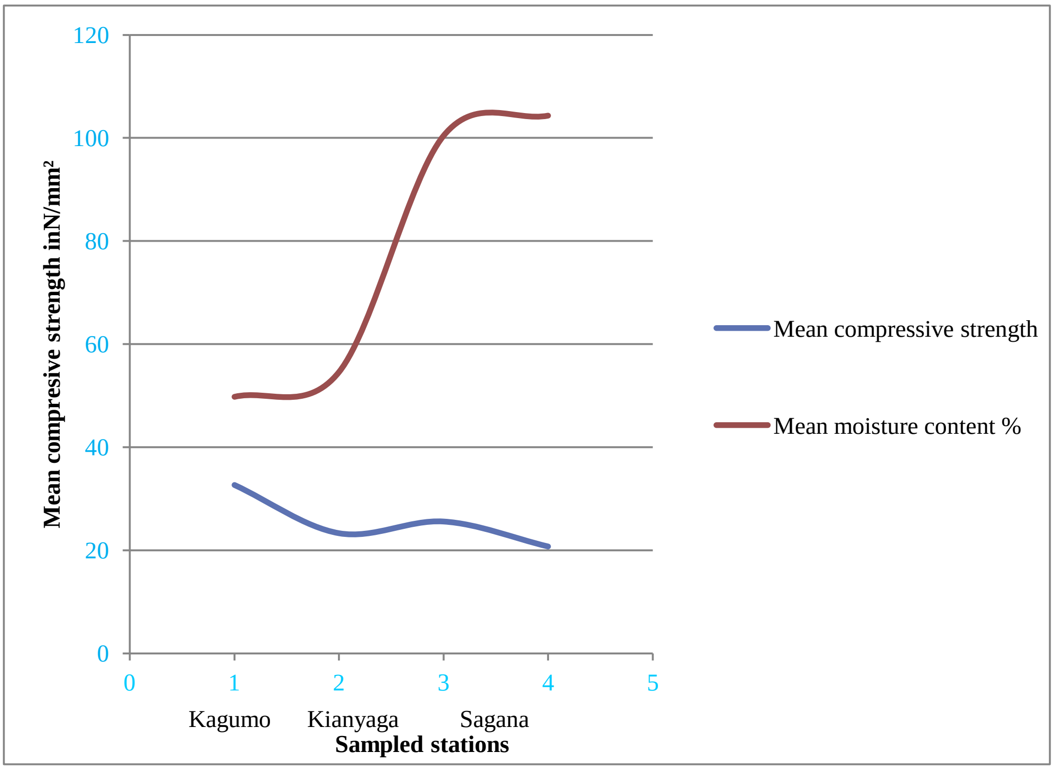

Figure 4.8: An observation between compressive strengths and mean moisture of *Grevillea robusta*.

Four test results of *grevilea robusta* sourced from four different locations are analysed as follows. *Grevilea robusta* from Kagumo town in Kirinyaga Central Constituency had a compressive strength of 32.7N/mm² and a moisture content of 49.8%. *Grevilea robusta* from Kianyaga town in Kirinyaga East Constituency had a compressive strength of 23.3N/mm² and a moisture content of 54.6%. *Grevilea robusta* from Sagana town in Kirinyaga West Constituency had a compressive strength of 25.6N/mm² and a moisture content of 100.4% and *grevilea robusta* from Ngurubani town in Kirinyaga South Constituency had a compressive strength of 20.7N/mm² and a moisture content of 104.3%, respectively. From the tabulation of the results of compressive strengths and their respective moisture contents of *grevillea robusta* as sourced from four diferent locations, it is evident that higher moisture contents percentages gives lower compressive strengths.

Figure 4.9 shows a relationship between compressive strengths and mean moisture content percentages of eucalyptus from diferent locations in Kirinyaga County. From the test results as shown in Figure 4.9, Eucalyptus from kagumo had a compressive strength of 35.1 N/mm² and eucalyptus from Ngurubani had a compressive strength of 28.9N/mm². This translates to a reduction of 6.2N/mm². The moisture content % of Eucalyptus from kagumo was 54.0% while the moisture content % of Eucalyptus Ngurubani was 82.5% which translates to a difference of 28.5%. From that analysis, and as is expected, the compressive strength reduced considerably as the level of moisture content increased.

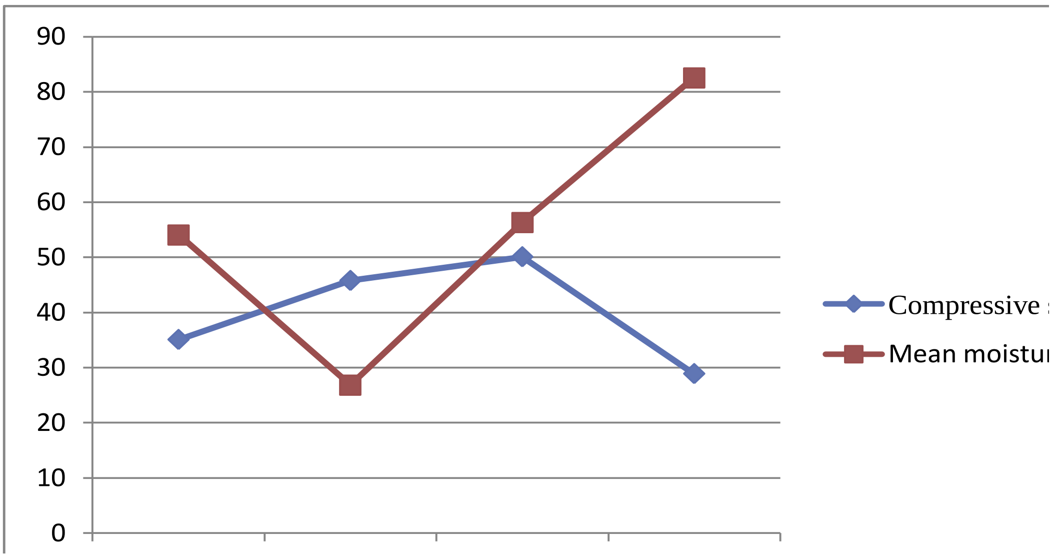

Figure 4.9: An observation between compressive strengths and mean moisture of Eucalyptus.

Quality control is a process of checking and monitoring of production which leads to a product of consistently satisfactory standards. In this study, there was actually no documentary evidence to show that any form of quality control was being undertaken by contractors. The failure to undertake the process of quality control could be attributed to rigorous process and the cost factor of the whole undertaking. The only rough check quality control undertaken by contractors on site is to physically check for common timber defects such as warping and shakes. A rough physical check is also done by most timber users in terms of the moisture content and the age factor of a particular tree. In particular, *grevillea robusta* shows a whitish colour if not mature and a redish colour when mature. These rough checks are merely sufficient for determining various structural properties of various types of timber.

4.2.3 Physical Attributes of Common Timber Species in Kirinyaga County

Timber as a natural resource is prone to defects(imperfections) which occur naturally in the tree as they grow or result out of converson or seasoning.From this study, a visual physical check up of mostly used timber species in the county was carried out to identify the common timber defects. No effort was made to measure the sizes of the defects. These tree species were: *Grevillea robusta*, Eucalyptus, Pine, *Cordia africana* and cypress. From the results of this study, it was established that there was presence of the following common timber defects:bow, spring, twist, cup, wane, knots,splits and bark and resin pockets. AYDIN*et al*. (2007), notes that the presence of defects such as checks,cross grain, knots,pitch pockets, shakes and warp causes considerable reduction in the mechanical properties of timber. Plate 4.2 shows some of the common timber defects identified.

Split Defect **Knot Defect**

Cup and Twist Defects **Bow Defect**

Plate 4.2: Common timber defects.

Bow and cup were common defects. Cup is a curvature of a piece of sawn timber across its width and affects timber during the drying process when moisture escapes to the atmosphere. Timber in Kenya is graded through Visual stress grading as either general structural grade(GS) or special structural grade(SS) according to KS 02-771:1991. KS 02-17: 1986 also gives specification for sawn timber which also outlines the maximum permissible defects for various grades of sawn timber in accordance with the limitations given in tables 2-5 of the standard.

According to KS 02-771:1991, knots of less than 5mm diameter may be ignored without giving a distinction whether they are knot holes, dead knots or live knots. The standard specifies that the slope of grain shall not exceed 1 in 6 for general structural grade and 1 in 10 for special structural grade. To grade timber with fissures and Resin and bark pockets, the standard specifies that if the size of the defect is less than or equal to half the thickness of the piece, then the fissures may be unlimited in number wherever they occur in the piece. In regard to distortion such as bow, spring, twist or cup to an excessive extent, the standard specifies that such timber shall be rejected, However, for seasoned timber(timber with 15% or less moisture content according to standard specification), the following tolerances are specified.Bow shall not exceed one half of the thickness in any 3 m length. Spring shall not exceed 15mm in any length. Twist shall not exceed 1 mm per 25mm of width in any 3 millimetre length. Cup shall not exceed 1/25 of the width. In reference to abnormal defects, the standard specifies that all pieces showing fungal decay, brittleheart and other abnormal defects affecting strength shall be excluded.The results from this study(Table 4.7), show that 6.25% of timber used in the county had moisture content in excess of 15% as specified by KS 02-17:1986 and therefore was prone to abnormal defects which ultimately reduces timber strength.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. The study findings show that there is a correlation between continued increase in population each year and the demand of construction timber and wood based products which has continued to outstrip supply not just in Kirinyaga County but nationally as well. Softwoods such as *Grevillea robusta,* Cypress or Pine are commonly used in the region due to their availability with a limited use of hardwoods such as Eucalyptus.It is also evident that though the Government has put in place mechanism to conserve forests and sensitize residents on planting more trees, there is also widespread usage of wood and wood based products in other application areas such as electricity transmission by Kenya Power, five tea factories which use wood as fuel for tea processing and general usage by both urban and rural household dwellers.
2. Green timber with moisture content levels above 25% generally affects negatively most of the mechanical properties of timber. Results from this study shows that nearly 69% of timber in this region had a moisture cotent beyond this range. Results also show that the strength of timber also varies with the area it was harvested and not only on moisture content as seen in the following example. A sample of Eucalyptus from Kagumo town had a moisture content of 54% with a compressive strength of 35.1 N/mm^2 while the same species from Kianyaga town had a moisture content of 26.8% with a compressive strength of 45.8 N/mm^2. The use of timber as fast as it is sawn leaves no room for seasoning and hence compromises on the quality aspect.
3. From the findings of this study, it is evident that some of the timber samples being sold in timber yards had one or the other type of timber defects. Some of these timber defects include bow, spring, twist, cup, wane, knots, fissure, decay, borer holes, splits and borer and resin pockets. The defects in timber affects negatively the mechanical properties of timber and consequently comprises on

the quality aspect. Majority of contractors rarely took time to present construction timber for quality checks. High moisture content levels was also responsible for timber defects such as warping, rots, termites infestation among others.

5.2 Recommendations

1. To counter the shortage of timber in the county and at national level, both the county and national governments need to sustainably and deliberately sensitize the members of public on the need to plant more trees so as to enhance timber sufficiency. Both governments need to do even more by exploration of use of bamboo in application areas such as scaffold construction which has not been tried both at county and national level. This might save us on very many young trees that are normally harvested for that purpose.
2. To save on our trees which are a critical component of our environment, the government needs to encourage and promote use of alternative materials to timber such as composites and steel. This could be done through tax icentives for those importing and setting up industries to process steel and composites.
3. Prudent use of available timber is also critical in saving our trees. This could be done by encouraging the end users on the need to apply Taylor's concept of the green hierarchy i.e, reduce, recycle, re-use and recover. For example, thousands of tons of used up papers are burned every year, these papers could be recycled to process more papers instead of cutting trees to extract raw materials for making new papers. More industries to recycle papers would mean more employment and a reduction on those who rely on forests for their livelihoods.
4. To ensure use of timber with good structural strength, the government needs to devolve important institutions such as KEBS to counties so that the end users have easier access for timber testing purposes. Through legislation other institutions such as the National Construction Authority (NCA) should be empowered to enforce the use of good structural timber. End users of construction timber should be encouraged to use *Grevillea robusta* for structural

purposes upon seasoning and treatment. The use of Pine and Cypress for structural purposes should be continued as before because of ease of availability.

5. On physical properties, the government needs to sensitize the timber yard owners, saw millers and the contractors on timber curing, grading and preservative treatment so as to ensure that timber without defects is used especially for construction purposes. Controls such as stamping inspected timber could be employed.
6. The Government should register timber Sawmillers on the level of their expertise including grading, curing, and treatment in every county and at national level.

5.2.1 Further Research

For further research purposes, there is the need to do further research on timber in Kirinyaga County when the sample species moisture content is controlled at 12%. The scope should also be widened to other species not covered in this study and also some other tests not covered such as slope of the grain and creep factors. The study should also cover tests on behaviour of timber with defects in terms of structural strength.

REFERENCES

Abimaje, J., & Baba, A. N. (2014). An assessment of Timber as a Sustainable Building Material in Nigeria. *International Journal of Civil Engineering, Construction and Estate Management.*

Adebara, S.A, Hassan, H, Shittu, M.B, &Anifowose , M.A. (2014). Quality and Utilization of Timber Species for Building Construction in Minna, Nigeria. *The International Journal of Engineering And Science (IJES), 3(5).*

Annete Harte, & Keith Grey, "Reinforcement of Timber Structures", vol 97(2015), *Construction and Building Materials Special Issues.*

Anyonge, H. C.& Roshetko, J.M. (d.n). *Making the Forestry Pay*. Forestry department.

Ashby, M. (2009).*Materials and the environment*. Elsevier Inc.

Ashby, M. F. & Jones, D.R.H. (2006).*Engineering materials 2* (3rd ed.). Elsevier Ltd.

AYDIN serdar; YARDIMCI Mert yucel, (2007), Mechanical Properties of Four Timber Species Commonly used in Turkey: *Turkish.J.Eng.Env.Sci. 31 (2007), 19-27.*

Balkau, F. & Sonnemann, G. (2009). Managing sustainability performance through the value chain. *Corporate Governance*, *1*(10), 46-58.

Belassi, W., & Tukel, O. I. (1996). A new framework for determining critical success/failure factors in projects. *International Journal of Project Management,* 14(3), 141-151.

Berge, B. (2000). *The ecology of building materials (English ed.).* United Kingdom: Reed Educational and Professional Publishing Ltd.

Black, A.D. (2004). *Picking the Right Lumber is an important Decision*. Retrieved from http://www.cumberlink.com/fall-home/lumber.php.

BS 373: (1957). Methods for testing Small Clear specimens of timber.

BS EN 338. (2003). Structural timber – Strength classes.

BS EN 408, (1995) Timber Structures – Structural timber and glued laminated timber – Determination of some Physical and Mechanical properties.

Carsan, S. (2007). Small holder timber demand in Kenya: a thesis on sustainable agriculture.

Carson, S. &Christine, H. (2006).*Growing farm timber: Practices, markets and policies*.World Agroforestry Centre. Retrieved from http://www.worldagroforestry.org.

Case, J., Clever, L. & Carl, T.F.(1999).*Strength of materials and Structures*. London: Butterworth- Heinemann.

Chi Sun,P.(2013).Special Section on Recycling Wastes for Use as Construction Materials.*Construction and Building Materials Special ssues.40.*

Chikamai B.N, Githiomi J.K, Gachathi F.N, Njenga M.G, (2001).Commercial timber resources of Kenya, Kefri. Paper Line Ltd.

Collins, A., (2007). Community-based natural resource management in Kenya'.*Management of Environmental Quality: An International Journal*, *18*(5).

County Governments Act No 17 (Revised edition 2012). National Council for Law Reporting. Retrieved from http://www.kenyalaw.org.

Dawes, K.(2009). Workshop on Wood Mobilization, Grenoble. Retrieved from http://www.cepf. eu.org/artikkel.cfm.

Erdogan, T.Y. (2002). *Materials of Construction.* Ankara: METU Press.

Fewings, P. (2005), Construction Project Management: An Integrated Approach. Taylor and Francis.

Food and Agricultural Organization (2010).*Global Forest Resources Assessment*. Retrieved from http://www.fao.org.

Forestry department, (2005). Global Forest Resources Assessment Progress towards sustainable forest management. Fao Forestry paper , 147. FAO

Ganiron, Jr, T. U. (2014). Investigation on the Physical Properties and Use of Lumampao Bamboo Species as Wood Construction Material. *InternationalJournal of Advanced Science and Technology, 72.*

Geldenhuys, C. J. (2005). Basic Guidelines for Silviculture and Forest Management Practices in Mozambique. Report Number FW-04/05. Pretoria: Forest wood.

Gilbert, M.M, & Wendell, P.E. (2009). Environmental Engineering and Science (3rd ed.). PH Learning Ltd. 601-628.

Grundy, I.M. (2005).Age and determination of Miombo Species Brachystegia Spiciformis (Leguminose – Caesalpinoideal) in Zimbambwe using growth rings.*S.Afri.For.J.*, 5-16.

International Energy Agency (IEA) and Organization for Economic Co-opreation Development (OECD) (2002).*World energy outlook.* Retrieved from http://www.worldenergyoutlook.org.

Kenya Bureau of Standards (1990). Methods of test for determination of physical and mechanical properties of wood. (Part 1): Moisture content.

Kenya Bureau of Standards ,(1990). Methods of test for determination of physical and mechanical properties of wood. Part 9. Static hardness.

Kenya Bureau of Standards, (1990). Methods of test for determination of physical and mechanical properties of wood.Part 4. Ultimate strength in static bending.

Kenya Bureau of Standards, (1990). Methods of test for determination of physical and mechanical properties of wood.Testing in compression perpendicular to grain.

Kenya Bureau of Standards, (1990). Methods of test for determination of physical and mechanical properties of wood KS 02-982: (Part 12): Sampling and general requirements.

Kenya Bureau of Standards, (1990). Methods of test for determination of physical and mechanical properties of wood (Part 2): Density.

Kenya Bureau of Standards, asq.org/learn about - quality assurance and quality.control.

Kenya Bureau of Standards. (1990). Methods of test for determination of physical and mechanical properties of wood (Part 6): Ultimate shearing stress parallel to grain.

Kenya Bureauof Standards, (1991). Specification for softwood timber gradesfor structural use KS 02-771

Kenya Forestry Master Plan (KFMP) (1994). Development Programmes. Ministry of Environment and Natural resources, Nairobi.

Kenya National Bureau of Statistics, (2015). Facts and Figures. Republic of Kenya. Retrieved from http://www.knbs.or.ke

Kenya National Bureau of Statistics, (2010).The 2009 Kenya population and housing census. Republic of Kenya. Retrieved from http:// www.knbs.or.ke

Kenya Population Data Chart (1990-2016). Retrieved from http://www.tradeeconomics/kenya/population.

Kimani, N. (2013). *Natural Resource Governance and Multi-stakeholder Dialogue*. Kenya: Twaweza communications.

Korde, T., Li, M & Russel, A.D.(2005). State-of the art review of Construction Performance Models and Factors: Broadening perspectives. Construction esearch Congress 2005, The American Society of Civil Engineers.

Kothari, C.R. (2004). *Research Methodology-methods and techniques*. New Delhi: New Age International (P) Ltd.

Lakshmi, R. (2015). Quality Control and Quality Assurance in Building Construction. National conference on research advances in communication,computation, electrical science and structures (NCRACCESS-2015). Retrieved from http://www.internationaljournalssrg.org

Larsen, H. J. (2001). *Properties affecting reliability design of timber structures.* Department of structural engineering- Technical University of Denmark.

Lusigi, W. (1994). Social economic and ecological aspects for the multiple use of protected areas in Africa.

Lyons, Arthur (2007). *Materials for architects and builders (3rd ed.)*. London: Elsevier Ltd.

Machado, J. S., Riggio, M. P. & D'Ayala, D. D. (2015).*Assessment of Structural Timber Members by non and semi-destructive Methods (Vol 101 part 2)*: *Construction and Building Materials Special Issues*.

Manalo, A, Aravinthan, T., Karunasena, W.& Ticoalu. (2010). A review of alternative materials for replacing existing timber sleepers. Retrieved from http://www.elservier.com/locate/compstruct.

McAlpine, J. L. (2011). Reporting Forests. Retrieved from http://www.unep. org/forests.

Megson, T.H.G. (2005). *Structural and Stress Analysis (2nd ed).* Elsevier Ltd.

Mfahaya, N, Ngige, J, Nyambuto, N. (2009). Farmers Guide to Sustainable Farm Forestry Tree Species. Kenya Forestry Service.

Millenium Ecosystem Assessment, (2005). Ecosystems and Human Wellbeing: Biodiversity Synthesis. World Resources Institute, Washington D.C.

Ministry of Environment, Water and Natural Resources (2014).Kenya Forest Policy. Retrieved from http://www.kenyaforestservice.org

Ministry of Planning and Natural Development. (2007). Kenya Vision 2030. Republic of Kenya. Retrieved from http://www.Planning.go.ke.

Misonge, F.M. (2012). Annual report for the year ended December 2011. Kirinyaga County. Ref: D/1/2 Vol/88.

Mutai (2010, November 21). Dire Shortage of Timber Forcing Merchants to Import Commodity. Daily Nation.

Ngigi, T.G,& Tateishi, R.(2004). Monitoring deforestation in Kenya. *International Journal of Environmental Studies, 61*,281-291.

Odera, E.C.& Chikamai, E.N. (2011). Kenya Forestry Research Institute. Significant Achievements 1986 to 2011. Print Maxim.

Owoyeni,J.M,Fuwape, J.A & Olaniran, O.S. (2010), The Role of Wood Preservation in Sustainable Supply of Forest Products. Proceedings of 33rd Annual conference of the forestry association of Nigeria. Vol. 2 pp 178-186.

Perera, P.K.P, Amarasekera, H.S., & Weerawardena, N.D.R. (2011). Effect of Growth Rate on Wood Specific Gravity of Three Alternative Timber Species in Sri lanka: *Switenia macrophylla,Khaya senegalensis and Paulownia fortune*. *Journal of Tropical Forestry and Environment* 2(1).

Pheng, L.S. (2006). Managing building projects in ancient China. *Journal on management history.*

Rakesh Gupta & Sinha, Arijit. (2012). Effect of Grain angle on Shear Strength of Douglas – fir wood. Holforschung, 66, 655- 658.

Rodenburg, E. (2000). The Limits of Supply. US Geological Survey .

Roy Chudley&Roger Greeno. (2001). *Construction Technology (5th ed.)*. New delhi: Pearson Education Limited, 196-207.

Sangeeta, B., Gudavali, S., Babu, M.S. & Biswas, S. (2009). Composites as building material: Indian scenario. Retrieved form http://www.tifac.orgiln -

Sebastian, W., Piazza, M., & Tomasi, R. (2016).State-of-the-art in Timber.*Materials and Structures in Building and Construction materials, 102*(2).

Shen, Y.& Gupta, R.(1995). *Evaluation of Creep behaviour of Structural Lumber in a Natural environment: Wood Engineering*.

Steiner, A. (2011). *Reporting Forests*. Retreaved from http:// www.unep.org/forests

Tanui, J. (2006). *Incorporating a Land care Approach into Community Land Management Efforts in Africa. A case study of Mt.Kenya Region*.

Taylor, G.D. (2002). *Materials in construction (2nd ed.)*. UK:Pearson Education limited

Techinical Data Sheet,(2014).Moisture in Timber.Retrieved from, www.dtimber.com.au.

The Timber Act Chapter 386. (Revised Edition 2009). National Council for Law Reporting.

Timber Act Chap. 386, (2009). Kenya Law Reports. The National Council for Law Reporting.Retrieved from http://www.kenya law.org.

Timoshenko, S. (2002). *Strength of materials: Elementary theory and problems (3rd ed.).* New delhi: S.K.Chain for CBS Publishers and distributors.

UNEP. (2011). Reporting Forests: A journalists guide to the role of forests in sustainable development and human wellbeing. Reteived from, www.unep.org/forests.

United Nations Framework Convention on Climate Change (UNFCC),(2010), Retreived from, unfcc.int

United Nations, (2015).Population Division, Retreived from, www.un.org

APPENDICES

Appendix 1: Letter of Introduction

James M. Muthike

P.O. BOX 657-10100

Nyeri.

Cell phone: 0728702023

TO WHOM IT MAY CONCERN

Dear Respondent,

Re: Research Questionnaire

I am an MSc Student of Jomo Kenyatta University of Agriculture & Technology. This research study forms part of the requirements of the qualification. My research undertaking is to assess the extent of usage and quality of timber as a building material in Kirinyaga County. I would appreciate it if you would kindly take a little of your time to complete the attached questionnaire. Any information provided by you is purely for academic purposes and all responses will be treated with the strictest confidence. Your cooperation is most valued and appreciated. I take this opportunity to thank you in advance for your kind participation and quick return of your completed questionnaire.

Yours faithfully,

James M. Muthike

Appendix 2: Questionnaires

2.1. Questionnaires for Contractors

1. Between steel and timber, which of the two materials would be your preference for construction purposes and why?
2. Between hardwoods and softwoods, which is your preference for construction works and why your choice?
3. How do you ensure that timber used for construction purposes is seasoned?
4. What is the extent of availability of timber for construction purposes?
5. To your assessment, is the cost of construction timber relatively affordable?
6. Which scientific methods of testing construction timber do you employ to ensure quality is achieved?

2.2. Questionnaires for County Forest Officers

1. Is the county self-sufficient with its timber requirements?
2. Which are the most commonly used timber species in the county and why?
3. What are the steps being taken by your office to ensure that the future demand of timber does not outstrip supply?
4. What are the steps being taken by your office to ensure timber used for construction in the county is of high quality?
5. Are there national and international policy guidelines that regulate timber production and usage to ensure quality timber sustainability?

2.3. Questionnaires for Saw Millers

1. Where do you get wood as a raw material from?
2. Do you consider the age factor for trees when buying and if so how do you determine it?
3. How many years have you been operating the business?
4. Who are your potential customers? i.e., individuals or contractors?

2.4. Questionnaires for Timber Yard Owners

1. Which major species of timber do you buy and sell as construction material?

   (i) *Grevillea Robusta* (ii) Eucalyptus (iii) Camphor (iv) Cypress (v) Pine (vi) *Cordia Africana*

2. What quantities for each species do you sell annually?

	Quantity (tons)			
Species	0-5	6-10	11-20	> 20
(i) *Grevillea robusta*				
(ii) Eucalyptus				
(iii) Camphor				
(iv) Cypress				
(v) Pine				
(vi) *Cordia Africana*				

3. Whom do you normally sell the timber to?

   (i) Contractors (ii) Individuals (iii) Kenya Power (iv) Government departments (v) Furniture makers

4. What proportion of the timber you sell do each of the categories listed in Question 3 above?

	Proportion (%)			
Category	0-25	26-50	51-75	76-100
(i) Contractors				
(ii) Individuals				
(iii) Kenya Power				
(iv Government dept				
(v) Furniture makers				

5. For what purpose do they (the customers) use the timber for construction?

   (i) Roofing (ii) Finishes such as doors, windows, wardrobes, etc.

   (iii) Flooring (iv) Formwork (v) Furniture

6. The timber readily available in Kirinyaga County?

   (i) Yes (ii) No

7. If your answer in Question 6 above is "No", then where do you buy the timber from?

   (i) Nyeri County (ii) Murang'a County (iii) Embu County (iv) Neighbouring Countries i.e., Tanzania (v) Imported from abroad.

8. How much do you buy from outside Kirinyaga County when compared with what is bought in the County?

   i) 0-25% (ii) 26-50% (iii) 51-75% (iv) 76-100%

9. Apart from construction, what other purposes is the timber used for?

i) Poles for fencing (ii) Fire wood (iii) Wooden boxes (iv) Railway sleepers

(v) Wood pallets

2.5 Questionnaires for Kenya Power

1(a) Kenya power has been using timber poles for transmitting power for a long time now. Which other types of transmission poles is it adopting currently? (i) Concrete poles (ii) Steel poles

(b) In terms of a percentage scale, state the amount of poles currently being used in each category i.e., Timber, Concrete and Steel.

2.Which type of tree species is the timber poles used by your company belong to?

(i) *Grevillea Robusta* (ii) Eucalyptus (iii) Camphor

(iv) Cypress (v) Pine (vi) *Cordia Africana*

3.What are some of the advantages of using concrete poles compared to timber poles?

(i) Concrete poles are durable (ii) Do not require preservatives (iii) available in long lengths and wider section sizes.

4.What other uses or disposal methods are adopted by your company for timber poles which have been replaced.

(i) Sold as fencing posts (ii) Sold as firewood (iii) cut into small logs for support to other power transmission poles. (iv) Burned down (v) Re used in other minor power transmission works.

5. Does Kenya power face constraints in acquiring the timber poles as a resource material?(i) Yes (ii) No

6. Is Kenya power company currently undertaking any measures to ensure future sustainability of trees as a resource?

2.6 Questionnaires for Tea Factory Managers

1.Tea could be processed using either wood or furnace oil types of fuels. Out of the two, which is your preferred choice and why the preference?

2.What quantities in tons do you use annually in either of the two fuels listed in 1 above?

	Quantity (tons)			
Species	0-5	6-10	11-20	> 20
(i) wood fuel				
(ii) Furnace fuels				

3.If wood is used as a fuel, which types of tree species is the wood harvested/processed from?

(i) *Grevillea Robusta* (ii) Eucalyptus (iii) Mango tree

(iv) Cypress (v) Pine (vi) Jacaranda

4. Again, if wood is used, where is the wood sourced from?

(i) Smallholder farms (ii) Government gazetted forests (iii) Imported

5.What measures is your company currently undertaking to ensure long term sustainability of trees as the source of wood fuel?

2.7 Questionnaires for Urban Household Dwellers

1.(a) What quantities in tons/Kilowatts of the types of cooking fuels listed below do you use per year?

	Quantity in tons/Kilowatts			
Type of fuel	0-5	6-10	11-20	> 20
(i) Gas fuel				
(ii) Charcoal				
(iii) Wood				
(iv)Electricity in Kilowatts				

(b) Out of the four types of cooking fuels listed above in 1(a), which is your preference and why the preference?

2. If in 1(b) above, wood is your preference, where do you source it from?

(i) Government gazetted forests (ii) Smallholder farms (iii) Saw mills

(iv) Timber yards (v) Other sources (specify)

3. Is wood readily available in the County whenever you want buy?

(i) Yes (ii) No

4. If your answer in Question 3 above is "No", then where do you buy the timber from?

(i) Nyeri County (ii) Murang'a County (iii) Embu County (iv) Neighbouring Countries i.e., Tanzania (v) Imported abroad

2.8. Questionnaires for Rural Household Dwellers

1.What quantities in tons/Kilowatts of the listed below types of cooking fuels fuels listed below do you use per year?

	Quantity in tons/Kilowatts			
Type of fuel	0-5	6-10	11-20	> 20
(i) Gas fuel				
(ii) Charcoal				
(iii) Wood				
(iv)Electricity in Kilowatts				

(b) Out of the four types of cooking fuels listed above in 1(a), which is your preference and why?

2.If in 1(b) above, wood is your preference, where do you source it from?

(i) Government gazetted forests (ii) Smallholder farms (iii) Saw mills

(iv) Timber yards (v) Specify other sources

3.Is wood readily available in the County whenever you want buy?

(i) Yes (ii) No

4.If your answer in Question 2 above is "No", then where do you buy the timber from?

(i) Nyeri County (ii) Murang'a County (iii) Embu County (iv) Neighbouring Countries i.e., Tanzania (v) Imported abroad

2.9 Questionnaires for Furniture Makers

1. Between hardwood and softwood timber, which among the two is readily available in the market?

2. Where do you source the timber for making furniture from?

(i) Farmers (ii) Smallholder farms (iii) Saw mills

(iv)Timber yards (v) Specify other sources

Appendix 3: Raw Data

3.1. Raw Data on Results from County Forest Officers

Question 1. Is the county self sufficient with its timber requirements?

(i) County relatively self sufficient with its timber requirements (1st respondent)
(ii) Distribution of tree growig is uneven
(iii) Most of the timber comes fromprivate farms and very little from government gazetted forests.
(iv) Species with poor timber qualities used eg croton mycrotasis, avocado and grevillea
(v) No supply is sourced from outside the county.
(vi) County not self sufficient with its timber requirements.

Question 2. Which are the most commonly used timber species and why?

(i) *Grevillea robusta* because its widely grown in al the zones in the county
(ii) Has a high growth rate, has good agroforestry properties
(iii) Cheaper than other timber species and has no negative effects to other food crops.

(iv) Other species include Eucalyptus, pine and *cuppressus lustanica*.

Question 3. What are the steps being taken by your office to ensure that the future.

demand of timber does not outstrip supply?

(i) Continous sensitization of the farmers on problems related to lack of trees
(ii) Support farm projects on agroforestry
(iii) Establishment of demonstration plots
(iv) Rehabilitation of degraded sites using indeginous trees
(v) Support to schools trees planting
(vi) Establishment of woodlots
(vii) Maximum utilization of available timber
(viii) Extension services
(ix) Capacity building to people in rice growing zone
(x) Encourage farmers to engage in other income generating activities other than in timber harvesting
(xi) Plantation management
(xii) Promote farm forestry
(xiii) Replacing harvested areas with timber tree species
(xiv) Promotion of commercial tree farming
(xv) Promotion of efficient energy saving jikos
(xvi) Strict adherence to vision 2030
(xvii) Introduction of plantation establishment and livelihood improvement scheme(PELIS)

Question 4. What are the steps being taken by your office to ensure timber used for

construction in the county is of high quality?

(i) Enhancing and promoting planting trees of high quality timber like eucalyptus
(ii) Allowing and enhancing proper seasoning through seminar and workshop training

(iii) Harvesting of fully mature trees that have reached rotatonal age.

(iv) Kenya forest serviceensures farmers use good quality seeds from KEFRI.

(v) Farmers adviced on the best spacing and timely pruning as well as harvesting the trees when they have attained rotational age (maturity age)

(vi) Education to farmers on proper farm management such as spacing,prunning, thining etc.

(vii) Technical management of plantation forest.

(viii) Glowing of high value tree species such as clonal which are fast growing. Diversification of growing trees and forest products such as baboo.

(ix) Domestication of high quality timber trees in private farms

(x) Advice farmers to purchase tree seedlings to qualified tree nursery practitioners

Question 5. Are there national and international policy guidelines that regulate timber production and usage to ensure quality timber sustainability?

(i) Permits and authority to cut trees required

(ii) In farm forestry, application of harvestig trees must be made through the chiefs to make recommendations and finally approved by foresters.

(iii) Policies exist on planting best trees phenotypically and genotypically

(iv) National policy guidelines include increasing tree cover to 10% by 2030 to increase supply of timber.

This is to be achived through:

(i) Support the formation of criteria and indicators for sustainable forest management.

(ii) Promotegood governance in the forest sector.

(iii) Forestand trees on private lands to be established and managed using sound business principles

3.2 Raw Data on Results from Contractors

Question 1. Between steel and timber, which of the two materials would be your preference for construction purposes and why?

(i) Timber is preffered because its economical and easily available locally than steel

(ii) The second respondent preffered steel because its available, long lasting, reusable, environmental freindly, it is strong, economical to use.

(iii) The third respondent said that timber is easily available, cheap compared to steel and not labour intensive.

(iv) Timber can be modified/flexibility in shaping.

(v) Timber can be reused i.e., use as firewood.

(vi) Use of timber as a fencing material.

Question 2. Between hardwoods and softwoods, which is your preference for construction works and why your choice?

(i) Takes many years toget destroyed by insects or rot.

(ii) The second respondent would prefer softwoods because they take little time to grow/mature in order to be sawn.

(iii) Softwoods would be prefered as a result of unavailability of hardwoods in Kirinyaga County.

(iv) Softwoods are cheaper than hardwoods.

(v) Softwoods are easily available compared to hardwoods.

(vi) Hardwoods have strong grains and they make tight joints for joinery works.

Question 3. How do you ensure that timber used for construction purposes is seasoned?

(i) Use of moisture metre.

(ii) Natural seasoning.

(iii) Air seasoning under sheds.

(iv) Keep in cool dry places.

(v) Stacking them above the ground to avoid dumpness to penetrate.

(vi) Avoiding direct sunshine for shrinking not to occur.

(vii) Treatment

Question 4. What is the extent of availability of timber for construction purposes?

(i) Scarcity being experienced.

(ii) Scarcity is as a result of government control of both the natural and artificial forests.

(iii) Licences are required to cut trees.

(iv) Timber for construction being imported fromTanzania.

(v) A fifth respondent feels that there is enough timber from Mt Kenya and Njukiini forests among others.

Question 5. To your assessment, is the cost of construction timber relatively affordable?

(i) As time elapses, the cost of timber is becoming unaffordable.

(ii) A second respondent feels that timber is relatively affordable because one can cutand saw timber into the required pieces.

(iii) The cost of timber is skyrocketing and is therefore not relatively affordable

(iv) A fouth respondent feels timber is not affordable and the imported timber makes hardwoods even more expensive.

(v) A fifth respondent feels that it is relatively affordable sice it is locally available and there is cheap transport cost.

Question 6. Which scientific methods of testing construction timber do you employ to ensure quality is achieved?

(i) Checking of the grains.

(ii) Ensuring seasoning is done before use.

(iii) Visual inspection of the defects.

3.3. Raw data on Registered Contractors with the National Construction Authority (NCA)

S/No	Regstration no	Company name	class	category	Town
1	1919/B/0214	Digial spares and electronics co ltd	Building works	8	kerugoya
2	2280/R/0214	Emanijo construction co ltd.	Civil engineering	6	kerugoya
3	3829/B/0214	Jimroenterprisees ltd	Building works	4	kerugoya
4	3832/B/0214	Jimroses k ltd	Building works	7	kerugoya
5	3860/B/0214	Jobec ventures	Building works	8	kerugoya
6	3970/B/0214	JosaG.Contractors	Building works	7	kerugoya
7	8243/B/0214	Speedman Constructors	Building works	7	kerugoya
8	8823/B/0214	Tonilo Builders	Building works	7	kerugoya
9	9038/B/0214	Umeme contractors ltd	Building works	6	kerugoya
10	6848/B/0214	Peresinvestment ltd	Building works	6	kerugoya
11	1362/B/0214	Cherith investments co.	Building works	7	Kutus
12	4105/R/0214	Kabuka contractors ltd	Civil engineering	7	Kutus
13	1771/B/0214	Davega enterprises ltd	Building works	7	kianyaga
14	12231/B/09 1444	Harikrishna hardware ltd	Building works	3	kerugoya

3.4. Raw Data on Results from Timber Yard Owners

Question 1. Which major species of timber do you buy and sell as construction material?

(i) *Grevillea robusta*

(ii) Cypress

(iii) Pine

(iv) Eucalyptus

Question 2. What quantities for each species do you sell annually?

Grevillea robusta

1st respondent	more than 20 tons
2nd respondent	more than 20 tons
3rd respondent	more than 20 tons
4th respondent	more than 20 tons
5th respondent	more than 20 tons
6th respondent	more than 20 tons
7th respondent	more than 20 tons
8th respondent	more than 20 tons

Eucalyptus

1st respondent	more than 20 tons
2nd respondent	more than 20 tons
3rd respondent	6 to 10 tons
4th respondent	more than 20 tons
6th respondent	6 to 10 tons
7th respondent	6 to 10 tons

8th respondent	more than 20 tons

Camphor

1st respondent	0 tons
2nd respondent	0 tons
3rd respondent	0 tons
4th respondent	0 tons
5th respondent	0 tons
6th respondent	0 tons
7th respondent	0 tons
8th respondent	0 tons

Cypress

1st respondent	6 to 10 tons
2nd respondent	0 tons
3rd respondent	0 to 5 tons
4th respondent	6 to 10 tons
5th respondent	more than 20 tons
6th respondent	more than 20 tons
7th respondent	0 tons

8th respondent	6 to 10 tons

<u>Pine</u>

1st respondent	more than 20 tons
2nd respondent	more than 20 tons
3rd respondent	6-10 tons
4th respondent	more than 20 tons
5th respondent	6-10 tons
6th respondent	6-10 tons
7th respondent	0 tons
8th respondent	more than 20 tons

<u>*Cordia africana*</u>

1st respondent	0 tons
2nd respondent	0 tons
3rd respondent	0 tons
4th respondent	0 tons
5th respondent	0 tons
6th respondent	0 tons
7th respondent	0 tons

8th respondent 0 tons

Question 3. Whom do you normally sell the timber to?

(i) Contractors
(ii) Individuals
(iii) Furniture makers
(iv) Schools
(v) Coffee factories
(vi) Government departments

Question 4. What proportion of the timber doyou sell do each of the categories listed in Question 3 above?

Respodents/category	contractors	Individuals	Kenya power	Government dept	Furniture makers
Respondent 1	50 – 75%	0-25%	0-25%	0-25%	26 -50%
Respondent 2	76- 100%	0-25%	0-25%	0-25%	0-25%
Respondent 3	76 – 100%	0-25%	0-25%	0-25%	0-25%
Respondent 4	26 -50%	0-25%	0-25%	0-25%	26 -50%
Respondent 5	50 -75%	26 -50%	0-25%	0-25%	0-25%
Respondent 6	76 -100%	0-25%	0-25%	0-25%	0-25%
Respondent 7	26 -50%	26 -50%	0-25%	0-25%	0-25%
Respondent 8	50- 75%	26 -50%	0-25%	0-25%	0-25%

Question 5. For what purpose do they (the customers) use the timber for construction?

(i) Roofing
(ii) Finishes such as doors, windows, wardrobes, etc.
(iii) Making Floor boards such as T and G boards

(iv) Formwork construction

(v) Furniture making

Question 6. Is the timber readily available in Kirinyaga County?

(i) Yes (ii) No

Question 7. If your answer in Question 6 above is "No", then where do you buy the timber from?

Not applicable in this case

Question 8. How much do you buy from outside Kirinyaga County when compared with what is bought in the County? 0-25%

Question 9. Apart from construction, what other purposes is the timber used for?

(i) Poles for fencing

(ii) Fire wood

(iii) Wooden boxes

(iv) Railway sleepers

(v) Wood pallets

3.5. Raw Data on Results from Saw Millers

Question 1. Where do you get wood as a raw material from?

(i) Suppliers.

(ii) Farmers.

Question 2. Do you consider the age factor for trees when buying and if so how do you determine it?

(i) Age factor of tree not considered.
(ii) Immature trees oftenly bought as a result of shortage.
(iii) In government owned forests it is possible to kep a record of planting and harvesting dates but this is not possible on proivate farms.
(iv) Sawmillers have a way/guide of identifying mature trees through checking the production of seeds and flowers for trees that have matured.

Question 3. How many years have you been operating the business?

(i) Ist respondent	no answer.
(ii) 2nd respondent	9 years.
(iii) 3rd respondent	30years.

Question 4. Who are your potential customers? I.e. individuals or contractors?

(i) 1st respondent	no answer.
(ii) 2nd respondent	carpenters, contractors, government agents.
(iii) 3rd respondent	carpenters, contractors.

3.6. Raw Data on Results from Kenya Power

Question 1. Kenya power has been using timber poles for transmitting power for a long time now. Which other types of transmission poles is it adopting currently?

(i) Concrete poles for transmission of lines carrying 240 volts, 11000 volt(11kv) and 33000 volts(33kv)
(ii) Steel poles for transmission of lines carrying 132kv and 22kv.

NB: Wood poles are normally 10 metres, 11metres and 15 metres with the 10 metres pole carrying low voltage, 11 metres carrying medium voltage and 15 metres pole carrying a shared voltage respectively.

Question 2. In terms of a percentage scale, state the amount of poles currently being used in each category i.e., Timber, Concrete and Steel.

(i) Timber 79%
(ii) Concrete 20%
(iii) Steel 1%

Question 3. Which type of tree species is the timber poles used by your company belong to?

(i) *Eucalyptus globulus* (Blue gum) which costs about Kenya Shillings 12,000 per pole.

Question 4. What are some of the advantages of using concrete poles compared to timber poles?

(i) Concrete poles are durable . They are used in waterlogged areas and in towns to avoid regular replacing during maintenance periods which normally disturbs the consumers.
(ii) Concrete poles do not require preservative treatment.
(iii) Concrete poles are impervious to weather.

Question 5. What other uses or disposal methods are adopted by your company for timber poles which have been replaced.

(i) The replaced poles are sold to Kenya Power staff at a cost of Kenya Shillings 400 plus 16% VAT who thereafter sell to individuals as fencing posts or as firewood.

(ii) The replaced poles are also re-used in other minor transmission works where upgrade is being done before the poles lifespan is spent.

Question 6. Does Kenya power face constraints in acquiring the timber poles as a resource material?

Yes, the Kenya power faces constraints in acquiring the timber poles as a resource material only when the demand surges, i.e., when the company demands the resource at a shorter notice.

Question 7. Is Kenya power currently undertaking any measures to ensure future sustainability of trees as a resource?

Yes, Kenya Power undertakes Corporate Social Rensponsibility through afforestation and water towers preservation in conjunction with the Kengen.

3.7. Raw Data on Results from Tea Factories Managers

Question 1. Tea could be processed using either wood or furnace oil types of fuels. Out of the two, which is your preferred choice and why the preference?

(i) For all the factories their Prefered source of fuel waswood.
(ii) Reason for the preference of wood is because Wood is cheap compared to furnace oil

Question 2. What quantities in tons do you use annually in either of the two fuels listed in 1 above?

	Quantity (tons)			
Species	0-5	6-10	11-20	> 20
(i) wood fuel				
(ii) Furnace fuels				

(i) All the factories used more than 20 tons of wood per year.
(ii) Most of the factories either used 0-5 tons of furnace oil or never used it at all.

Question 3. If wood is used as a fuel, which types of tree species is the wood harvested/processed from?

(i) Grevillea robusta, Eucalyptus, cypress, pine,

NB: All fruit bearing trees such as mango and avocado are only bought by the factories on condition the suppliers have permits.

Question 4. Again, if wood is used, where is the wood sourced from?

(i) Smallholder farms
(ii) Government gazette forests

Question 5. What measures is your company currently undertaking to ensure long term sustainability of trees as the source of wood fuel?

(i) Establishing tree nurseries within the factory premises so as to distribute tree seedlings to farmers, neighbours and wood supplliers at subsidized prices.
(ii) Buying large tracts of land to plant own forests for harvesting wood in future.
(iii) Reducing consumption at the point of use i.e., at the boiler by improving the boiler efficiency through the use of advanced boilers and improving on the existing boilers by fitting on the pre-heaters.
(iv) Involvement with conservation efforts such as tree planting in public open lands and schools.

3.8 Raw Data on Results Urban Household Dwellers

Question 1. What quantities in tons/Kilowatts of the types of cooking fuels listed below do you use per year?

	Quantity in tons/Kilowatts			
Type of fuel	0-5	6-10	11-20	> 20
(i) Gas fuel				
(ii) Charcoal				
(iii) Wood				
(iv)Electricity in Kilowatts				

Respondents	**Usage of Gas in Kgs per month**	**Usage of Gas in Kgs per year**	**Usage of Gas in tons per year**
1	13	156	0.156
2	0	0	0
3	0	0	0
4	8.5	102	0.102
5	4.34	52	0.052
6	0	0	0
7	3	36	0.036
8	6	72	0.072
9	0	0	0
10	10	120	0.12
11	13	156	0.156
12	4.34	52	0.052
13	0	0	0
14	8	96	0.096
15	6.5	78	0.078
16	2	24	0.024
17	6	72	0.072
18	3	36	0.036

19	0	0	0
20	0	0	0
21	0	0	0
22	4.34	52	0.052
23	9	108	0.108
24	3.25	39	0.039
25	0	0	0
26	0	0	0
27	6.5	78	0.078
28	9	108	0.108
29	6	72	0.072
30	2	24	0.024
31	0	0	0
32	4.34	52	0.052
33	8	96	0.096
34	13	156	0.156
35	13	156	0.156
36	0	0	0
37	8.5	102	0.102
38	3.25	39	0.039
39	9	108	0.108
40	8	96	0.096
41	4.34	52	0.052
42	13	156	0.156
43	0	0	0
44	0	0	0
45	3.25	39	0.039
46	8	96	0.096
47	13	156	0.156
48	6	72	0.072

49	3.25	39	0.039
50	9	108	0.108

Respondents	Usage of Charcoal in Kgs per month	Usage of Charcoal in Kgs per year	Usage of Charcoal in tons per year
1	5	60	0.06
2	15	180	0.18
3	10	120	0.12
4	5	60	0.06
5	10	120	0.12
6	30	360	0.36
7	10	120	0.12
8	15	180	0.18
9	45	540	0.54
10	5	60	0.06
11	0	0	0
12	30	360	0.36
13	30	360	0.36
14	10	120	0.12
15	15	180	0.18
16	30	360	0.36
17	10	120	0.12
18	15	180	0.18
19	45	540	0.54
20	45	540	0.54
21	30	360	0.36

22	20	240	0.24
23	10	120	0.12
24	15	180	0.18
25	25	300	0.3
26	5	60	0.06
27	5	60	0.06
28	10	120	0.12
29	5	60	0.06
30	15	180	0.18
31	30	360	0.36
32	10	120	0.12
33	10	120	0.12
34	0	0	0
35	0	0	0
36	20	240	0.24
37	10	120	0.12
38	5	60	0.06
39	0	0	0
40	5	60	0.06
41	15	180	0.18
42	5	60	0.06
43	30	360	0.36
44	45	540	0.54
45	10	120	0.12
46	10	120	0.12
47	5	60	0.06
48	10	120	0.12
49	20	240	0.24
50	5	60	0.06

Respondents	Usage of Wood in Kgs per month	Usage of Wood in Kgs per year	Usage of Wood in tons per year
1	0	0	0
2	200	2400	0.24
3	250	3000	0.3
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	150	1800	0.18
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	300	3600	0.36
20	200	2400	0.24
21	250	3000	0.3
22	0	0	0
23	0	0	0
24	0	0	0
25	200	2400	0.24

26	100	1200	0.12
27	0	0	0
28	0	0	0
29	0	0	0
30	0	0	0
31	150	1800	0.18
32	0	0	0
33	0	0	0
34	0	0	0
35	0	0	0
36	0	0	0
37	0	0	0
38	0	0	0
39	0	0	0
40	0	0	0
41	0	0	0
42	0	0	0
43	250	3000	0.3
44	200	2400	0.24
45	0	0	0
46	0	0	0
47	0	0	0
48	0	0	0
49	0	0	0
50	0	0	0

(i) A bigger percentage of households used about 480 kilowatts per year.

(b) Out of the four types of cooking fuels listed above in 1(a), which is your preference and why the preference?

Gas: most of the respondents said gas is quicker, economical compared to other fuels and hygienic because it does not produce the black smoke like in case of charcoal.

Question 2. If in 1(b) above, wood is your preference, where do you source it from?

(i) Timber yards
(ii) Saw mills
(iii) Smallholder farms.

Question 3. Is the wood readily available in the County whenever you want to buy?

Yes

Question 4. If your answer in Question above is "No", then where do you buy the timber from?

Not applicable in this case.

3.9. Raw Data on Results Rural Household Dwellers

Question 1. (a) What quantities in tons/Kilowatts of the types of cooking fuels listed below do you use per year?

	Quantity in tons/Kilowatts			
Type of fuel	0-5	6-10	11-20	> 20
(i) Gas fuel				
(ii) Charcoal				
(iii) Wood				
(iv)Electricity in Kilowatts				

Respondents	**Usage of Gas in Kgs per month**	**Usage of Gas in Kgs per year**	**Usage of Gas in tons per year**
1	6	72	0.072
2	1.2	14.4	0.014
3	3.25	39	0.039
4	6.5	78	0.078
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	2	24	0.024
11	4	48	0.048
12	1.5	18	0.018
13	3.25	39	0.039
14	0	0	0
15	0	0	0
16	0	0	0
17	6.5	78	0.078
18	0	0	0
19	2	24	0.024

20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24	1.2	14.4	0.014
25	0	0	0
26	0	0	0
27	6.5	78	0.078
28	3.25	39	0.039
29	3	36	0.036
30	1.5	18	0.018
31	0	0	0
32	0	0	0
33	0	0	0
34	1.2	14.4	0.014
35	6.5	78	0.078
36	0	0	0
37	0	0	0
38	3	39	0.039
39	0	0	0
40	0	0	0
41	1.5	18	0.018
42	1.2	14.4	0.014
43	0	0	0
44	0	0	0
45	3.25	39	0.039
46	0	0	0
47	6.5	78	0.078
48	6	72	0.072
49	0	0	0

50	0	0	0

Respondents	Usage of Charcoal inKgs per month	Usage of CharcoalinKgs per year	Usage of Charcoal in tons per year
1	0	0	0
2	0	0	0
3	10	120	0.12
4	1	12	0.012
5	25	300	0.3
6	0	0	0
7	6	36	0.036
8	0	0	0
9	6	36	0.036
10	2	24	0.024
11	20	240	0.024
12	25	300	0.3
13	0	0	0
14	0	0	0
15	4	48	0.048
16	6	36	0.036
17	0	0	0
18	2	24	0.024
19	6	36	0.036
20	10	120	0.120
21	0	0	0
22	0	0	0
23	10	120	0.12

24	5	60	0.06
25	6	36	0.036
26	0	0	0
27	15	180	0.18
28	20	240	0.24
29	0	0	0
30	25	300	0.3
31	0	0	0
32	0	0	0
33	5	60	0.06
34	10	120	0.12
35	6	36	0.036
36	4	48	0.048
37	0	0	0
38	2	24	0.024
39	20	240	0.24
40	0	0	0
41	0	0	0
42	0	0	0
43	10	120	0.12
44	20	240	0.24
45	25	300	0.3
46	0	0	0
47	6	36	0.036
48	4	48	0.048
49	2	24	0.024
50	0	0	0

Respondents	Usage of Wood in Kgs per month	Usage of Wood inKgs per year	Usage of Wood in tons per year
1	500	6000	6
2	250	3000	3
3	500	6000	6
4	200	2400	2.4
5	180	2160	2.16
6	125	1500	1.5
7	250	3000	3
8	500	6000	6
9	500	6000	6
10	500	6000	6
11	250	3000	3
12	200	2400	2.4
13	250	3000	3
14	180	2160	2.16
15	500	6000	6
16	125	1500	1.5
17	250	3000	3
18	100	1200	1.2
19	200	2400	2.4
20	500	6000	6
21	250	3000	3
22	300	3600	3.6
23	100	1200	1.2
24	200	2400	2.4
25	180	2160	2.16
26	500	6000	6
27	250	3000	3

28	125	1500	1.5
29	250	3000	3
30	200	2400	2.4
31	180	2160	2.16
32	500	6000	6
33	200	2400	2.4
34	100	1200	1.2
35	250	3000	3
36	300	3600	3.6
37	500	6000	6
38	250	3000	3
39	200	2400	2.4
40	500	6000	6
41	300	3600	3.6
42	500	6000	6
43	180	2160	2.16
44	125	1500	1.5
45	180	2160	2.16
46	500	6000	6
47	250	3000	3
48	100	1200	1.2
49	200	2400	2.4
50	500	6000	6

(i) In rural areas, all the respondents never used electricity for cooking.

(b) Out of the four types of cooking fuels listed above in 1(a), which is your preference and why the preference?

(ii) most of the respondents said they would prefer gas/electricity but because of their unavailability they are left with no alternative but to use wood which is readily available in the rural set up.

Question 2. If in 1(b) above, wood is your preference, where do you source it from?

(i) Timber yards
(ii) Saw mills
(iii)Smallholder farms.

Question 3. Is the wood readily available in the County whenever you want buy?

Yes

Question 4. If your answer in Question above is "No", then where do you buy the timber from?

Not applicable in this case.

3.10: Raw Data on Results for Furniture Makers

Question 1. Between hardwood and softwood timber, which among the two is readily available in the market?

Respondents	**Readily available type of timber**
1	Softwoods
2	Softwoods
3	Softwoods
4	Hardwoods
5	Softwoods
6	Softwoods
7	Softwoods
8	Softwoods

9	Softwoods
10	Softwoods
11	Hardwoods
12	Softwoods
13	softwoods
14	Softwoods
15	Softwoods
16	Softwoods
17	Hardwoods
18	Softwoods
19	Softwoods
20	Softwoods
21	Softwoods
22	Softwoods
23	Softwoods
24	Softwoods
25	Softwoods
26	Softwoods
27	Softwoods
28	Softwoods
29	Softwoods
30	Softwoods

Question 2. Where do you source the timber for making furniture from?

(i) Farmers

(ii) Smallholder farms

(iii) Saw mills

(iv) Timber yards

Raw Data on Laboratory Tests carried out.

Sample size of (20x20x20)mm to test shear strength

specimen	Initial weight	Maximum load (KN)		Oven dry weight
		tangential	Radial	
Gre 1	7.02g	3.73		4.72g
Gre 2	7.03g		3.55	5.17g
Gre 3	6.49g	3.41		4.82g
Gre 4	7.35g		3.32	5.01g
Gre 5	7.26g	3.68		4.91g
Gre 6	7.15g		2.90	4.69g
Cyp1	4.48g	4.99		3.79g
Cyp2	3.74g		2.84	3.13g
Cyp3	4.59g	5.02		3.85g
Cyp4	4.47g		4.18	3.70g
Cyp5	3.73g	4.38		3.12g
Cyp6	3.73g		3.35	3.11g
Cord1	4.34g	4.37		3.66g
Cord2	4.13g		3.90	3.44g
Cord3	4.53g	3.90		3.81g
Cord4	5.46g		5.76	4.64g
Cord5	3.96g	2.80		3.31g
Cord6	4.14g		4.05	3.46g
Euc1	7.10g	4.72		4.71g
Euc2	6.23g		3.58	4.23g
Euc3	6.19g	3.76		4.14g
Euc4	6.15g		3.22	4.19g
Euc5	7.35g	5.24		5.28g
Euc6	6.80g		3.63	4.76g
Dk1	6.40g	3.45		3.10g
Dk2	7.20g		3.24	3.21g
Dk3	7.60g	4.42		4.23g
Dk4	7.94g		5.08	4.25g
Dk5	6.23g	3.62		4.04g
Dk6	6.65g		4.89	4.00g

Dk7	5.81g	1.83		2.79g
Dk8	6.85g		3.41	2.80g
Dk9	8.17g	4.20		3.84g
Dk10	8.75g		5.05	4.31g
Dk11	6.05g	3.52		3.47g
Dk12	6.93g		4.48	3.40g
CN1	6.50g	5.45		3.85g
CN2	6.44g		3.61	3.87g
CN3	6.10g	5.13		3.80g
CN4	6.28g		3.70	3.82g
CN5	5.85g	4.11		3.72g
CN6	5.80g		3.79	3.77g
CN7	5.80g	4.22		3.66g
CN8	6.02g		3.90	3.76g
CN9	6.03g	4.60		3.76g
CN10	5.88g		4.02	3.72g
CN11	5.16g	5.36		3.57g
CN12	5.22g		3.93	3.61g
DS1	3.99g	5.15		3.49g
DS2	4.64g		4.18	4.03g
DS3	2.20g	1.18		1.18g
DS4	2.27g		2.28	1.95g
DS5	3.75g	2.51		3.27g
DS6	3.61g		3.14	3.14g
DS7	233g	1.24		1.99g
DS8	2.44g		2.33	2.08g
DS9	5.40g	6.95		4.71g
DS10	5.29g		5.46	4.66g
DS11	3.35g	2.84		2.91g
DS12	3.26g		2.71	2.84g
CS1	5.11g	4.22		3.49g
CS2	5.32g		3.57	3.54g
CS3	5.31g	3.21		3.33g
CS4	5.29g		3.14	3.31g
CS5	6.09g	3.80		3.46g
CS6	6.10g		3.24	3.47g
CS7	5.18g	3.68		3.48g
CS8	5.06g		3.40	3.52g

CS9	5.72g	4.00		3.38g
Cs10	5.60g		3.68	3.38g
CS11	5.71g	4.02		3.54g
CS12	5.46g		4.42	3.44g
GN1	7.63g	3.22		3.91g
GN2	8.11g		2.97	3.87g
GN3	8.15g	2.80		3.92g
GN4	7.85g		3.10	3.83g
GN5	7.75g	2.99		3.82g
GN6	8.01g		3.06	3.87g
GN7	7.18g	3.23		4.09g
GN8	6.23g		2.72	3.87g
GN9	7.30g	2.99		3.88g
GN10	7.75g		2.40	3.82g
GN11	7.38g	3.47		3.77g
GN12	6.56g		3.31	3.66g
EK1	6.08g	4.89		4.83g
EK2	6.06g		2.54	4.82g
EK3	7.65g	6.29		5.87g
EK4	7.21g		4.80	5.50g
EK5	6.40g	4.26		5.03g
EK6	6.49g		4.04	5.14g
EK7	6.86g	5.09		5.20g
EK8	6.60g		3.68	5.03g
EK9	6.13g	4.76		4.64g
EK10	6.26g		3.40	4.74g
EK11	5.79g	4.62		4.60g
EK12	5.79g		4.20	4.58g
ES1	7.92g	4.77		5.48g
ES2	8.17g		4.81	5.56g
ES3	8.19g	4.51		5.41g
ES4	8.33g		4.37	5.47g
ES5	7.70g	3.99		5.10g
ES6	7.79g		3.98	5.17g
ES7	8.11g	4.64		5.49g
ES8	8.33g		4.95	5.60g
ES9	7.96g	4.23		5.38g
ES10	7.94g		4.54	5.42g

ES11	8.52g	3.52		5.62g
ES12	8.63g		5.31	5.66g
GK1	6.59g	3.76		4.18g
GK2	7.02g		3.95	4.21g
GK3	6.33g	3.21		4.08g
GK4	6.50g		3.78	4.18g
GK5	5.55g	4.00		4.41g
GK6	6.19g		3.59	4.42g
GK7	5.61g	3.53		4.48g
GK8	6.33g		3.62	4.47g
GK9	7.17g	3.64		4.42g
GK10	7.49g		3.58	4.49g
GK11	6.88g	2.92		4.45g
GK12	6.82g		4.65	4.43g
NE1	6.36g	3.70		3.81g
NE2	6.69g		3.18	3.75g
NE3	8.07g	3.85		4.20g
NE4	7.60g		3.36	3.95g
NE5	6.94g	3.83		4.46g
NE6	6.39g		3.48	4.14g
NE7	7.49g	3.28		4.09g
NE8	7.38g		3.55	4.01g
NE9	6.73g	4.15		3.85g
NE10	7.24g		3.70	3.91g
NE11	6.83g	3.55		3.84g
NE12	7.14g		3.78	3.89g
DN1	3.83g	2.25		3.17g
DN2	3.63g		3.18	2.96g
DN3	3.38g	2.96		2.77g
DN4	3.36g		2.87	2.75g
DN5	3.57g	3.56		2.94g
DN6	3.50g		3.27	2.90g
DN7	4.08g	3.23		3.36g
DN8	3.95g		2.96	3.25g
DN9	3.39g	2.87		2.80g
DN10	3.47g		3.10	2.87g
DN11	3.14g	2.54		2.62g
DN12	2.98g		2.76	2.46g

PS1	3.41g	3.56		2.92g
PS2	3.47g		2.88	2.91g
PS3	3.68g	2.90		3.06g
PS4	3.63g		3.02	3.01g
PS5	3.63g	2.64		3.02g
PS6	3.59g		3.43	2.99g
PS7	4.73g	3.70		4.04g
PS8	4.68g		3.72	4.01g
PS9	4.81g	4.30		4.07g
PS10	4.68g		4.43	4.00g
PS11	4.56g	5.52		3.88g
PS12	4.55g		5.46	3.88g
GS1	7.67g	3.69		4.45g
GS2	8.00g		4.31	4.40g
GS3	7.79g	3.72		4.25g
GS4	8.41g		4.12	4.19g
GS5	8.11g	3.72		4.25g
GS6	8.15g		4.18	4.31g
GS7	8.55g	3.94		4.43g
GS8	8.59g		4.44	4.37g
GS9	8.26g	3.54		4.34g
GS10	7.80g		3.86	4.32g
GS11	8.06g	3.65		4.47g
GS12	8.20g		4.11	4.33g

Sample Size of (20x20x60)mm to Test Compresive Strength

Specimen	Initial weight	Maximum load (KN)	Oven dry weight
		tangential	
EUC1	19.65g	12.82	12.82g
EUC2	23.09g	12.98	14.06g
EUC3	24.84g	13.32	15.68g
EUC4	20.01g	14.92	12.97g
EUC5	21.94g	16.78	15.19g
EUC6	21.89g	13.32	14.63g
Cord1	13.65g	15.07	11.77g
Cord2	11.46g	12.42	9.74g
Cord3	11.43g	12.40	9.76g
Cord4	12.79g	14.57	10.92g
Cord5	15.47g	15.80	13.33g
Cord6	12.40g	13.41	10.57g
Cyp1	13.52g	15.24	11.50g
Cyp2	12.66g	14.72	10.69g
Cyp3	11.69g	11.38	9.82g
Cyp4	11.56g	12.36	9.69g
Cyp5	11.34g	13.86	9.54g
Cyp6	13.67g	13.90	11.49g
Gre1	23.10g	11.92	14.36g
Gre2	23.25g	12.97	15.28g
Gre3	20.28g	13.71	14.43g
Gre4	22.23g	13.43	14.68g
Gre5	21.95g	11.89	14.12g
Gre6	19.89g	14.50	14.41g

ES1	22.39g	20.37	15.54g
ES2	23.41g	19.03	15.71g
ES3	21.80g	18.46	14.80g
ES4	23.62g	19.59	16.33g
ES5	24.63g	21.10	16.49g
ES6	23.78g	21.56	16.62g
PS1	10.35g	5.29	8.94g
PS2	9.91g	5.44	8.50g
PS3	12.20g	6.79	10.57g
PS4	12.22g	7.79	10.54g
PS5	11.79g	7.65	10.18g
PS6	13.47g	9.30	11.54g
DN1	9.34g	8.85	7.83g
DN2	9.99g	10.64	8.46g
DN3	9.46g	9.46	7.96g
DN4	10.42g	9.77	8.75g
DN5	10.07g	10.10	8.53g
DN6	8.45g	7.70	7.16g
DK1	19.50g	15.62	13.83g
DK2	17.80g	14.19	12.72g
DK3	22.80g	10.50	10.14g
DK4	22.14g	9.12	8.36g
DK5	24.64g	14.74	12.82g
DK6	22.14g	10.30	9.73g
GN1	23.60g	8.50	11.43g
GN2	24.50g	9.20	11.57g
GN3	24.03g	8.76	11.50g
GN4	21.44g	8.61	11.77g
GN5	23.19g	7.48	10.67g
GN6	22.59g	7.16	11.34g

NE1	19.91g	11.14	11.09g
NE2	24.22g	12.53	12.46g
NE3	18.19g	12.29	11.43g
NE4	21.94g	11.60	11.21g
NE5	22.61g	10.92	11.89g
NE6	20.27g	10.82	11.50g
CS1	15.13g	9.35	9.96g
CS2	15.01g	8.05	9.61g
CS3	15.01g	7.95	9.97g
CS4	15.83g	8.77	10.22g
CS5	16.54g	8.86	9.87g
CS6	15.14g	8.86	10.44g
DS1	10.32g	7.30	8.97g
DS2	7.04g	6.18	6.04g
DS3	11.47g	12.46	10.05g
DS4	7.42g	6.86	6.39g
DS5	12.16g	9.94	10.65g
DS6	15.40g	14.53	13.51g
GS1	24.04g	11.46	12.91g
GS2	25.82g	8.35	12.28g
GS3	25.80g	9.36	12.44g
GS4	26.23g	10.72	13.11g
GS5	24.90g	10.58	12.37g
GS6	24.98g	10.90	12.67g
GK1	18.67g	9.82	12.16g
GK2	21.81g	9.24	13.08g
GK3	19.89g	8.83	13.30g
GK4	19.38g	8.73	13.20g
GK5	20.13g	9.18	12.81g
GK6	19.43g	10.15	12.65g

EK1	17.81g	17.49	14.35g
EK2	19.96g	18.11	15.42g
EK3	18.00g	18.35	14.25g
EK4	17.56g	17.97	13.83g
EK5	16.47g	17.66	12.95gg
EK6	19.69g	19.03	15.50g
CN1	18.05g	12.93	11.29g
CN2	17.67g	12.77	11.06g
CN3	17.69g	11.83	11.20g
CN4	16.94g	12.34	11.02g
CN5	17.82g	12.54	10.74g
CN6	15.89g	13.35	10.65g

Sample Size of (20x20x100)mm to Test Janka Hardness

Specimen	Initial weight	Maximum load (KN)	Maximum load (KN)	Oven dry weight
		tangential	radial	
Gk 1	31.65g	2.74	2.58	20.08g
Gk2	34.65g	2.96	2.97	21.07g
Gk3	35.44g	3.04	2.75	21.24g
Gk4	34.48g	2.76	3.01	21.73g
Gk5	32.44g	3.02	2.29	20.95g
Gk6	33.08g	3.10	3.02	21.07g
Gn1	41.52g	3.30	2.04	19.70g
Gn2	41.79g	2.36	2.22	19.55g
Gn3	41.12g	1.88	2.30	18.94g
Gn4	37.11g	2.57	2.31	19.47g
Gn5	40.85g	2.30	2.18	18.69g
Gn6	38.37g	1.94	2.05	18.48g
Ps1	22.02g	2.64	2.60	18.80g
Ps2	16.34G	1.08	0.97	13.73g
Ps3	17.31g	1.19	1.23	14.59g
Ps4	22.02g	1.69	1.46	18.77g
Ps5	19.03g	1.58	1.42	16.13g
Ps6	23.70g	1.75	2.27	20.12g
Gs1	40.61g	3.15	3.10	21.70g
Gs2	39.81g	2.63	2.57	21.24g
Gs3	42.70g	2.63	2.92	21.30g
Gs4	43.02g	2.89	2.79	21.34g
Gs5	41.64g	2.99	3.02	20.48g
Gs6	42.14g	2.94	3.00	21.11g
Ne1	35.16g	1.67	2.28	18.57g
Ne2	39.48g	2.06	2.91	18.29g
Ne3	32.23g	2.15	1.77	18.86g
Ne4	40.95g	3.03	2.82	21.06g
Ne5	36.29g	2.78	2.86	19.92g
Ne6	38.52g	1.90	2.60	19.51g
Cs1	27.60g	2.09	1.85	16.73g
Cs2	26.06g	1.74	1.90	15.84g
Cs3	29.40g	2.17	2.15	16.55g

Cs4	28.63g	2.02	1.97	17.39g
Cs5	26.11g	1.82	1.66	16.10g
Cs6	25.32g	2.35	2.12	16.82g
EK1	32.00g	4.14	3.99	25.36g
EK2	32.92g	4.66	4.13	25.28g
EK3	30.79g	3.54	3.16	23.12g
EK4	27.75g	2.58	2.63	21.75g
EK5	27.11g	2.76	2.55	21.17g
EK6	23.67g	2.62	2.57	19.24g
Dk1	41.77g	2.32	2.42	14.97g
Dk2	42.09g	3.85	3.49	21.55g
Dk3	35.50g	3.42	3.25	19.01g
Dk4	40.00g	1.80	3.24	17.17g
Dk5	43.08g	2.68	3.36	20.43g
Dk6	38.12g	1.30	2.00	16.38g
Dn1	13.85g	0.57	0.62	11.36g
Dn2	17.03g	1.36	1.65	14.17g
Dn3	13.52g	0.90	0.63	11.15g
Dn4	15.44g	0.95	1.06	12.77g
Dn5	15.28g	0.93	1.78	12.65g
Es1	38.46g	3.80	3.78	25.72g
Es2	38.87g	3.26	3.52	25.55g
Es3	35.87g	3.35	3.27	24.63g
Es4	40.17g	3.99	3.73	27.41g
Es5	38.83g	4.25	3.85	27.69g
Es6	40.85g	3.96	3.55	27.21g
Ds1	13.94g	2.10	1.78	11.89g
Ds2	12.27g	1.41	0.91	10.33g
Ds3	22.36g	2.19	2.20	19.35g
Ds4	13.17g	1.07	1.28	11.11g
Ds5	20.82g	2.33	2.54	18.00g
Ds6	17.17g	2.49	1.45	14.60g
CN1	21.95g	2.44	2.11	18.25g
CN2	25.02g	2.75	2.12	18.06g
CN3	30.64g	2.26	2.12	18.06g
CN4	26.67g	2.17	2.16	17.86g
CN5	27.61g	2.29	1.99	18.26g
CN6	26.00g	2.09	2.28	17.61g

Sample Size of (20x20x300)mm to Test Static Bending

specimen	Deflection in mm	Maximum load in kN
Gre 1	14	1.34
Gre 2	11	1.28
Gre 3	13	1.35
Gre 4	11	1.45
Gre 5	13	1.42
Gre 6	12	1.48
Cyp1	8	1.30
Cyp2	7	1.20
Cyp3	10	1.21
Cyp4	8	1.11
Cyp5	8	1.15
Cyp6	10	1.20
Cord1	11	1.11
Cord2	11	1.17
Cord3	12	1.40
Cord4	13	1.37
Cord5	10	1.28
Cord6	10	1.10
Euc1	13	1.45
Euc2	11	1.57
Euc3	14	1.47
Euc4	13	1.56
Euc5	11	1.24
Euc6	10	1.36
Dk1	11	1.59
Dk2	13	1.0
Dk3	13	1.46

Dk4	9	1.08
Dk5	12	1.37
Dk6	13	1.28
CN1	12	1.27
CN2	12	1.43
CN3	12	1.42
CN4	12	1.32
CN5	12	1.31
CN6	13	1.45
DS1	7	0.48
DS2	9	0.72
DS3	12	1.19
DS4	8	0.65
DS5	11	1.18
DS6	13	1.32
CS1	14	1.03
CS2	14	0.84
CS3	12	0.81
CS4	11	1.09
CS5	14	0.81
CS6	14	0.77
GN1	11	0.92
GN2	11	0.97
GN3	12	0.91
GN4	13	1.07
GN5	8	0.77
GN6	14	1.05
EK1	10	1.95
EK2	9	1.68
EK3	12	1.71

EK4	11	1.60
EK5	9	1.75
EK6	10	1.80
ES1	9	1.97
ES2	10	1.80
ES3	9	1.94
ES4	12	2.21
ES5	8	1.85
ES6	11	2.13
GK1	10	0.97
GK2	6	0.89
GK3	9	0.91
GK4	10	0.97
GK5	11	0.93
GK6	8	0.89
NE1	8	1.27
NE2	8	1.43
NE3	6	1.10
NE4	7	1.33
NE5	8	1.27
NE6	7	1.20
DN1	8	0.85
DN2	8	1.18
DN3	7	0.93
DN4	7	0.83
DN5	7	1.01
DN6	8	1.03
PS1	10	1.11
PS2	9	0.68
PS3	7	0.98

PS4	7	0.79
PS5	8	1.40
GS1	12	1.26
GS2	10	0.89
GS3	9	0.91
GS4	14	1.41
GS5	14	1.24
GS6	8	1.08