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# BASIC DENSITY AND PHYSICAL PROPERTIES MAPPING OF *EUCALYPTUS GRANDIS* GROWN IN NEKEMTE AREA.

**BY**

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**AUGUST, 2024**

**ADDIS ABABA, ETHIOPIA**

# BASIC DENSITY AND PHYSICAL PROPERTIES MAPPING OF *EUCALYPTUS GRANDIS* GROWN IN NEKEMTE AREA.

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**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER OF SCIENCE IN WOOD SCIENCE TECHINOLOGY**

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**AUGUST, 2024**

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**APPROVAL SHEET-I**

This is to certify that the thesis entitled "**Basic density and physical properties mapping of *Eucalyptus grandis* grown in Nekemte area**", submitted in partial fulfillment of the requirements for the degree of Master of science with specialization in Wood science and Technology of the Graduate Program of the Department of Wood Technology, Federal technical and vocational training institute, and is a record of original research carried out by Megersa Gudeta under my supervision, and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during the course of this investigation have been duly acknowledged. Therefore I recommend that it can be accepted as fulfilling the thesis requirements.

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**LIST OF ABBREVIATIONS**

| | |
|---|---|
| BD | BASIC DENSITY |
| CM | CENTIMETER |
| $CM^3$ | CUBIC CENTMETER |
| DBH | DIAMETER AT BREAST HEIGHT |
| EMC | EQUILIBRIUM MOISTURE CONTENT |
| KG | KILOGRAM |
| LB/FT3 | POUND PER CUBIC FOOT |
| LS | LONGITUDINAL SHRINKAGE |
| $M^3$ | CUBIC METER |
| MC | MOISTURE CONTENT |
| RS | RADIAL SHRINKAGE |
| SPSS | STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES |
| TS | TANGENTIAL SHRINKAGE |
| VS | VOLUMETRIC SHRINKAGE |

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**BASIC DENSITY AND PHYSICAL PROPERTIES MAPPING OF EUCALYPTUS GRANDIS GROWN IN NEKEMTE AREA.**

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## ABSTRACT

Basic wood density and physical property mapping was studied in three age groups 10-15 years,15-20 years and 20-25 years-old on three trees from each age group of *E. grandis* to provide information on variation in basic density between and within trees and at various ages and height. Wood sample discs were taken from nine trees at five height levels (70 cm from base, DBH, 30%, 50%, 70% ) from total tree height of each tree for the determination of basic wood density and physical properties as well as ratio of heartwood and sapwood. Analysis of variance revealed significant effects($p<0.001$) of tree height and diameter on density, with oven-dry density being more strongly influenced by diameter than basic density. The average mean value at age 10-15 years (0.558 g/cm$^3$) and highest at age 20-25 years (0.706 g/cm$^3$) for minimum age to highest age. Basic density of *E. grandis* differed significantly ($p < 0.001$) at various ages. Significant differences were also apparent between various height levels and also between sapwood and heartwood. Additionally basic density also significantly affected by tree diameter at $p<0.05$ level. Tangential, radial and longitudinal shrinkages obtained in heartwood part were increased from the base (70 cm) to 30% height level and then decreased to the top (70%) of the tree height level and they also different on age group. Therefore, the rotation age and height of *E. grandis* tree had a significant effect on all properties. The findings aligned with previous research and contribute valuable insights into the density characteristics of *E. grandis*, potentially informing its use for specific applications Age groups, tree height, wood density, moisture content and shrinkage properties have to be considered when selecting and using *E. grandis* wood for various applications in Ethiopia. Heartwood might be suitable for structural components or outdoor applications. Sapwood, less dense, could be used for applications where strength is not a primary concern, such as furniture or decorative applications.

**Keywords**:- Age, *Eucalyptus grandis*, Basic density, Shrinkage, Heartwood, Sapwood, radial and tangential and longitudinal shrinkage, age, tree height, diameter

# CHAPTER ONE

## INTRODUCTION

### Background of the study

*E. grandis* Hills ex Maiden, also known as flooded or rose gum, is a highly significant species of Eucalyptus Worldwide and belongs to the Myrtaceae family (Lahr et al., 2018; Miranda et al., 2019). This species holds great importance in tropical and subtropical environments across the globe (Da Silva et al., 2019). *E.grandis* plays a crucial role in commercial forestry plantations and has been the focus of genetic improvement programs for several decades in countries like South Africa, Australia, Brazil, and Sri Lanka. These programs have implemented recurrent selection and open pollinated breeding to enhance its generations(Da Silva et al., 2019). Introduced to Ethiopia in the 1960s for afforestation purposes, *E. grandis* is one of the ten Eucalyptus species that have been extensively tested in suitable ecological zones (Hunde et al., 2003; Desalegn, et al., 2012) Whether used in its pure form or as a parent of hybrid varieties, *E. grandis* demonstrates high productivity in suitable sites and yields timber with versatile properties for various applications (Da Silva et al., 2019). Due to its favorable silvicultural characteristics, wood properties, economic significance, and wide range of uses. *E. grandis* is the most commonly cultivated species in Eucalyptus plantations(Miranda et al., 2013;Rawat and Tekleyohannes, 2021)

In Ethiopia, specifically in the Amhara, Oromia, and the Southern Nations, Nationalities, and Peoples' Regions (SNNPRs), the majority of eucalyptus varieties are cultivated (Desalegn et al., 2012; Rawat and Tekleyohannes, 2021). Initially, eucalyptus trees were planted out of curiosity in botanical gardens, arboreta, and parks for their aesthetic appeal. However, they were later discovered to have various practical uses such as fuel-wood, charcoal, paper pulp, shade and shelter, posts, poles, mine props, sawn timber, plywood, fiberboard, tannin, production of eucalyptus oil, ornamental purposes, and as a source of nectar for honey production. (Birara Dessie et al., 2019; Hambisa et al., 2023). Among the fast-growing exotic tree species planted in the Nekemte area of Ethiopia, *E. grandis* is highly favored. The wood of *E. grandis* is light, fairly hard, and easy to work with. It has straight fibers, tends to crack easily, and has a light reddish color. The heartwood of this species is dark reddish, while the sapwood has a lighter color and is susceptible to Lyctus (Christoforo et al., 2015; Lahr et al., 2018). Due to its versatile properties, *E. grandis* wood is highly valued and finds applications across various industries. It is commonly used in construction for structural framing, beams, and columns due to its strength and durability. It is also popular in the furniture industry. In Ethiopia, *E. grandis* wood is commonly used for construction purposes, as fuel-wood, and for electric poles (Hunde et al., 2003). Additionally, the

wood is used in the production of different wood products, including veneer, plywood, and engineered wood products like laminated beams and panels (Gonçalves et al., 2019). However, certain characteristics determine the quality of *E. grandis* for its intended purpose. Hence, it is essential to have a thorough understanding of the basic density and physical properties of this species to optimize its use in various applications (Lahr et al., 2018).

Wood density mapping of *E. grandis* refers to the process of measuring and mapping the density variations within the wood of this particular species of *Eucalyptus* tree (Carolina et al., 2022). Basic density serves as a primary indicator of wood quality, correlating with various other wood properties. This information is crucial for forestry management, timber quality assessment, and the wood processing industry ((Zhou et al., 2013). The ever rising demand for wood and its derived products due to a high population growth and the growing construction industry (Emmanuel et al., 2020) entails to study and utilize *E. grandis* wood. Use of wood to the best of its potential requires knowledge about its physical, anatomical, chemical and mechanical properties, and that causes studies to assess wood quality as feedstock to become lengthy, expensive processes (Couto et al., 2013). In particular, detailed studies on wood properties especially the physical properties of wood provide the advantage of triggering better *E. grandis* wood quality processing efficiency. Further, the production of in depth knowledge on some wood properties such as wood basic density and shrinkages, not only guide efficient processing, but also support the improvement of the service life of wood structures (Emmanuel et al., 2020). According to Sseremba et al., (2016), there are many complaints related to the processing of *E. grandis* such as dimensional instability, high volumes of processing wastes and seasoning defects are rampant in the industry.

Therefore, it is important to study the physical properties of *E. grandis* to partly solve these challenges. Knowledge of the physical properties of wood is essential if the processing efficiency is to be optimized. Basic density (BD), calorifc value (CV) and volumetric shrinkage (VS) are key wood quality parameters whose findings improve the efficient utilization of *E. grandis* wood (Emmanuel et al., 2020). Most important to note is that, if the variation of wood quality is known within the tree and with age of trees, wood utilization becomes easier since more accurate estimations of wood properties will be obtained. These wood property estimates, not only guide harvesting but also, support the appropriate choice of the most efficient utilization (Palermo et al., 2015). The most important wood properties that influence wood quality for most end uses are density, shrinkage, moisture content and proportion of heartwood and sapwood. Density is a function of the proportion of cell wall material and is a direct indicator for most strength properties of wood (Langat and Kariuki, 2004).

Wood basic density is the amount of wood substance in a unit volume of wood material and hence the most indicative predictor of most of the inherent and processing properties of wood (Wessels et al., 2016). It is one of the important wood characteristics of standing trees that affect the properties and performance of various wood products, such as sawn timber, reconstituted products, and pulp and paper (Gao et al., 2017). Density is an important wood property due to its correlation with other wood properties such as stiffness and pulp yield, as well as being central to the accounting of carbon sequestration in forests. According to the explanation of Pima et al., (2018), the suitability of raw wood for various uses is determined by its properties. Some of the important properties for the above end uses include basic density, fiber length and mechanical properties. Wood of most trees can be divided into two distinct regions in terms of their physiological activity: sapwood and heartwood. These regions are identified in many species, although their occurrence, properties and color can vary (Cherelli and Sartori, 2018). Quantification of these regions is possible, in some species, by direct visual analysis of the wood due to pronounced differences in color between sapwood and heartwood conferred by the accumulation of extractives. The central portion (heartwood) is darker than the peripheral one (near the bark) which is clearer (sapwood) (Cherelli and Sartori, 2018). The proportion of heartwood affects most physical and chemical properties of wood and has been found to be heritable (Langat and Kariuki, 2004).

Shrinkage in wood properties refers to the decrease in dimensions of wood as it loses moisture. This shrinkage occurs primarily in the radial and tangential directions, with minimal shrinkage in the longitudinal direction (Yang et al., 2022). Shrinkage can affect wood quality in several ways such as dimensional stability, strength, machinability and durability. Controlling shrinkage is important for maintaining the quality and performance of wood products (Yang, 2021). Proper drying and conditioning techniques can help minimize shrinkage and improve the overall quality of wood(Artwel and Gonya, 2020). However, little information is available on the determining of basic density and physical property of *E. grandis* in Nekemte area, Ethiopia. Therefore, the present study has dealt with determining of the basic density and physical properties mapping of *E. grandis* wood growing in Nekemte area.

## 1.2 Statement of the problem

The wood density has a significant influence on the properties of timber, so it is important to be able to determine the areas for application with respect to forest products (i.e., construction, furniture, paper production) by ensuring that they are properly known about variation in wood density. In Nekemte city, *E. grandis* plays a significant role in the construction sectors and the

majority of the scaffolding work meets their wood demand from it and they use it for the purpose of fuel-wood. Construction sectors need quality *Eucalyptus* for general purposes. There is dimensional instability on different trees. This dimensional instability leads to an uneven surface of the final product after drying, resulting in a lot of wastage during the planning of the products. Understanding the variations in basic density and physical properties of *E.grandis* trees in this region is crucial for effective forest management and resource utilization. The problem to be addressed in this study is to investigate how the basic density and physical properties of *E. grandis* grown in the Nekemte area vary depending on the age, height, and diameter of the tree. But there is no attention to determining the quality existing plantation *Eucalyptus* by identifying their density for different purposes. Thus, attention to determination of the basic density and physical property mapping should have a great role to enhance the value of *E. grandis* and improve the quality of the selection of this wood for the construction working. Even though the study of the basic density and shrinkage mapping of *Eucalyptus* have been carried out in different countries, studies that deal with the basic density and shrinkage mapping of *E. grandis* in Nekemte is not done. In this regard, this study is aims to determine problem forms of basic density along three age classes of *E. grandis* ,which age is more highly dense, which age of wooded sample is highly formed shrinkage and the variation of density along the anatomical direction on radial, tangential and longitudinal direction of a disks.

## 1.3 Objectives of the study

### 1.3.1 General objective

The general objective of the study is to map basic density, oven dried density, shrinkage and explore their relationship to diameter at breast height (DBH) in addition to looking into the possibility of forecasting other basic properties of *E. grandis* grown in the Nekemte area.

### 1.3.2 Specific objectives

1. To map the density of a stem of the *E. grandis* along height
2. To map the ratio of heartwood to sapwood and their moisture content
3. To investigate the density variation across the diameter
4. To map shrinkages along tree height and across locations

## 1.4 Research questions

1. How does the stem density of *E. grandis* vary along its height?
2. What is the relationship between heartwood-to-sapwood ratio and moisture content in *E. grandis*, and how does this vary along the height and age of the tree?
3. How does stem density vary across the diameter of *E. grandis* trees?

4. What is the spatial distribution of shrinkages along the height of *E. grandis* trees, and how does this differ across various locations?

## 1.6 Significance of the study

The study on basic density and physical properties mapping of *E.grandis* in the Nekemte area holds a significant importance for several reasons,

Firstly, understanding the basic density and shrinkage properties of this species is crucial for the efficient utilization of *E.grandis* in various industries such as construction, furniture making, and paper production.

Secondly, the research is useful contribute to sustainable resource management in the Nekemte area. By mapping the basic density and shrinkage properties of *E. grandis*, the study provided valuable information for land use planning and forest management practices.

Furthermore, the study's findings may have implications for carbon sequestration and climate change mitigation efforts the by contribute to sustainable forest management, biodiversity conservation and ecosystem services. *E. grandis* plays a role in sequestering carbon, and understanding its basic density and shrinkage properties can provide insights into its potential as a tool for carbon storage and contribute to broader discussions on sustainable land use and environmental conservation.

Generally, the research on basic density and shrinkage mapping of *E. grandis* in the Nekemte area is significant for its potential to inform industrial applications, support sustainable resource management, and contribute to environmental considerations. The study's outcomes should have far-reaching implications for local communities, industry stakeholders, and policymakers involved in natural resource management and environmental conservation efforts.

## 1.7 Scope of the study

The scope of the study is limited on the mapping of basic density and physical properties of *E. grandis* from samples harvested from farm forest that are located on the farms of households mainly planted around Nekemte area owing to time and financial constraints

## 1.8 Limitation of the study

There were several limitations to consider for the study on the basic density and shrinkage mapping of *E. grandis* in the Nekemte area. Political issue were one of the limitation in this research and the other materials like chain saw for felling the tree also were challenge in this research.

### 1.9 Definition of key terms

***Eucalyptus grandis***:- *E. grandis* is species of *Eucalyptus* tree. It is commonly known as the flooded gum or rose gum. *E. grandis* is a tall tree that can grow up to 60 meters (200 feet) in height and has smooth, grey bark that sheds in long ribbons. This species is widely cultivated for timber production, as it has a straight trunk and produces strong, durable wood that is used in construction, furniture-making, and paper production..

**Basic density** :- basic density specifically refers to the mass of wood substance present in a given volume of wood

**Shrinkage** :- Shrinkage refers to the reduction in dimensions or volume experienced by wood as it loses moisture.

**Moisture content** :- Moisture content refers to the amount of water present in a material, typically expressed as a percentage.

**Oven dry density**:- Oven dry refers to the process of removing all moisture from a material by placing it in an oven at a specific temperature for a specified period of time.

**Green density**:- Green density refers to the density of a material in its "green" or freshly cut state, typically when it still contains a significant amount of moisture.

**DBH**:- DBH stands for "Diameter at Breast Height." It is a standard measure of the diameter of a tree trunk taken at a specific height above the ground.

**ANOVA**:- ANOVA stands for "Analysis of Variance." It is a statistical technique used to compare the means of three or more groups and determine whether there are statistically significant differences between them. ANOVA assesses the variability between groups relative to the variability within groups to determine if the group means are different enough to reject the null hypothesis that the means are equal across all groups.

# CHAPTER TWO

## LITERATURE REVIEW

This chapter provides theoretical and empirical frameworks for the study by reviewing related literatures on basic density and physical property mapping in two broad sections. The first section presents theoretical literatures and other theories on the arguments for general overview of *E. grandis* characteristics of *E. grandis*, physical property of wood and factors of wood property variation. The second section is devoted to the reviews of empirical studies in other countries at large and in Ethiopia, along the gaps observe, in particular. This empirical studies helps as bridge for this study.

### 2.1 Theoretical Literature Review

#### 2.1.1 Over view of *Eucalyptus grandis*

*E. grandis* Hill ex Maiden is a fast growing indigenous species in Queensland and New South Wales of Australia, belonging to the family Myrtaceae. The species is commonly known as fooded gum or rose gum and Key Bahir Zaf in Amharic. It is a tall tree with a height of up to 55 m tall and a diameter of 2 m. The species name *E. grandis* is related to its large size. *E. grandis* is commonly planted in trail plots, woodlots, and large-scale plantations throughout Ethiopia in Shewa, Arsi, Harerge, and Kefa foral regions within altitudinal ranges of 1,700-2,500 m above sea level (Bahru et al.,2023). *E. grandis* has an excellent straight trunk with white, grey white, or blue-grey smooth bark and some rough faky bark at the base. It has a good all-round red, light, and durable timber and yields 0.26% oil (Bahru et al.,2023)

#### 2.1.2 Characteristics of the *Eucalyptus grandis*.

*E. grandis* a well-known species in the Myrtaceae family, *E. grandis* is also sold under the trade names Rose gum and Flooded gum. It is a member of the global market. Workable, reasonably hard, and relatively light wood is *E. grandis*. It is straight-fibered, easily cracked, and light reddish in color, with the heartwood having a dark reddish color and the sapwood being lighter in color and prone to *Eulyptus* (Lahr et al., 2018).

#### 2.1.3 Physical property of wood

The physical properties of wood include a wide range of characteristics that describe its behavior and response to external forces and environmental conditions. It is also refer to the characteristics and attributes of wood that can be measured or observed without altering the chemical composition of the material. These properties are essential for understanding and evaluating the behavior, performance, and potential uses of wood in various applications (Pima et al., 2018).

### 2.1.3.1 Determination of Basic Density

Density is a physical property of wood that refers to the mass of wood per unit volume. It is typically expressed in kilograms per cubic meter ($kg/m^3$) or pounds per cubic foot ($lb/ft^3$), is one of the most useful measures of a wood"s potential for use because it has a strong correlation with its mechanical and physical properties, such as stiffness, strength, and hardness. As a general rule, the mechanical properties should better with denser wood material (assuming clear, defect-free sections).

Generally, density is measured and reported as basic, green, or air-dry, depending on the wood samples' moisture content (MC) state (Harding et al., 2012).

Density is an important attribute of wood that contribute to the quality and therefore economic value of timber (Thomas et al.,2007).Additionally, the density of wood can vary widely depending on the species, growth conditions, and other factors. It is an important characteristic as it can affect various aspects of wood's performance and suitability for different applications. For example, denser woods tend to be harder and stronger, making them more suitable for applications where durability and load-bearing capacity are important. In contrast, less dense woods may be more suitable for applications where lightweight properties are desired.

Basic density is a measure of the oven-dry mass of a saturated volume of wood and is the standard density measure used for scientific comparisons of density (Emmanuel et al., 2020). It can also be used to model or predict wood mass at different moisture content levels, for example for shipping and freight logistics calculations. In addition, the basic density is determined by green volume and the oven dry weight for each sample disc. The base density of wood was determined from fresh samples using the most widely used wood base density measurement, which is the mass of a given volume of material divided by the mass of an equivalent volume of water (Mekonen, 2018).

$$\text{Basic density} = \frac{\text{Oven dry weight of specimen}}{\text{Green volume}} \left[\frac{g}{cm^3}\right] \quad \ldots\ldots\ldots \text{ equation (1)}$$

### 2.1.3.2 Determination of Shrinkage

Shrinkage of wood refers to the decrease in dimensions of wood as it loses moisture. When freshly cut or sawn, wood contains a significant amount of moisture, and as this moisture evaporates, the wood undergoes shrinkage. The shrinkage of wood occurs in both the radial (across the growth rings) and tangential (along the growth rings) directions, but it is typically more pronounced in the tangential direction. Changing environmental conditions such as seasonal variations in humidity, or the use of climate control devices in buildings, cause wood components to shrink and/or expand as the wood material equalizes to the surrounding conditions. This movement is measured as unit shrinkage and described by the percentage of dimensional change

per1% change in conditions(equilibrium moisture content, combined environment from temperature and relative humidity)(Harding et al., 2012).

The three dimensional measurements in green condition were made for radial, tangential and longitudinal lengths and each experimental specimens were then weighed before the specimens were placed in an oven. The weight and dimension of all samples were weighing and measured at green level by using sensitive balance and digital Vernier caliper, respectively. All the specimens were dried in the oven at 105±2$^{o}$C until constant weight is obtained. Weight and dimensional readings from the oven were made within 4 hours interval. Each specimen were consequently removed from the oven and immediately put back in the oven after weighing and measuring, and this continued until a steady weight is recorded. The percentage of shrinkage was then calculated by using the following formula (Mekonen, 2018).

$$\text{shrinkage}(\%) = \frac{\text{change in dimensional(radial,tangential or longitudinal}}{\text{green dimension(radial,longitudinal}} X100 \quad \ldots\ldots\ldots\ldots\ldots\text{Equation (2)}$$

**2.1.3.3 Characteristics of shrinkage**

The principal causes of warp (cup, bow, twist, crook/spring), distortion in and around knots, splits, and other seasoning stresses (cracks and checks) are the shrinkage characteristics brought on by the variations in tangential, radial, and longitudinal directions as well as outer and inner fibers (Desalegn and Gezahegn, 2010).

Shrinkage rates of each specimen at tangential, radial and longitudinal directions, and volumetric were determined from green (≥ 30%) to 12% MC, and from green to 0% MC, respectively. Shrinkage values from green to oven dry were classified based on position the tree anatomy (Desalegn and Gezahegn, 2010).

**2.1.3.4 Determination of Moisture content**

Wood's moisture content, which can be determined by wet or dry weight basis, is the weight or amount of water it contains. It is expressed as a percentage of the wood's moisture-free or oven-dry weight. The range of the equilibrium moisture content (EMC) for wood used both indoors and outdoors is 5 to 8 percent, while the range for wood used outdoors is 12 to 15 percent (Desalegn and Gezahegn, 2010). Desalegn and Gezahegn, (2010) explained that for every type of wood, MC has been calculated for both air and kiln seasoning. This test used the standard oven-dry weight method of MC determination because it indicates the amount of solid timber properties of *Eucalyptus* species substance present. The formula of MC present in the following Equation.

$$\text{MC (\%)} = \frac{Green\ weight\ of\ wood\ sample - ovendry\ weight\ wood\ sample}{ovendry\ weight\ wood\ sample} x\ 100 \ldots\ldots\ldots\text{(Equation 3)}$$

### 2.1.4 Oven dry density and green density

#### 2.1.4.1 Oven Dry Density

Oven dry density refers to the density of wood when it is completely dried in an oven to remove all moisture. This process ensures that the wood is at its "oven-dry" state, with no moisture content remaining. The oven dry density is an important measure of the basic density of wood and is often expressed in units such as grams per cubic centimeter ($g/cm^3$) or kilograms per cubic meter ($kg/m^3$). It provides valuable information about the solid wood substance and is a crucial parameter for assessing the quality and strength characteristics of timber (Chan et al., 2012).

#### 2.1.4.2 Green Density

Green density, on the other hand, refers to the density of wood when it is freshly harvested and contains its natural moisture content (Chan et al., 2012). This moisture content can vary depending on factors such as species, climate, and time of year. Green density is typically higher than oven dry density due to the presence of water in the wood cells. Green density is also expressed in units such as grams per cubic centimeter ($g/cm^3$) or kilograms per cubic meter ($kg/m^3$) and is important for understanding the weight and volume relationship of freshly harvested wood. Green density is highly dependent on the proportion of heartwood to sapwood in the tree which in turn is affected by age, height in the stem, and site (Chan et al., 2012).

### 2.1.5 DBH (Diameter breast height)

DBH stands for "diameter at breast height" and is a standard measurement used in forestry and arboriculture to determine the diameter of a tree trunk. The measurement is taken at a specific height above the ground, typically 4.5 feet (1.37 meters) above the forest floor. This standardized height allows for consistent and comparable measurements of tree diameter across different trees and forest stands. DBH is an important parameter for assessing the size, growth, and volume of individual trees, as well as for estimating the overall stand structure and timber yield in forest management. It is commonly used in forest inventory, tree growth studies, and timber harvesting operation (Kimberley et al., 2018).

### 2.1.6 Density of *Eucalyptus* wood

The density of *Eucalyptus* wood is a complicated property because the tissue is composed of various cell types with different dimensions, wall thicknesses, and lengths, as well as different concentrations of non-structural materials like extractives and xyloses. According to additional reports, the density varies with harvesting age; wood from young *Eucalyptus* plantation trees has a

lower density than wood from mature trees, as discussed by Githiomi and Kariuki (2010). Wood density is said to be strongly associated with numerous wood attributes. It can be used to provide a general indication of the mechanical strength, hardness, shrinkage, heating value, and other properties of wood in the absence of additional actual test data (Githiomi and Kariuki,2010)

### 2.1.7 Factors of wood property variation.

Variation in wood properties reduces the efficiency of using wood as a raw material, which is one of the main issues users face. There is a lot of variation both within and between trees overall. Within families of the same species, it is likewise high. One of the main causes of this variation is the environment. Every property of wood is the result of the interaction between a tree's genetic potential and its growth environment(Sakagami et al., 2013). This environment condition leads to the variation of property by age, location, and height of the tree. Because this three factors are depending environmental condition of the tree grown. The other researcher also addressed that, different growth conditions significantly affect wood density and shrinkage of selected young poplar hybrid crosses (Listyanto et al., 2020).Therefore the factors are determine wood property.

### 2.1.8 Relation of wood property and quality of wood

The wood quality and properties of plantation-grown wood generally differ from those of mature and regrowth wood, sourced from similar sized trees from managed native forests. These differences can have implications for processing, manufacturing and product performance (Harding et al., 2012). Plantation systems allow for manipulation of wood characteristics through tree breeding programs and silvicultural interventions, and have efficiencies for harvesting. However, the younger age and faster growth rates of genetically improved and silviculturally managed plantation trees affect the properties of their wood (Harding et al., 2012).

Wood quality can be defined as the characteristics of wood that in turn affect the properties of the manufactured product. Wood density and shrinkage are often used as general indicators of the suitability of wood for many purposes, including manufacture products. This is because the density of wood is a main determinant of strength; consequently, density and strength are directly related to each other. Wood density also has an influence on wood processing, including on cutting, gluing, finishing, rate of drying and paper making, while shrinkage is important in terms of the stability of wood during and after drying (Listyanto et al.,2020).

### 2.1.9 Factors influencing basic density and physical properties in wood

Wood properties are determined by genetic, environmental and management factors. Factors that cause variation in the different types of cells produced by trees are usually interactive,

so there is rarely a single factor that controls variation. Wood properties that show marked within-tree variation are anatomical characteristics like fibre (cell) diameter, fibre length, fibre wall thickness, vessel frequency and physical properties like density (Plessis, 2012)

#### 2.1.9.1 Factors influencing wood density of wood

Density is influenced by several factors which are also in correlation with each other. Temperature is the major factor that influences basic density (Thomas et al., 2007). The temperature optimum for maximum growth (i.e., biomass accumulation, stem volume, leaf area) of *E. grandis* differed from the temperature for maximum wood density. Stem radial growth and stem volume were principally related to the production of new cells rather than cell expansion(Thomas et al.,2007)

The temperature and wood density of *Eucalyptus* have a positive relationship, but in recent years, this relationship has broken down, with wood density falling as global temperatures have risen. In order to ascertain the anatomical reasons behind the temperature-related variations in wood density, *E. grandis* W. Hill ex Maiden seedlings were raised in cabinets with regulated environments and maintained at temperatures between 10 and 35 °C. Furthermore, higher growth temperatures have been linked to higher wood densities in mature *Eucalyptus* trees; however, the anatomical factors causing these variations in *Eucalyptus* wood density remain unclear. Furthermore, historical climates have been deduced using seasonal variation in wood density as a stand-in for temperature. However, the previously observed positive correlation between temperature and wood density has faltered in recent years, with wood density falling as global temperatures have increased (Thomas et al., 2007). The other is moisture content which it influences most properties of the wood as well as density. Filling up the intermicellar cavities of the cell wall and the lumen of the cells with water increases the density of porous wood (Pásztory et al., 2014). Additionally, other researches indicated that position of the tree is special changes occur along the trunk's length and cross section due to changes in the size features and chemical composition of tissue elements (Pásztory et al., 2014). When the wood is young, the average density increases steadily from the pith outward to the maximum level in the mature stage. In line with (Pásztory et al., 2014) describe trees with distinct colored heartwood, where the sapwood has a 5–15 percent lower density than the heartwood. The shape of the crown and the mechanical operations of the trunk are related to the change in density along the trunk. Pasztory et al.,(2014) explained that, the location within the forest, the tree's height, the diameter of its trunk, and the size of its crown all affect how dense the wood is ultimately determine its quality and potential uses. As a result, for instance, in the ring-porous wood species, individuals with a larger diameter

and those that attain the prevailing height tend to have an average density that is 5-7 percent higher than that of the thinner or lower individuals (Pásztory et al.,2014).

Further studies indicated that the middle of the species geographic range, where the climate is at its best, has the highest wood density. Wood typically has a higher average density in fully stocked stands where the trees are grown with careful silvicultural practices (Pásztory et al.,2014). In line with (Pásztory et al., 2014) based on a survey of the technical literature mentioned above, it can be determined that within a trunk, the variety of density varies between 15 and 20 percent depending on the species; within a stand, there can be notable variations in the average density of trunks, with a relative deviation of 20 to 30 percent. As long as the wood stands belong to the same species, are from the same region, and are roughly the same age, there shouldn't be any appreciable differences in density (5-10 percent). Significant variations in wood density, ranging from 10 to 20 percent, can be found among wood stands with greater geographic and topographic differences; in these situations, genetic effects should also be taken into account (Pásztory et al.,2014).

#### 2.1.9.2 Factors influencing the shrinkage of wood

According to the various studies, wood density has the biggest impact on shrinkage because wood shrinks in a way that is proportionate to the moisture removed from the cell wall. Because it is connected to the strength and pulping properties of wood, wood specific gravity the ratio of the oven-dry weight of a given volume of wood to the weight of an equal volume of water is regarded as a reliable indicator of the quality of wood (Listyanto et al., 2020). Another indicator of the amount of wood material in a tree is wood density, which is the weight of wood per unit volume. The two terms are frequently used interchangeably. However, wood density is only equal to specific gravity at 0% moisture content; it should only be reported at specific moisture contents. According to (Al-Sagheer and Prasad, 2010), a tree's cell diameter, cell wall thickness, and quantity of latewood produced all contribute to its wood density, also known as specific gravity. The shrinkage variations in the stem of the log and the relationships between the primary factors influencing shrinkage and the actual shrinkage have been the subject of more investigation (Listyanto et al., 2020). A few of the factors that are evaluated are micro fibril angle, density, and extractives content. Wood shrinkage is also influenced by differences in wood types, such as sapwood and heartwood, juvenile and mature wood, and early and latewood (Artwel and Gonya, 2020). Although, a large proportion of wood variability is under genetic control, the environment and silvicultural practices under which a tree is growing is also a major driver of variation (Plessis, 2012).

Generally according to previous research on *E. grandis* tree in terms of determining basic density and shrinkage mapping several research experiments are not conducted widely studied in Ethiopia especially in Nekemte area for determining the utilization of forest products for different applications, this is one of the research gaps ,the second research conducted broadly the age of the trees under 15 years old according to many resent studies from different countries. This is not enough to determine basic density and the shrinkage of a mature tree and requires further research to decide for different application, it will be found necessary to address this gap by conduct experiment to determine variation of density and shrinkage mapping with in tree ages of *E. grandis* grown in Nekemte area between age from 10 to 25 years plantations.

### 2.1.10 Importance of basic density and physical property mapping

The most significant wood characteristics that affect wood quality for the majority of end uses are density, collapse, seasoning, and the ratio of heartwood to sapwood. The majority of the strength characteristics of wood can be directly predicted by density, which is a function of the percentage of cell wall material. The splitting and collapse properties are influenced by density and moisture content. Additionally, there is a strong correlation between natural resistance and density (Langat and Kariuki, 2004).The importance of basic density and physical property mapping of *E. grandis* lies in its implications for forest management, wood utilization, and the development of improved breeding and selection programs. Understanding the variation in basic density and physical properties across different environmental conditions can have significant practical and scientific implications. Some of the key reasons for the importance of this mapping include (Elissetche et al., 2024).

Forest Management: Basic density and physical properties mapping can provide valuable information for forest managers to optimize silvicultural practices, such as site selection, tree spacing, and rotation length. This knowledge can help in maximizing wood quality and yield, as well as in identifying suitable areas for *E. grandis* plantations (Elissetche et al., 2024).

Wood Utilization: Mapping basic density and physical properties can assist in matching specific wood properties with appropriate end uses. For example, knowledge of the variation in basic density can help in determining the suitability of *E. grandis* wood for different applications, such as pulp and paper production, solid wood products, or bioenergy. Understanding the genetic and environmental factors influencing basic density and physical properties can aid in the development of improved breeding and selection programs for *E. grandis*. This can lead to the selection of genotypes with desirable wood properties, contributing to the sustainable production of high-quality timber (Lahr et al., 2018). According to (Lahr et al., 2018) it is important for the

optimal utilization of wood to understand the nature and causes of the intra-specific variation in wood properties within trees and inter-specific variation between trees of the same species. This variation, despite the fairly accurate way of measurement, remains difficult to predict accurately.

## 2.2 Empirical literature Review

### 2.2.1 Relationship of Wood density and other property

The wood density of a stem can be described as a gross measurement of its internal anatomy; it is not a single wood property but represents a combination of characteristics. Wood density is determined largely by fibre wall thickness as well as the proportions of thick and thin-walled cells that are present (Naidoo, 2011). However, density does not automatically correlate with fiber cell wall dimensions as density also measures vessels and parenchyma, which have thinner walls and wider lumens and hence reduce density ( Naidoo,2011). According to Cremonez et al., (2019) a strong correlation exists between the wood basic density and other wood properties, making it one of the most significant parameters in the assessment of wood quality. The ratio between the weight of completely dry wood and the volume of saturated wood defines this physical attribute. As findings of (Barotto) density does not automatically correlate with fiber cell wall dimensions (Barotto et al.,2017). Wood density may be considered a measure of internal wood structure, reflecting the combination of features of the various cellular elements that compose wood (Barotto et al.,2017). This trait is associated with not only mechanical wood strength and fiber walls, but also with the structure of vessel and parenchyma cells, which have thinner walls and larger lumens (Naidoo et al., 2006). Wood density therefore correlates with cavitation resistance, and the thickening of vessel and fiber walls could be related to the stress that xylem vessels must withstand during high tension periods (Barotto et al., 2017).

### 2.2.2 Relationship of basic density and wood anatomy

The proportion of the vessels and the thickness of the fiber cell walls influence variations in the basic density of wood. Both an increase in the fibers' cell wall thickness and an increase in the proportion of fibers corresponding to the proportion of vessels may be the cause of the density growth. However, a decrease in cell wall thickness or not, combined with an increase in the proportion of vessels, results in a reduction of density(Cremonez et al., 2019). Basic density does not automatically correlate with fibre cell wall dimensions, because density also measures vessels and parenchyma, which have thinner walls and wider lumens and reduce density. In mature *E. grandis*, density increases rapidly from pith to bark, especially in the zone of juvenile wood (Barotto et al.,2017).

Wood density is a measure of the internal structure of the wood, a combination of the characteristics of the different cellular elements that make up the wood (Barotto,et al., 2017). This characteristic is linked to the structure of vessel and parenchyma cells, which have thinner walls and larger lumens, in addition to mechanical wood strength and fiber walls. As a result, wood density and cavitation resistance are correlated. Additionally, the stress that xylem vessels must endure during times of high tension may be linked to the thickening of vessel and fiber walls (Barotto et al., 2017). Gradually, the density increases because during the early stages of secondary growth, when more robust cells are produced to form mature wood, xylem is produced with thin cell exchange and is referred to as juvenile wood (Castro et al., 2020). The most significant increase in basic wood density was in the top part of the tree. Wood basic density increases at higher stand density and at the top of the tree as reported by (Samuel Mekonen, 2018). The increased basic density in the top portion of tree may be due to a higher percentage of latewood vs. juvenile wood impacts. It is difficult to predict the impact of juvenile wood, but the lower percentage of juvenile wood results in higher wood basic densities in closer spacing. Samuel Mekonen (2018) also reported that juveniles have a high percentage moisture content, which results in lower basic densities due to the inverse proportionality of moisture content to basic wood density in this study.

### 2.2.3. Variation of basic density along diameter of wood

Wood density varies greatly within and between trees. Radially, wood density increases from pith to bark (as the cambium matures). Longitudinally, trends in variation differ among studies due to the sampling strategy and treatments used leading to conflicting results. However, these authors offered an alternative explanation for the conflicting results in variation in density. It is possible that the magnitude of the treatment effect is relatively small compared to the natural variation that exists which leads to difficulty in establishing consistent trends of longitudinal variation in density (Naidoo, 2011). In mature *E. grandis*, density increases rapidly from pith towards the bark, especially in the zone of juvenile wood according to (Naidoo, 2011 )but in young fast growing trees, such steep gradients do not exist. Density starts to level off 27 from about the age of 15 years, depending on the rate of growth. According to the study of (Naidoo 2011) the slower the growth, the steeper the gradient. On a good quality site, the air-dry wood density of *E. grandis* at breast height ranges between 400 kg/m$^3$ (close to the pith) to approximately 750 kg/m$^3$ in the outer layers of a 30- year old tree. Logically, faster growth rate over a shorter period can yield the same amount of growth as slower growth over a longer period. However, the differing growth rates are expected to result in different wood properties (Naidoo, 2011). Both age and

relative position of the stem were important sources of variation in density. Along the stem, density declined initially from stump level to 25% of tree height and then gradually increased towards the top (Deng et al., 2014).

Density marked differences, however, do exist between early and latewood zones making the wood extremely variable within trees (Naidoo, 2011). In areas of fast growth, such as South Africa, juvenile wood is important since it constitutes a large proportion of the stem and is a major source of within tree variability. Variation in density along the stem is less consistent than that in the radial direction. According to findings of in (Naidoo 2011) studies density within trees decreases with increasing height between 1.5 and 4.5m above ground level and thereafter increases (Naidoo, 2011). Similarly, (Naidoo, 2011) found that density in *E. grandis* declined from stump level to 25% of tree height and then gradually increased towards the top in a curvilinear manner.

#### 2.2.3.1 Variation of basic density with age

Further analysis indicated that trees of ages 4, 5, 6 and 7 were not significantly different in basic density whereas trees of ages 8, 9 and 10 were distinctly different from one another and from ages 4, 5, and 6( Githiomi and Kariuki,2010). In a similar study in Central Highlands of Ethiopia, a weak but positive correlation was established between tree age and basic density of *E. grandis* (Lemenih and Bekele, 2004). According to (Githiomi and Kariuki, 2010) the density was significantly influenced by age and tree height. It increased with age and was lowest at age 4 years (0.414 g /cm-3) and highest at age 10 years (0.517 g /cm-3) in their study.

#### 2.2.3.2 Variation in basic density with height

The basic wood density varied significantly with tree height, with the highest average density at 60% of total tree height and the lowest at breast height (Githiomi and Kariuki, 2010). According to Githiomi and Kariuki (2010) there was a general tendency for basic density to decrease from base to breast height and then increase to a maximum at 60% height point before decreasing at 80% with the exception of ages 6 and 8. The basic densities for sapwood and heartwood varied significantly. In general, sapwood had higher basic density than heartwood in all ages except for ages 4 and 5 according to result finding of research in Kenya (Githiomi and Kariuki, 2010) Additionally, other research results in southern china showed that the wood density at different height was significantly different from the whole-stem density except the relative height of 0.1. An overall decrease of 133.8 kg/$m^3$ in density was found from stem base to top. Wood density was significantly influenced by relative heights, tree age, and social class. Density of each relative height in mature trees was significantly higher than that of younger trees. Tree

social class can affect wood density development in the axial direction at age classes 2 and 3. Combining the fixed plus random effects, the final model explained 91 % of the observed variation in wood density(Deng et al., 2014).

According to Deng et al,. (2014) the basic wood density of trees varied significantly with height, showing the highest average density at 60% of total tree height and the lowest at breast height. There was a general trend of decreasing density from base to breast height, followed by an increase to a maximum at 60% height before decreasing again at 80%, with exceptions at ages 6 and 8. Sapwood generally exhibited higher basic density than heartwood across different ages, except for ages 4 and 5. Research in southern China also found significant differences in wood density at different heights along the stem, with an overall decrease in density from base to top (Deng et al., 2014). Factors such as relative height, tree age, and social class were found to influence wood density, with mature trees generally having higher densities than younger trees. Tree social class was noted to impact wood density development in the axial direction at certain age classes. The final model explained 91% of the observed variation in wood density, indicating the complex interplay of factors influencing this important wood property (Githiomi and Kariuki, 2010; Deng et al., 2014).

#### 2.2.3.3 Variation of basic density between sapwood and heartwood

The basic density of sapwood was higher than the basic density of heartwood. Further analysis showed that the difference was only statistically significant from age 7 to 10, where sapwood density was greater than that of heartwood (Githiomi and Kariuki, 2010). At younger ages, there was no difference in sapwood basic density compared to heartwood basic density, as the wood was in a transitional stage with little chemical transformation. There was only a very slight difference in basic density from sapwood to heartwood up to a height level of 65% (Githiomi and Kariuki, 2010). In the present study, heartwood was not present at 80% in all age groups.

Additionally, other research in Turkey also has been reported that the basic density of sapwood is greater than that of heartwood (Bedelean, 2012). According to Bedelean (2012) some of the physical properties of heartwood and sapwood of *E. grandis* grown in Karabucak, Turkey were determined. The physical properties determined were air-dried density, oven-dried density, basic density, shrinkage, swelling, fiber saturation point, and maximum moisture content. According to the test results, the physical properties of the heartwood samples differed from those of the sapwood samples due to the presence of high proportion of juvenile wood in the heartwood (Bedelean, 2012). Dedelean (2012) also reported that the shrinkage and swelling percentages were

better for heartwood than sapwood. Air-dried density, oven-dried density, and basic density of sapwood were higher than those of heartwood.

Therefore, the basic density of sapwood was found to be higher than that of heartwood, with a statistically significant difference observed between ages 7 to 10. At younger ages, the basic density of sapwood and heartwood showed little variation due to the wood being in a transitional stage with minimal chemical transformation (Githiomi and Kariuki, 2010). The difference in basic density between sapwood and heartwood was minimal up to a height level of 65%. Research in Turkey also supports the finding that sapwood has a greater basic density than heartwood, attributing this difference to the presence of a high proportion of juvenile wood in the heartwood (Bedelean, 2012). Physical properties such as air-dried density, oven-dried density, and basic density were higher in sapwood compared to heartwood, while shrinkage and swelling percentages were better for heartwood (Bedelean, 2012).

### 2.2.4 Longitudinal shrinkage across diameter

Many researches generally accepted that the longitudinal shrinkage of normal wood during the drying process from green to oven dry condition is negligible, and it ranges from 0.1 to 0.3 percent (Batista et al., 2013). Boards that contain abnormal tissue such as that found in juvenile wood, compression, or tension have a higher longitudinal shrinkage and may warp significantly when they dry (Cassidy et al., 2013).Wood can shrink or swell as a result of moisture fluctuations below the fiber saturation point (FSP) (Artwel and Gonya, 2020), changing the wood's dimensions. The dimensions do not change significantly when the moisture fluctuates above fiber saturation point (FSP). Wood shrinks and swells as a result of losing water to adjust its moisture content to the surrounding environment when the environment is dry and taking up water when the environment is humid. Moreover, in explanation of Artwel and Gonya, (2020) wood exhibits anisotropy, suggesting that the direction of shrinkage determines its magnitude. Therefore, there are differences in the shrinkage properties in the three dimensions (tangential, longitudinal, and radial). Shrinkage and collapse have a similar effect on wood as they both reduce its dimensions and hence, a distinction between collapse-free shrinkage and shrinkage including collapse is important (Artwel and Gonya, 2020).

### 2.2.5 Shrinkage in radial differences across the tree disc

The amount of cell wall (cell wall thickness), particularly in the S2layer, has been proposed as an explanation for the density effect (Artwel and Gonya, 2020). According to Artwel and Gonya (2020), wood with higher densities has thicker cell walls. Moreover, high density wood swells and

shrinks more because it has more material to absorb water and more sorption areas available (Batista et al., 2013). This causes the wood to absorb more moisture in the cell wall.

### 2.2.6 Relationship of density and shrinkage

Research by Artwel and Gonya (2020) revealed a correlation between high densities and high shrinkage. According to this report, density exhibits the previously stated relationship with only tangential and radial shrinkage, indicating that longitudinal shrinkage does not always increase with density (Artwel and Gonya, 2020). Wood density and tangential and radial shrinkage have a strong correlation, as discussed by Artwel and Gonya (2020). Therefore, since density also decreases with tree height, radial and tangential shrinkage along the axis can be predicted with density. According to this report, shrinkage increases with increasing density because it is correlated with the amount of cell wall material or moisture lost from the cell wall (Artwel and Gonya, 2020).

### 2.2.7 Heartwood and sapwood

Physiologically, wood is divided into two areas: sapwood and heartwood. These areas are identified in many species, but their color, nature, and presence can vary. Heartwood is the inner part of the trunk from the tree with dead cells and does not contribute to physiological activity such as respiration or water transport. In most tree species, its color is darker than the sapwood part and usually has lower water content (Cherelli and Sartori, 2018). Some species have been shown to have heartwood parts with higher natural durability compared to sapwood parts. Heartwood is the most valuable part of the wood because it often provides high natural durability or resistance to decay which is good for outdoor use (Cherelli and Sartori, 2018). Furthermore, its color had a higher aesthetic value with the dark color compared to sapwood pale (Arisandi et al., 2023a). Wood of most trees can be divided into two distinct regions in terms of their physiological activity: sapwood and heartwood. These regions are identified in many species, although their occurrence, properties and color can vary (Arisandi et al., 2023b). According to Arisandi et al (2023) Quantification of these regions is possible, in some species, by direct visual analysis of the wood due to pronounced differences in color between sapwood and heartwood conferred by the accumulation of extractives. The central portion (heartwood) is darker than the peripheral one (near the bark) which is clearer (sapwood). However, in certain species, despite the existence of heartwood, there are little or almost no visually detected differences between heartwood and sapwood colors (Arisandi et al., 2023b). In such cases, identification requires the analysis of differences in the chemical level as a difference in pH between the sapwood and heartwood (Cherelli and Sartori, 2018). Due to the importance of the proportion of heartwood and sapwood,

its density variations as well as uniformity in the use of wood in certain applications and the possibility of using greater potential techniques to deeply differentiate these regions (Cherelli and Sartori, 2018).

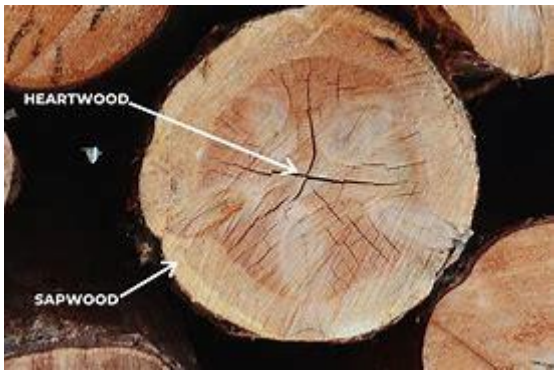



**Figure 2.1.Heartwood and sapwood**

## 2.3 Summary and gap

The literature review provides valuable information on the physical properties of *E. grandis*, including its basic density, which is a crucial factor in determining the wood's potential for various applications (Githiomi and Kariuki, 2010). However, there is a research gap regarding to investigating the variation of basic density in *E. grandis* concerning the tree's age, diameter, and height in our country, especially around Nekemte area. Understanding how these factors influence the basic density of *E. grandis* can provide insights into the quality and economic value of the timber produced from different trees. The basic density of *E. grandis* changes with age, diameter, and height, researchers and industry professionals can better optimize wood utilization, predict wood properties, and enhance the efficiency of timber processing operations (Githiomi and Kariuki, 2010; Lahr et al., 2018). This gap in the literature highlights the need for further research to explore the relationship between basic density and tree characteristics in *E. grandis* in Ethiopia, especially in Nekemte area, ultimately contributing to sustainable forest management practices and improved wood product quality.

## 2.4 Framework for the study

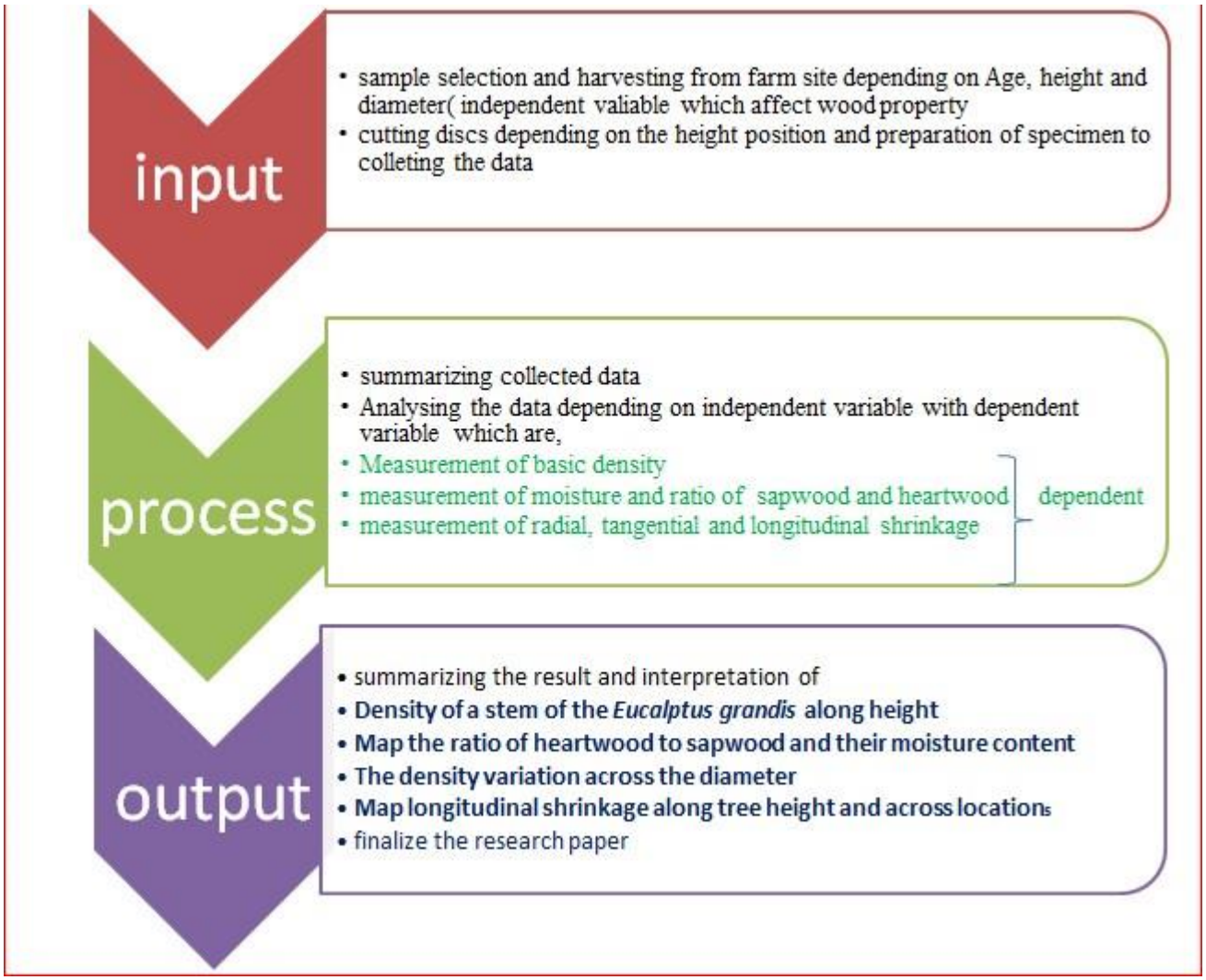



**Figure 2.2. Conceptual framework**

# CHAPTER THREE

## MATERIALS AND METHOD

### 3.1 Description of the study area

This study was conducted in the area of Nekemte town, the capital city of East Wollega Zone in the Oromia Region of western Ethiopia. Nekemte is known for its abundance of *E. grandis* tree plantations, widely planted by the farmers on their private land for various purposes (such as selling for house building, for firewood). The specific study site, located in the Gari Kebele, Koromi area, was chosen due to the availability of *E. grandis* according to proposed age groups for basic density and physical property mapping (**Figure 3.1**). This site is situated approximately 328 kilometers west of Addis Ababa, the capital city of Ethiopia. The surrounding rural areas of Nekemte are characterized by numerous state-owned forests, where *E. grandis* trees are a primary species harvested for various uses.

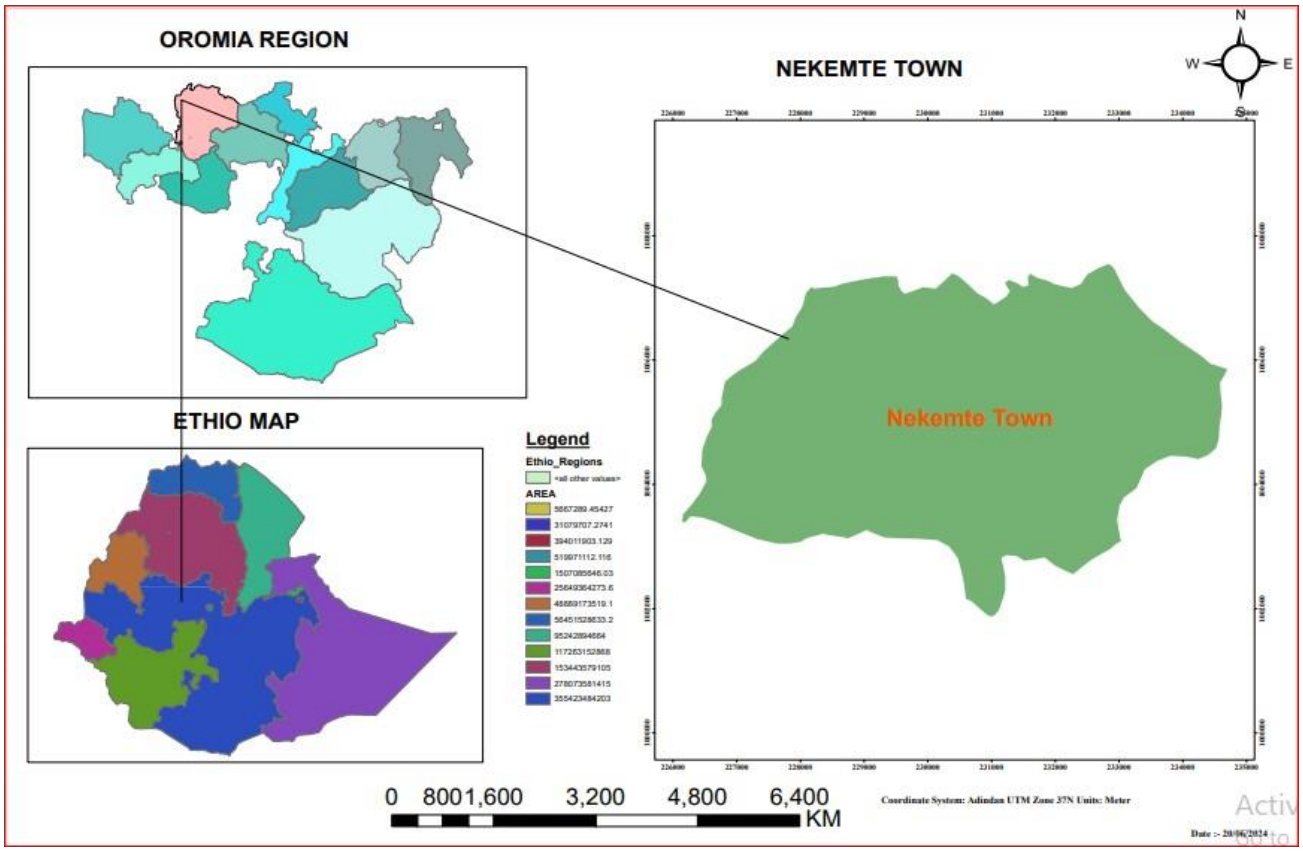



**Figure 3.1 Map of study area (Source: Own design 2024)**

**Topography and Geology**

The land of Nekemte area is  a flat, hilly landscape. Nekemte area is composed of alluvium deposit (mainly composed of the clay soil) at the most top part and volcanic rocks particularly massive basalt, and weathered and fractured basalt. The clay seems developed from the weathering of the underlying basalt. At many sites it has reddish to black color and variable thickness. The most abundant and dominant volcanic rock unit which composed of mostly basalt is fine grained, black to grayish in color and strongly subjected to weathering and varies degree of fracturing (Carlson and Ortiz, 2006).

**Climate and rainfall**

The city has a mild highland subtropical climate with a lower elevation than Addis Ababa, Nekemte has a slightly higher average temperature, differing mainly in the low averages. The average annual temperature is 18.3 °C (high: 24 °C and low: 12.6 °C), although to the north of Equator March is the warmest month and July the coldest month (Gurmessa et al., 2012). The main rainy seasons in this town are from June to August and dry season between October to January. The weather is cold during the rainy season in the highland. According to the annual rainfall mapping of the study area gets annual rainfall ranging from 1500mm to 2200mm (Carlson and Ortiz, 2006).

**Vegetation and wildlife**

East Wollega Zone, with its capital city Nekemte, is renowned for its extensive forestlands, encompassing both natural and man-made stands. A total of 215,967 hectares of land is covered by forests, with 128,724 hectares classified as natural high forests and 87,243 hectares as man-made forests. The eastern highlands of Wollega are characterized by broad-leaved, evergreen moist forests. These forests boast a rich diversity of tree species, including *Albizia schimperiana, Bersama abyssinica, Cordia africana, Croton, macrostachyus, Syzygium species, Sapium ellipticum, Grevillea robusta, Jacaranda species, Cupressus lusitanica, Pinus patula, Juniperus procera, Pouteria adolfi-friedericii, Ekebergia capensis, Eucalyptus globulus, Eucalyptus grandis, Eucalyptus camaldulensis,* and *Afzelia africana* (Gurmessa et al., 2012). Within the Nekemte area, the Komto Forest provides a refuge for a variety of wildlife species. These include the *spotted hyena, Abyssinian black and white colobus monkey,* common jackal, blue monkey, bushbuck, common duiker, aardvark, olive baboon, hare, vervet monkey, and crested porcupine. However, the wildlife, like the forest itself, faces significant threats from deforestation and habitat fragmentation due to human encroachment (Gurmessa et al., 2012).

**Socio-economic and livelihoods**

East Wollega, including the town of Nekemte, is a region in western Ethiopia with a diverse socio-economic landscape. The area is predominantly rural, with a population of over 2 million people, according to the Central Statistical Agency (CSA) of Ethiopia. Nekemte town itself has a population of around 200,000. The majority of the population relies on agriculture for their livelihood, engaging in livestock farming, crop cultivation, and small-scale trading. *Eucalyptus* trees, such as *E. grandis* and *E. saligina*, have been planted in the region, providing a valuable source of income for farmers who sell the wood for house building and firewood. Despite the economic importance of agriculture, Nekemte area faces significant socio-economic challenges. Poverty remains a widespread issue, with many households struggling to meet their basic needs. Limited access to education and healthcare services further exacerbates these disparities. Nekemte town serves as a commercial hub for the surrounding rural areas, offering markets, services, and employment opportunities. In recent years, infrastructure development in both the town and the wider region has been improving.

### 3.2 Research Methodology

The type of methodology for this research quantitative and qualitative (mixed) research approach

## 3.3 Research design

The research designs that applied for this study is explanatory research design because explanatory research design aims to explain the relationship between variables by manipulating one variable (independent variable) and observing its effect on another variable (dependent variable) to this research topic for determining the basic density and physical property of the selected species.

## 3.4 Sampling design and Method of data collection

### 3.4.1 Survey, sampling techniques and sample harvesting

The sample of *E. grandis* were harvested from around Gari Kebele farmland in Nekemte area Oromia region, approximately from 1.5 hectares of *E. grandis* plantation by random purposive sampling techniques depending on the targeted three age group (10-15 years old ,15-20 years old and 20-25) years old. The random purposive sampling technique is a random sampling methodology where the sample group is targeted to have specific attributes. In total, nine *E. grandis* trees were randomly selected from farmland village depending on age group equal number for the study.

### 3.4.2 Sample size

Nine(9) sample trees were selected and harvested from three age groups of *E. grandis* tree which are 10-15 age,15- 20 age and 20-25 age groups (**Table 3.1**). Three age groups were used to evaluate the density variation along the tree height and across tree diameter. Three sample trees from each age were purposively selected from the sites in order to explore the influence of age on the basic density. All sample trees were grouped into three age categories based on availability. After felling, 50 mm thickness discs were cut from each log, according to height (from base stump height, i.e.70cm height, DBH(1.37m), 30%, 50%, and 70%) along trees height and 45 discs were collected from nine sample trees. The sample discs were cut in to 50 mm thickness by chain saw after trees were felled according to proposed height measurement and packed in the plastic bags to avoid the moisture loss and also directly transported to laboratory shop after all sample discs are packed. Detail of the total average log length and diameter at breast height of the three logs in each age group are described in table 3.1 and figure 3.2.

**Table 3.1. The sample selection**

| Number of sample, Average sample tree Height and diameter at breast height | | | | | | |
|---|---|---|---|---|---|---|
| Age group | | 10-15 Years | 15-20 Years | 20-25 Years | | Total number of trees |
| No of sample tree at each age group | | 3 | 3 | 3 | | 9 |
| Average tree height (M) | | 17 | 21 | 22 | | |
| Average DBH diameter (cm) | | 20 | 27 | 32 | | |
| Position of disks was sampled along the height | | | | | | Total number of discs |
| Discs (at the heights for sampling) | Knee height (70 cm) | DBH (130cm) | 30% | 50% | 70% | 45 |

**Note: 5 discs from each tree at different heights X 3 (age groups) = 15 discs X 3 (replicates) = 45 discs.**

### 3.4.2.1 Method of cutting discs from stand tree.

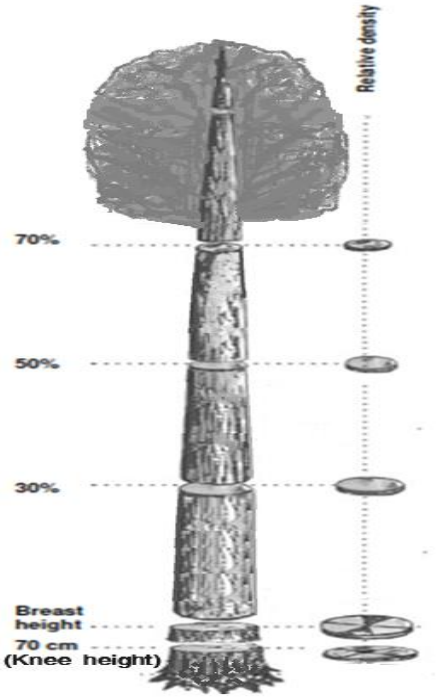



**Figure 3.2 Position of sample disks along the tree height for collecting data on basic density, moisture content and shrinkage.**

### 3.4 3. Tree sampling

A total of nine trees of 10-15 ,16-20 and 21-25 years old *E. grandis* were randomly selected and harvested from Gari Kebele farmland forest in koromi area, Nekemte Oromia region (**Figure 3.3 and Figure 3.4**). The selected sampled trees were straight trunks. The height of selected trees were ranging from 15 m to 25 m. Each sampled tree was cross-cut into stump height. i.e. 70 cm height, DBH (1.37m), 30%, 50% and 70%, along trees height from all stump 45 discs which 50 mm thick were cut. Then the sample logs were transported to converting the discs in to a necessary samples specimen processing to Nekemte Polytechnic College in furniture work shop and for laboratory processing used in Nekemte Polytechnic College department of road technology workshop. Figure 3.4 showed when the tree is selected, felled down and ready for processed).



**Figure 3.3 The measurement and selection of the sampled trees from farmland forest**.



**Figure 3.4 The sampled trees were felled for the preparation of sample discs**



**Figure 3.5 The logs were cut into the sample discs for further laboratory test**

## 3.4.4 Samples preparation for physical property

The physical properties planned to be studied in this study are basic density, moisture content, shrinkage and swelling and sapwood and heartwood ratio. Thereafter, from the felled sample trees 50mm thick 45 discs were obtained based on the sampling plan shown on Figure 3.6. from stump height,(70cm height), DBH, 30%, 50% and 70% height. From each sampled tree discs were prepared to quantify the physical properties such as moisture content, basic density, radial, tangential, longitudinal, volumetric shrinkage and sapwood heartwood ratio. The total number of sample discs were collected from 9 trees and totally 45 sample discs were used for further analysis. Each disc was immediately put in plastic bag after cutting and was transported to the testing lab in Nekemte Polytechnic College and stored in clean and cool place (**Figure 3.6**).



**Figure 3.6 The discs harvested from stem and branches covered in plastic bag**

### 3.4.4 Sample preparation and measurement of basic density and shrinkage

There were 45 discs which have a uniform thickness of 50mm disc each. The density of each specimen was determined based on ISO 13061-2 -2014 (Determination of density for physical and mechanical tests). Samples to be taken from each disc was laid as shown on **Figure 3.7** to get

50mm wide strips from which were obtained 50 mm thick and 50 mm length (along the grain) strips which were square in shape. Finally, the strips cut into 50 mm X 50 mm cross section for basic density specimens. The number of specimens obtained in this way was depending on the diameter of the discs from which the specimens was being prepared.

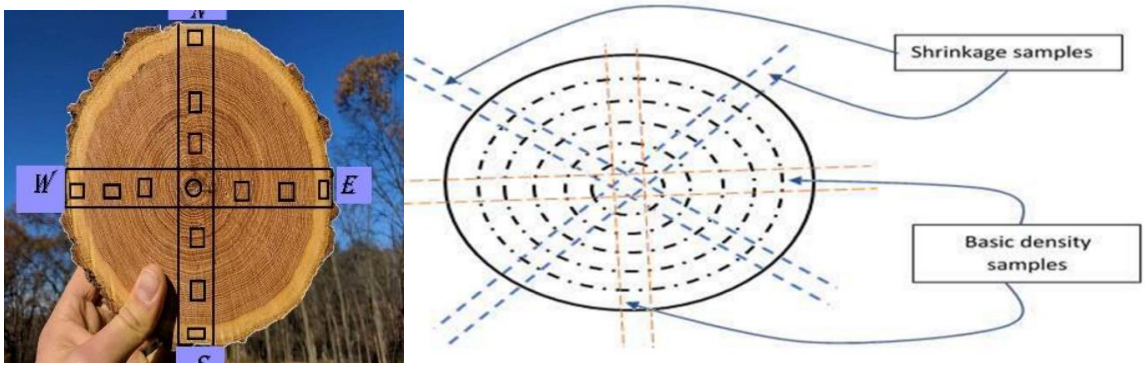



**Figure 3.7. The marking for sample cubes for basic density and shrinkage specimens**

The weight and dimensions (radial, tangential and longitudinal)of each specimen was measured immediately after conversion so that the green density can be calculated. The specimens were being dried in oven at the temperature 105$^{o}$c for about 24hrs with periodic weighing and dimensional measurement as equivalent to conditioning to 12% moisture content in a constant humidity chamber. Weight and dimensions (radial, tangential and longitudinal) of each specimen was measured and there after dried in oven for 24hrs using digital sensitive balance and vernier caliper(Figure 3.8).



**Figure 3.8. Procedure of preparing specimens from the discs**

### 3.4.4.1 Sample preparation for experimental study of basic Density

Three replicate sample trees from each age group were harvested from a single site and 5 discs were cuts for the evaluation of basic wood density at knee height (70 cm), DBH (130 cm), 30%, 50% and 70%, respectively (Table 3.1).

The corresponding weight of each disc was measured using electric sensitive balance with accuracy of 0.01kg. The green density of the disc was calculated by the formula on Equation 1. For gradient basic density and shrinkage determination samples were cuts out from each of the discs as shown in the Figure.3.1 and figure.3.2 and their weights and volume were measured accurately (accuracy of 0.001 kg). Thereafter, they were taken into oven set at 105±2$^{o}$C until they attain constant weight, and their weight and volume were measured again. Wood basic density for each disc were determined as the ratio of oven-dry mass to green volume; while oven dried density calculated as the ratio of oven dried weight to oven dried volume (Figure 3.9).



**Figure 3.9. Sample specimen were measured for basic density**

$$Basic\ density = \frac{fresh\ weight\ of\ wood\ sample}{Green\ volume\ of\ the\ sample}\ \left[\frac{g}{cm^3}\right] \text{.....(Equation 1)}$$

$$Oven-dried\ density = \frac{Oven\ dry\ weight\ of\ specimen}{Oven\ dried\ volume}\ \left[\frac{g}{cm^3}\right] \text{.....(Equation 2)}$$

### 3.4.4.2 Samples preparation and measurement of radial, tangential and longitudinal shrinkage

Shrinkage measurements sample material were taken from the same tree height as given in table 3.1 for basic density. The 50 mm thick discs were cut on a band saw square to the pith, then parallel to the grain. Excess wood were trimmed away to reveal fresh green wood. Branch stubs are avoided as much as possible. Two strips which are perpendicular to each other (but adjacent to the basic density strips as shown on (**Figure 3.7**) cuts from the same disc from which sampled for basic density specimens. The shrinkage specimens dimensions established based on ISO 13061-2 standard and adequacy of discs for multiple specimens at each of the relative positions. First dimensions of the specimen was measured in green condition in the three anatomical directions (Radial, Tangential and longitudinal). Following green condition measurements, the specimen oven

dried at 105±2$^{o}$C for 24 hours, then each of the dimensions for each of the specimens was measured again(**Figure 3.10**). Shrinkage in the given anatomical direction expressed as a percent length loss based on the original green length/dimension using equation 3**.**



**Figure 3.10. The sampled cubes were prepared for shrinkage estimation**

$$\text{Shrinkage} = \frac{\text{change in dimensional(radial, tangential or longitudinal}}{\text{green dimension(radial, longitudinal}} X100 \quad \ldots\ldots\ldots \text{(Equation 3)}$$

$$\text{Volumetric Shrinkage} = \frac{\text{green volune } - \text{oven dry volume}}{\text{green volume}} X100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 4)}$$

### 3.4.5 Samples preparation and measurement of heartwood and sapwood ratio and their moisture content

The proportion of heartwood and sapwood mostly identified by using visual method to distinguish between sapwood and heartwood area by the cross-section of the wood disc or increment core sample according (Arisandi et al., 2023b). The sapwood most often has a light color and low biological resistance, while the heartwood has a higher resistance to decay and is darker than sapwood. Depending on this each of the disks the heartwood and sapwood was measured and their proportion established(**Figure 3.11**).

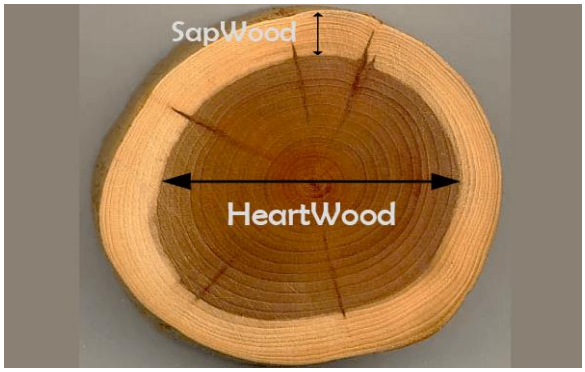



**Fig 3.11. Diagram to show the heartwood and sapwood**



**Figure 3.12. Sapwood and heartwood of the sample discs measured for the estimation of the ratio of heartwood and sapwood**

To determine the moisture content of heartwood and sapwood from the discs of the trees at different position (from east to west and south to north) direction of the discs**(Figure 3.12**). Thickness of the disc was 50mm thick. Each sample was prepared from both wood (heart wood and sap wood), the size of specimen was 50 mm x 50 mm x 50 mm along the grain (longitudinal) direction. The moisture content of sap wood and heart wood was determined by sorting sapwood and heart wood into separate groups using **Eq. (5) and Eq. (6).** After sorting, the results of moisture content measurements for the two types of wood were recorded separately, summarized, analyzed and reported in the result and discussion.

$$MC = \frac{m_I - m_O}{m_O} X100 \quad \ldots\ldots\ldots\

Generally, density and shrinkage were measured as a preliminary indication of wood quality. Nine samples of wood were cuts from three age group (10-15,15-20 and 20-25) equal and 5 cm thick of 45 discs or 5 discs from each trees from height of the tree (70cm from base, DBH (1,37 m), 30%, 50% and 70%) of the total height were cuts. Then the discs were cut into 50 mm x 50 mm x 50 mm specimen for wood oven-dry density assessment and shrinkage equally. A total of 416 samples specimens(cubes) were collected. Wood density and shrinkage of the wood sample were determined in the radial, tangential directions and longitudinal heartwood and sapwood ratio was also recorded.

### 3.5 Statistical data analysis

The correlation between dependent and independent variables, as well as the degree of significance of the correlation, were analyzed using and SPSS 26.0 latest version of software. Data obtained were analyzed using analysis of the initial analysis involved checking the data for normality and satisfying the conditions for validity of ANOVA. Tests were carried out to determine whether or not the differences in means were significant. The mean percentage of basic density, oven dry density, shrinkage and heartwood and sapwood ratio were calculated. Further analysis was carried out using various graphs and plots and detailed analysis was carried out for each age group separately.

### 3.6 Laboratory measurements

The densities was measured on the basis of oven dry weight per green volume of samples. The green MCs was measured by oven-drying procedures and expressed on an oven dry weight basis. All laboratory measurements on each tree conducted based on the mean of three replications five stem discs.

## 3.7 Equipment's required for laboratory work

### 3.7.1 Oven Dried Machine

This is a vacuum or machine used for drying the wood timber specimen at a particular temperature stipulated, usually, a well-ventilated oven drying machine is the one with temperature round between 101$^{o}$C to 105$^{o}$C, which is the most acceptable record temperature needed for drying of wood specimen or section. The industries that usually used to test the wood using this method should the suitable forced ventilation, electrical heated drying oven (**Figure 3.13**).



**Figure 3.13. The Oven Drying Machine**

### 3.7.2 The Weight Balance

The weight balance was used for weighing the wood specimen or beam balance which had a sensitive range from 100mg up to 100g (that is for small specimen weighed balance) and also expressed in decimal system of number that simplified the calculations. There are so many types of weighed balance used for weighing the wood specimens, we have the brass weighed balance, stainless steel and iron weighed balances, but from all, stainless weighed balance likely and more used than the others. If routine tests are to be carried out on many sections, much time can be carried out many sections; much time can be saved by using mainly semi-automatic or fully automatic balance which eliminates partially or entirely the handling of weight respectively. Such a balance must read to 0 to 3100g and an accuracy of 0.01g. or to say more than that is readily available. The balance should be located in a position that can be sheltered from droughts, and also is near test piece preparation area and the drying Oven (**Figure 3.14**).



**Figure 3.14. The sensitive balance**

### 3.7.3 Vermeer Caliper

The caliper was used to measure the dimensions of the specimens. The are many types fernier caliper the below fig are the manual and the digital both are measurement range of 0.01 to 2000 mm and Accuracy of 0.01 mm (**Figure 3.15**).



**Figure 3.15. Digital vernier caliper**

### 3.7.4 Caliper

Is the most efficient to measure DBH directly whenever there is direct access to the tree. It has two arms one fixed and a graduated bar/beam on which the second arm slides. To measure with a caliper, hold it firmly and horizontally as well as perpendicular to stem axis at the same time. Usually two readings are taken perpendicular to each other rat breast height and then the average value will be recorded (**Figure 3.16**).



**Figure 3.16. DBH Caliper**

### 3.7.5 Tape measurement

A tape measure is effective a flexible ruler that is usually sprung on a rectangular mechanism to easy storage, helping to measure the distance or size of any space or object (**Figure3.17**).




**Figure 3.17. Tape measurement**

### 3.7.6 Chainsaw

It is used in activities such as cutting discs . Chainsaws with specially designed bar-and-chain combinations have been developed as tools for use in chainsaw art and chainsaw mills (**Figure 3.18**).




**Figure 3.18. a chainsaw were used to make the discs**

# CHAPTER FOUR

## 4. RESULTS AND DISCUSSION

### 4.1 Density variation of *E. grandis* stem along height

The analysis of variance showed that the tree height had significant ($p$<0.001) effects on both oven-dry and basic density of *E. grandis* wood (**Table4.5**). The interaction effect between tree height and age group had a significant effect (p<0.001) on oven-dry density, but not on the basic density (**Table 4.1**) due to different ways of these two density measures are influenced by growth factors. However, the interaction effects between tree height and tree age, and as well as the interaction effects between tree height, tree diameter and age groups had not shown significant effects on both densities (**Table 4.5**) due to the strong correlation between tree height and diameter. Similar study reported that there is significant interactions between these factors also indicated that there was no uniformity in basic density among height levels in the various ages and also between sapwood and heartwood of different ages and height levels in country of Kenya (Githiomi and Kariuki,2010). Average basic density at breast height(DBH) was calculated 562 kg/m$^3$. Similar results for basic density were determined (517 kg/m$^3$) by Githiomi and Kariuki (2010); Cihad et al., (2010) on *E. grandis* in area of Kenya wood which was 10-15 years old. This study was similar to other studies (**Table 4.1**). The combined density decreased from tree base to breast height and then increased to a maximum at the 50% height point before decreasing at 70%. A similar trend was observed when basic density was plotted against height for each age class separately, as shown in **Figure 4.1**. Analysis of means variation on **table 4.1** showed that basic density increases as age increases and basic density with in tree height increases from bottom to middle before tends to decrease on top of the tree in all age group (**figure 4.1)**. Similar study also supported this findings which reported by Li (2024) in area Southwest China revealed that the basic density of *E. grandis* tree increased with tree age increase (Li, 2024). Therefore the findings showed that the younger trees have less density than mature wood because of variation ratio of the extractives in their cell. In the case of all age groups, the oven-dry density and basic density at the base of the tree height had increased from base to 50% tends to be lowest at 70% of the tree height level. Generally, for the age groups of 10-15, 16-20, and 21-25-year-old trees showed a pattern that depicts an increase in both densities from bottom to the middle parts and then a decrease to the top of the tree (**Figure 4.1a, 4.1b**). A similar trend for *E. grandis* has been reported by (Githiomi and Kariuki, 2010, Artwel and Gonya, 2020, Ruckowski et al., 2023) who reported at the base of the tree height had a low and highest at middle tends to be lowest at upper part of the tree height level. The results

revealed that the oven-dry and basic density mean values obtained in the sapwood part was slightly higher than the heartwood part for all age groups due to the heart wood part are become dead which lead to decompose the cell wall **(Figure 4.1a, 4.1b).** This implies that the sapwood of *E. grandis* trees, regardless of age, tends to be denser than the heartwood. Generally the decrease in basic density towards the top of the tree could be explained by the decrease in mature wood as one moves to higher portions of the tree with an increase in juvenile wood ratio (Emmanuel et al., 2020).

**Table 4.1: Means variations in physical properties of *E. grandis* tree height levels and within a tree**

| Age group | Properties | Tree height level | | | | |
|---|---|---|---|---|---|---|
| | | 70cm | DBH | 30% | 50% | 70% |
| 10-15 | MC(%) | 15.91±0.751 | 14.213± 0.60 | 11.15±0.55 | 10.55±0.96 | 9.05±1.025 |
| | OD ($g/cm^3$) | 0.689±0.029 | 0.695±0.0215 | 0.704±0.027 | 0.686±0.035 | 0.674±0.026 |
| | BD($g/cm^3$ | 0.551±0.023 | 0.562±0.025 | 0.578±0.022 | 0.575±0.025 | 0.533±0.035 |
| | TS(%) | 7.483±0.168 | 7.39±0.115 | 7.166±0.0523 | 7.5±0.054 | 7.67±0.079 |
| | RS(%) | 4.058±0.082 | 4.2±0.05 | 4.25±0.07324 | 4.331±0.036 | 4.05±0.067 |
| | LS(%) | 0.37±0.046 | 0.39±0.019 | 0.41±0.027 | 0.45±0.027 | 0.46±0.028 |
| | VS(%) | 11.71±0.377 | 12.70±0.172 | 12.39±0.132 | 12.5±0.07 | 11.661±0.441 |
| 16-20 | MC(%) | 14.214±0.58 | 12.185±1.265 | 10.89±0.50 | 9.273±0.88 | 7.8±0.66 |
| | OD($g/cm^3$ | 0.699±0.0336 | 0.767±0.037 | 0.794±0.028 | 0.796±0.0291 | 0.706±0.030 |
| | BD($g/cm^3$ | 0.61±0.042 | 0.623±0.022 | 0.641±0.031 | 0.663±0.0286 | 0.632±0.031 |
| | TS(%) | 6.51±0.079 | 6.75±0.234 | 6.743±0.100 | 6.78±0.3 | 6.5±0.325 |
| | RS(%) | 3.413±0.56 | 3.45±0.038 | 3.7±0.056 | 3.76±0.04 | 3.2±0.141 |
| | LS(%) | 0.31±0.0315 | 0.36±0.026 | 0.37±0.013 | 0.38±0.036 | 0.41±0.019 |
| | VS(%) | 10.20±0.21 | 10.72±0.35 | 11.50±0.101 | 11.78±0.113 | 9.70±0.25 |
| 21-25 | MC(%) | 12.373±0.46 | 7.98±0.31 | 8.402±0.58 | 7.64±0.553 | 7.023±0.66 |
| | OD($g/cm^3$ | 0.843±0.019 | 0.863±0.023 | 0.873±0.027 | 0.88±0.0341 | 0.814±0.03 |
| | BD($g/cm^3$ | 0.695±0.021 | 0.693±0.035 | 0.71±0.022 | 0.73±0.030 | 0.686±0.222 |
| | TS(%) | 5.4±0.068 | 5.84±0.113 | 6.22±0.29 | 6.10±0.0801 | 5.38±0.101 |
| | RS(%) | 2.97±0.67 | 3.13±0.041 | 3.5±0.055 | 3.61±0.141 | 2.96±0.09 |
| | LS(%) | 0.29±0.018 | 0.34±0.04 | 0.32±0.021 | 0.37±0.185 | 0.43±0.020 |
| | VS(%) | 9.541±0.06 | 10.040±0.153 | 10.48±0.062 | 11.06±0.10 | 10.03±0.104 |

Note: Different superscript letters across the rows shows that significant difference at $p<0.05$ level

Where;- MC=moisture content, OD= Oven dry density, BD= Basic density, TS= Tangential shrinkage, RS= Radial shrinkage, LS= Longitudinal shrinkage, VS=volumetric shrinkage

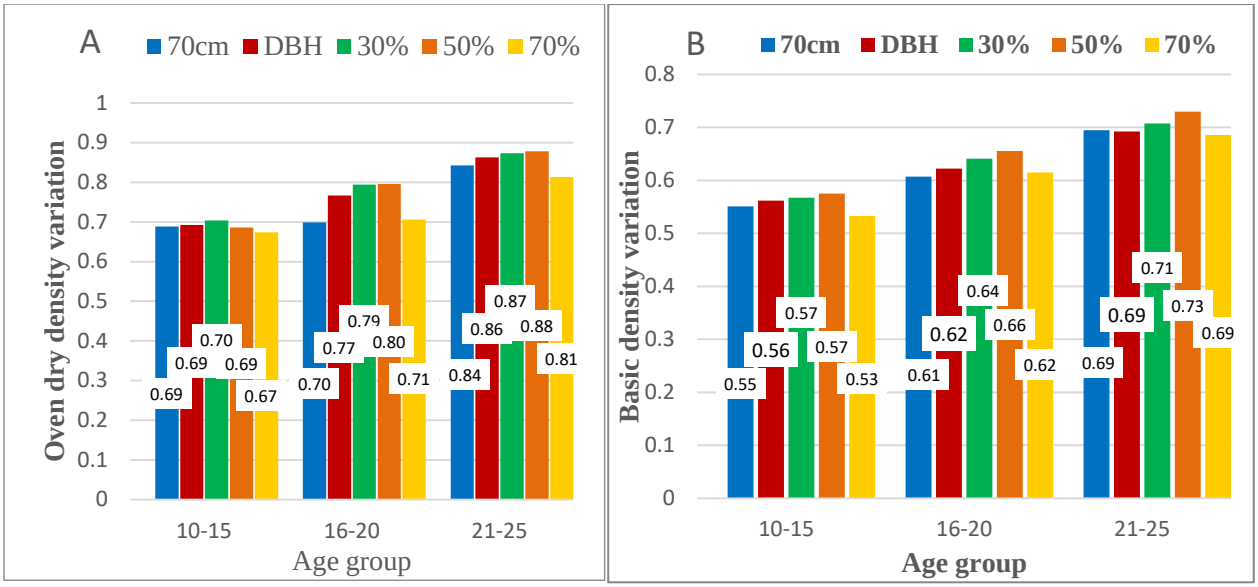



**Figure 4.1: Oven-dry (a) and basic density (a) variations in three age group along the tree height levels of *E. grandis* tree**

## 4.2 Map the ratio of heartwood to sapwood and their moisture content

### 4.2.1 Heart and sapwood Proportion within a tree height

Heartwood and sapwood have different properties and proportions in the trunk, which have a significant effect on wood utilization (Arisandi et al., 2023b). According to the explanation of Arisandi et al (2023) the presence of heartwood is often used to determine the wood value. The result in this study shows that the proportions of the heartwood in the stem cross-section were decreased within the tree from base (70cm) to the top (70%) of the tree height levels for all the three age groups (**Figure 4.2**) due to increase the presence of sapwood on top part of the tree. This result implies that the base of the tree have more heartwood than sapwood. While the sapwood proportion were showed an increasing trend from the base (70cm) towards the top (70%) of the tree height levels for all the three age groups **(Figure 4.2)** due to the presence of juvenile wood on the top. similar study reported that there is a reduction in heartwood percentages in the base-top direction of the stem (Arisandi et al., 2023b). This implies that heartwood development is proportional to the age of the wood, with this behavior justified by the higher proportion of juvenile wood in the upper tree positions (Brito et al., 2019; Arisandi et al., 2023b). The height and the diameter of the tree also perform a fundamental role in heartwood and sapwood formation (Arisandi et al., 2023b). There depending to age to height heartwood ratio is more than sapwod ratio (**Table 4.2**).

**Table 4.2.A: Analysis of variance for Heartwood and sapwood proportions in *E. grandis* at different age groups and tree height levels**

| Source of variation | DF | Mean squares and Statistical significances | |
|---|---|---|---|
| | | HWP (%) | SWP (%) |
| Age group (AG) | 2 | 245.165* | 228.174* |
| Tree height (TH) | 4 | 1942.645** | 1953.843** |
| AGxTH | 8 | 11.464ns | 11.166ns |

ns is Not significant at p>0.1, * significant at p<0.05, ** significant at p<0.01, *** significant at p<0.001. where, HWP is heartwood proportion, SWP is sapwood proportion

**Table 4.2 B Estimated means of heartwood and sapwood ratio at different tree height**

| Tree diameter | Tree height | | | | |
|---|---|---|---|---|---|
| | 70 cm | DBH | 30% | 50% | 70% |
| Heart woodratio | 76.3± 2.133 | 72.23±2.133 | 65.54±2.133 | 55.49±2.133 | 39.65±2.133 |
| Sapwood ratio | 23.71±2.175 | 27.77±2.175 | 33.79±2.175 | 44.51±2.175 | 60.35±2.175 |

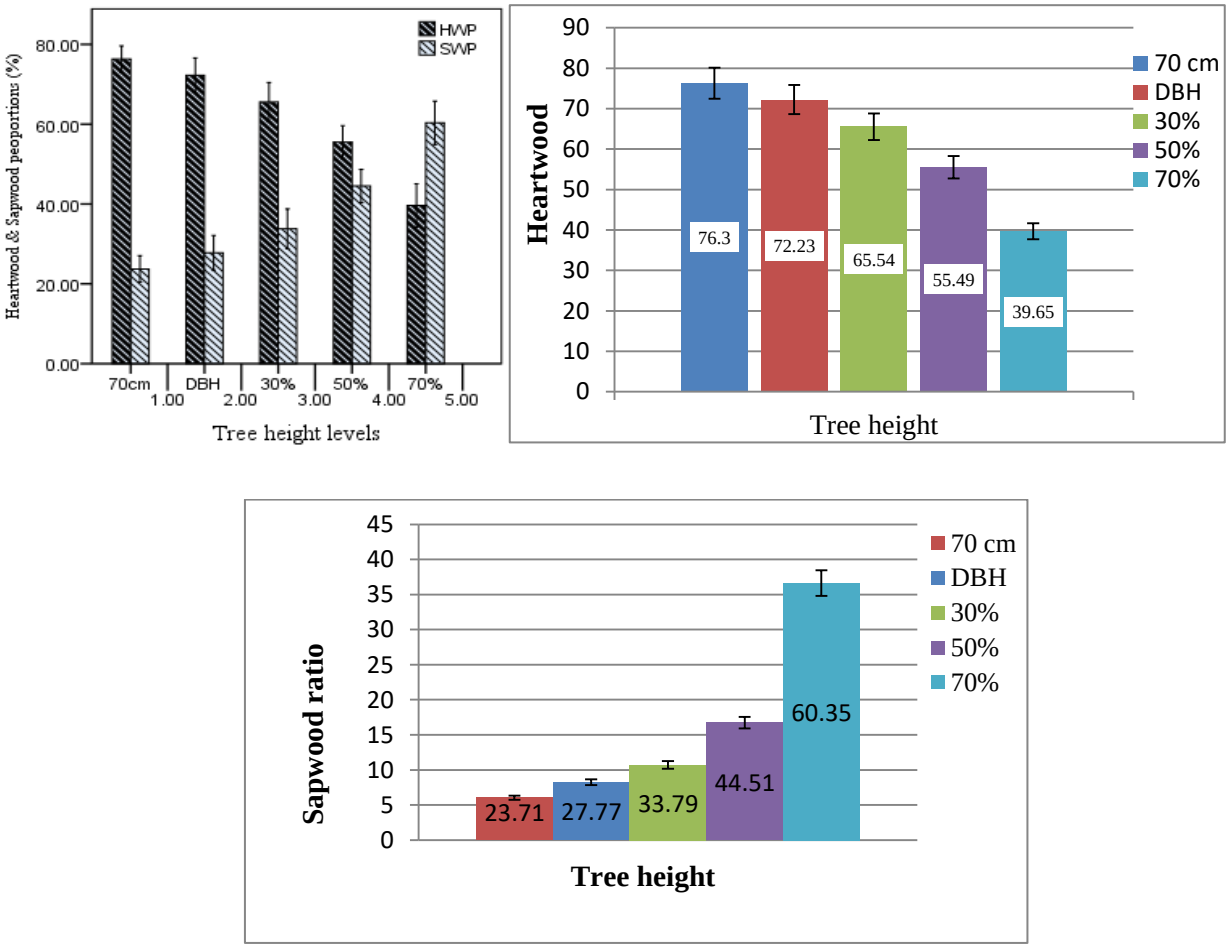



**Figure 4.2: Variation of heartwood and sapwood proportions in different tree height levels of *E. grandis* tree**

### 4.2.2 Heartwood Proportion between age groups

The analysis of variance shows that both heart and sapwood proportions were significantly affected by age groups (**Table 4.2**). The heartwood proportion was showed an increasing trend with the increment of age groups; however, the sapwood proportion was showed a decreasing trend with the increase of age groups (**Table4.3**). Similar study was reported by (Cherelli and Sartori, 2018; Arisandi et al., 2023b), which is an increasing of heartwood ratio with increasing the age of the tree. Another similar research finding shows that there was also a general reduction in heartwood proportion with increasing height of the tree in Kenya country (Langat and Kariuki, 2004). Therefore, this results revealed that the age and height of the tree have significant effect on ratio of heartwood and sapwood(**Figure4.3**).

**Table 4.3: Estimated means of Heartwood and sapwood proportions in *E. grandis* at different age groups**

| s/no | Category | Age group | | |
|---|---|---|---|---|
| | | 15-15 | 16-20 | 21-25 |
| 2 | Heart wood | 58.95±2.33 | 60.1±2.33 | 66.46±2.33 |
| 3 | Sapwood | 40.64 ±2.38 | 39.89±2.38 | 33.54±2.38 |

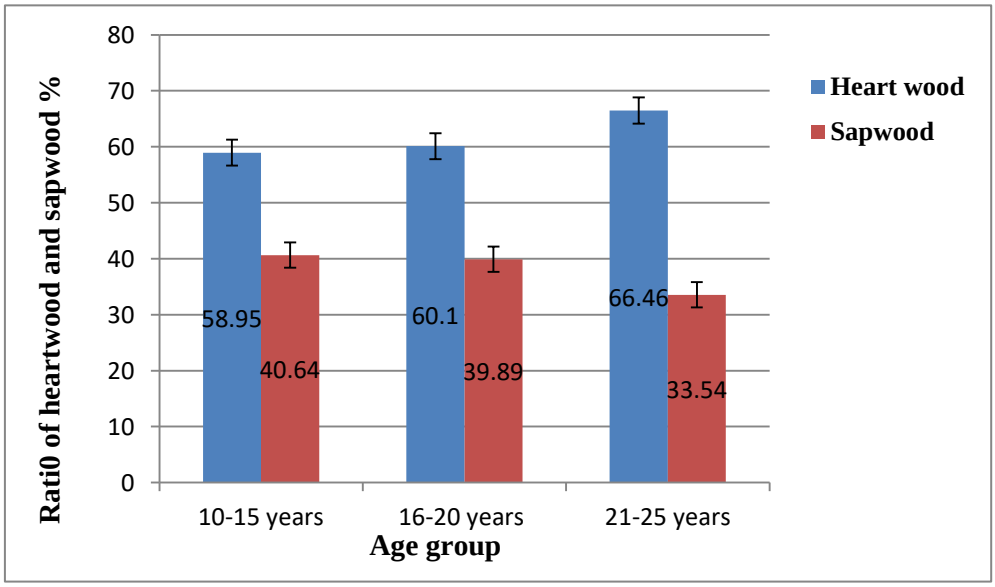
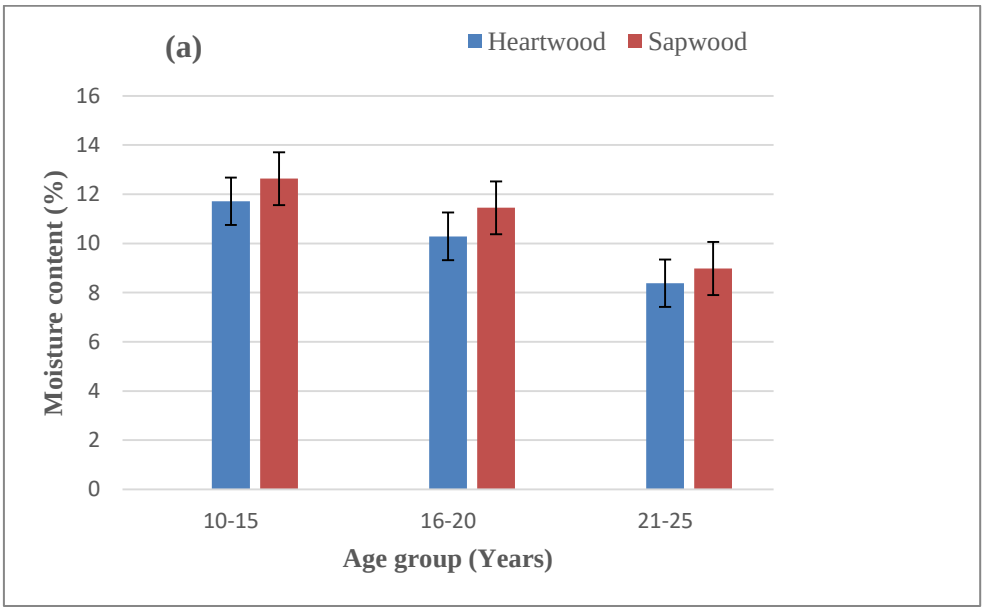



**Figure 4.3: Variation of heartwood and sapwood proportions in different tree age groups of *E. grandis***

### 4.2.3 Moisture content ratio of heartwood to sapwood

The statistical analysis showed that the tree age and height had significant effect on the moisture content. The moisture content decrease with increasing the age (**Figure 4.4a**) However, the moisture content between heartwood and sapwood didn't show a significant difference due to

relatively small difference in moisture content between heartwood and sapwood of *E. grandis* (Li, 2024). However, the moisture content of heartwood is lower than sapwood in all age group. The results revealed that the moisture content of *E. grandis* stem wood significantly decreased from the base (stump height) to the top (70% height) of the tree and also shows that the moisture content had decreased from young tree to mature tree, this implies that the mature tree have lower moisture content **(Figure 4.4b**). Similar results were found by (Artwel and Gonya, 2020) in South Africa country revealed that moisture content decreased with height this might be due to the fact that at the top leaves continuously uses water for photosynthesis. The effect of age is observed as both the young groups had the highest MC at breast height and the oldest group had the lowest MC(**Figure 4.4**). This implies that the young age group had a more moisture than oldest age groups. On the other hand the oldest trees are mature than young trees. The similar the heartwood section had a less more moisture content than the sapwood one. This variation may be due to the presence of extractives in the heartwood of the species. It can be concluded that moisture content was a function of age as it appears to decrease with age from 25-20 to 20-15 to 15-10 the moisture contents tends to increase (Vinha Zanuncio et al., 2015; Artwel and Gonya, 2020; Arisandi et al., 2023). This may be explained by the fact that older trees had more heartwood than sapwood which is primarily responsible for water transportation see **figure 4.4**.



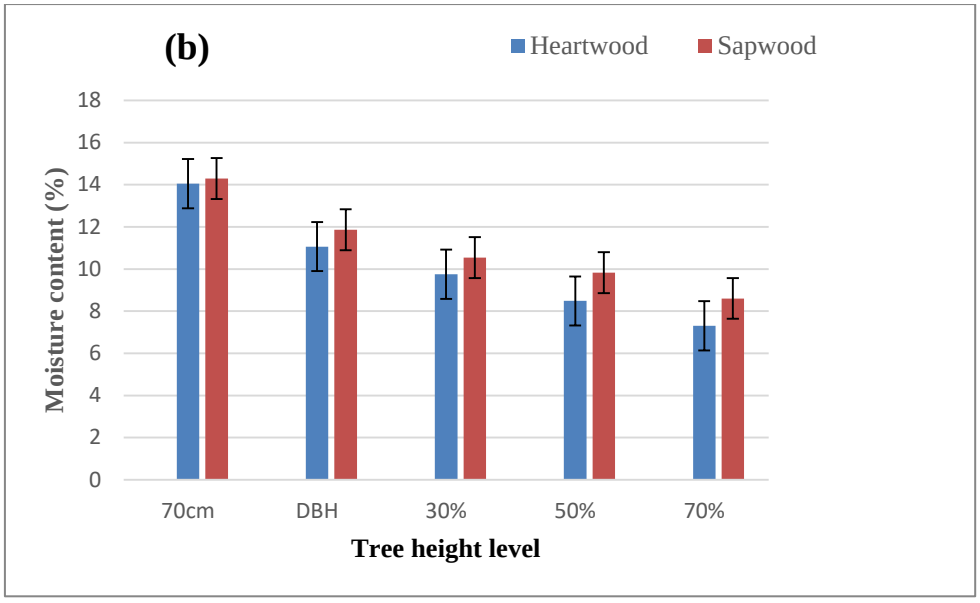



**Figure 4.4: Moisture content variations( a and b) in heartwood and sapwood between age groups and along the tree height level**

### 4.3 Density variation across the diameter

The oven-dry density and basic density of *E. grandis* were significantly affected by age groups which are related to diameter (**Table 4.4)**. The oven-dry density significantly affected by tree diameter at $p<0.001$, whereas the basic density significantly affected by tree diameter at $p<0.05$ level (**Table 4.5**).There were general increment of oven dry density and basic density with the tree age groups (**Figure 4.5**). On the other hand, in the case of both heartwood and sapwood the densities were increased in line with the increase of the tree age groups (**Figure 4.5A, Figure 4.5B**). The analysis reveals that a significant relationship between age and density in *E. grandis*, with both oven-dry density and basic density increasing with increasing tree age. This general trend is consistent across both heartwood and sapwood, suggesting a consistent pattern of wood densification as the tree matures. Several factors contribute to the increase in density as *E. grandis* trees age such as cell wall thickening, as trees mature, the cell walls of their wood fibers thicken (Hirigoyen et al., 2021). This thickening increases the proportion of solid wood material within the cell, resulting in higher density. The other reason is cell lumen reduction, the central cavity (lumen) of wood cells gradually decreases in size with age (Emmanuel et al., 2020). This reduction also contributes to a higher density by increasing the relative proportion of solid cell wall material and also moisture content reduction, older trees typically have a lower moisture content, which contributes to a higher dry-weight density (Hirigoyen et al., 2021). This is because older trees have had more time to loss water through transpiration and aging processes (Li, 2024). The oven-dry density of 10-15, 16-20, and 21-25years old *E. grandis* is 0.688g/cm$^3$, 0.753g/cm$^3$, and 0.854g/cm$^3$,

respectively; and the basic density of 10-15, 16-20, and 21-25 years old *E. grandis* is 0.558 g/cm$^3$, 0.626g/cm$^3$, and 0.706g/cm$^3$, respectively (**Figure 4.6**). In a similar study in Central rift valley, Kenya, positive correlation was established between tree age and basic density of *E. grandis* (Githiomi and Kariuki, 2010). They discovered that the younger trees generally had a lower basic density, which increased with increasing age.

**Table 4.4: Analysis of variance for Physical properties in *E. grandis* at different age and tree diameter**

| Properties | Age group | Tree diameter | Mean | Std. Deviation |
|---|---|---|---|---|
| MC (%) | 10-15 | Heartwood | 11.7157 | 2.83846 |
| | | Sapwood | 12.6340 | 2.40491 |
| | | Total | 12.1748 | 2.64903 |
| OD (g/cm$^3$) | | Heartwood | 0.6770 | 0.02548 |
| | | Sapwood | 0.6997 | 0.02566 |
| | | Total | 0.6883 | 0.02781 |
| BD(g/cm$^3$) | | Heartwood | 0.5573 | 0.03062 |
| | | Sapwood | 0.5583 | 0.02666 |
| | | Total | 0.5578 | 0.02847 |
| TS(%) | | Heartwood | 7.4097 | 0.17531 |
| | | Sapwood | 7.4613 | 0.20599 |
| | | Total | 7.4355 | 0.19142 |
| RS(%) | | Heartwood | 4.1370 | 0.14010 |
| | | Sapwood | 4.2070 | 0.10449 |
| | | Total | 4.1720 | 0.12752 |
| LS(%) | | Heartwood | 0.4078 | 0.08823 |
| | | Sapwood | 0.3914 | 0.07571 |
| | | Total | 0.3996 | 0.08193 |
| VS(%) | | Heartwood | 12.2787 | 0.36905 |
| | | Sapwood | 12.0857 | 0.58670 |
| | | Total | 12.1822 | 0.49558 |
| MC(%) | 16-20 | Heartwood | 10.2860 | 2.44067 |
| | | Sapwood | 11.4487 | 2.23189 |
| | | Total | 10.8673 | 2.39167 |
| OD(g/cm$^3$) | | Heartwood | 0.7487 | 0.05686 |
| | | Sapwood | 0.7563 | 0.04781 |
| | | Total | 0.7525 | 0.05223 |
| BD(g/cm$^3$) | | Heartwood | 0.6170 | 0.04170 |
| | | Sapwood | 0.6357 | 0.04116 |
| | | Total | 0.6263 | 0.04214 |
| TS(%) | | Heartwood | 6.6310 | 0.29482 |
| | | Sapwood | 6.6553 | 0.20209 |
| | | Total | 6.6432 | 0.25089 |
| RS(%) | | Heartwood | 3.4510 | 0.24289 |
| | | Sapwood | 3.5408 | 0.17691 |
| | | Total | 3.4959 | 0.21548 |

| | | | | |
|---|---|---|---|---|
| LS(%) | | Heartwood | 0.3558 | 0.03360 |
| | | Sapwood | 0.3882 | 0.02573 |
| | | Total | 0.3720 | 0.03386 |
| VS(%) | | Heartwood | 10.7564 | 0.71217 |
| | | Sapwood | 10.7856 | 0.91811 |
| | | Total | 10.7710 | 0.81476 |
| MC(%) | 21-25 | Heartwood | 8.3837 | 2.25069 |
| | | Sapwood | 8.9803 | 1.65647 |
| | | Total | 8.6820 | 1.98219 |
| OD($g/cm^3$) | | Heartwood | 0.8643 | 0.03501 |
| | | Sapwood | 0.8443 | 0.03308 |
| | | Total | 0.8543 | 0.03524 |
| BD($g/cm^3$) | | Heartwood | 0.7127 | 0.03079 |
| | | Sapwood | 0.6997 | 0.03473 |
| | | Total | 0.7062 | 0.03320 |
| TS(%) | | Heartwood | 5.7223 | 0.41440 |
| | | Sapwood | 5.8469 | 0.33764 |
| | | Total | 5.7846 | 0.37998 |
| RS(%) | | Heartwood | 3.1470 | 0.40229 |
| | | Sapwood | 3.3027 | 0.31129 |
| | | Total | 3.2249 | 0.36515 |
| LS(%) | | Heartwood | 0. 2919 | 0.04587 |
| | | Sapwood | 0. 3076 | 0.03727 |
| | | Total | 0.2998 | 0.04219 |
| VS(%) | | Heartwood | 10.2087 | 0.50203 |
| | | Sapwood | 10.2477 | 0.55140 |
| | | Total | 10.2282 | 0.52318 |

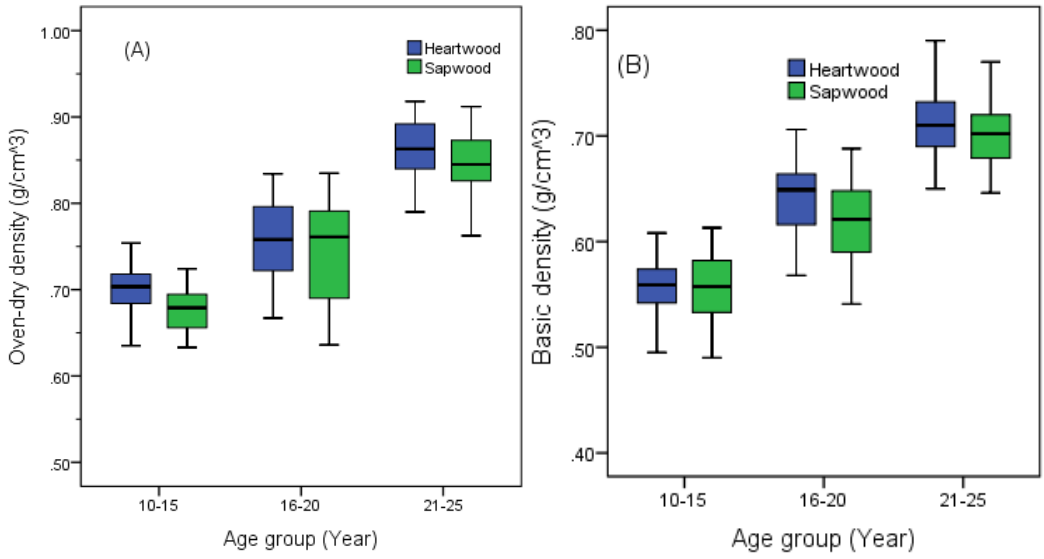



**Figure 4.5: Oven-dry and basic density variations in heartwood and sapwood parts for the three age groups of *E. grandis* wood**

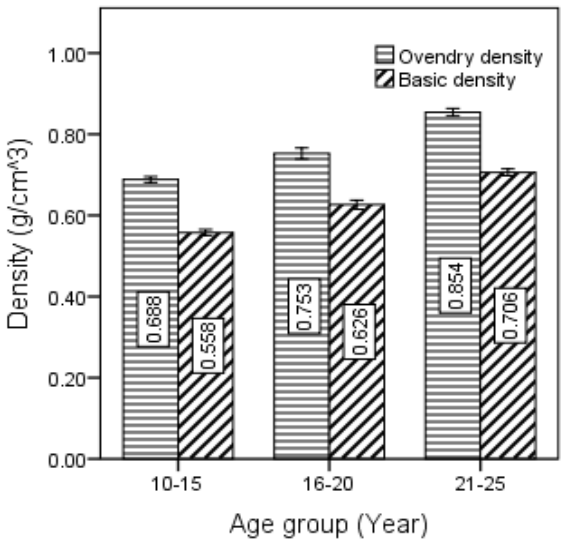



**Figure 4.6: Oven-dry and basic density variations between age groups of *E. grandis* wood**

**Table 4.5: Analysis of variance for Physical properties in *E. grandis* at different age, tree height and tree diameter**

| Source of variation | Variables | DF | Sum squares | Mean square | F | P value |
|---|---|---|---|---|---|---|
| Age group (AG) | MC | 2 | 373.70 | 186.851 | 899.316 | 0.000 |
| | OD | 2 | 0.841 | 0.420 | 595.422 | 0.000 |
| | BD | 2 | 0.661 | 0.331 | 377.876 | 0.000 |
| | TS | 2 | 81.81 | 40.903 | 3641.027 | 0.000 |
| | RS | 2 | 28.56 | 14.277 | 4860.318 | 0.000 |
| | LS | 2 | 0.320 | 0.160 | 186.078 | 0.000 |
| | VS | 2 | 122.09 | 61.042 | 3263.321 | 0.000 |
| Tree height (TH) | MC | 4 | 819.58 | 204.896 | 986.166 | 0.000 |
| | OD | 4 | 0.100 | 0.025 | 35.296 | 0.000 |
| | BD | 4 | 0.064 | 0.016 | 18.354 | 0.000 |
| | TS | 4 | 2.701 | 0.675 | 60.118 | 0.000 |
| | RS | 4 | 6.415 | 1.604 | 545.963 | 0.000 |
| | LS | 4 | 0.169 | 0.042 | 49.250 | 0.000 |
| | VS | 4 | 49.38 | 12.344 | 659.930 | 0.000 |
| Tree diameter (TD) | MC | 1 | 35.85 | 35.849 | 172.544 | 0.000 |
| | OD | 1 | 0.013 | 0.013 | 17.939 | 0.000 |
| | BD | 1 | 0.005 | 0.005 | 6.097 | 0.015 |
| | TS | 1 | 0.012 | 0.012 | 1.050 | 0.307 |
| | RS | 1 | 8.542E-5 | 8.542E-5 | .029 | 0.865 |
| | LS | 1 | 3.125E-7 | 3.125E-7 | .000 | 0.985 |
| | VS | 1 | 0.078 | 0.078 | 4.163 | 0.043 |
| AGxTH | MC | 8 | 75.96 | 9.495 | 45.700 | 0.000 |
| | OD | 8 | 0.046 | 0.006 | 8.093 | 0.000 |
| | BD | 8 | 0.008 | 0.001 | 1.202 | 0.301 |
| | TS | 8 | 7.195 | 0.899 | 80.055 | 0.000 |
| | RS | 8 | 0.956 | 0.120 | 40.696 | 0.000 |
| | LS | 8 | 0.179 | 0.022 | 26.041 | 0.000 |
| | VS | 8 | 12.89 | 1.612 | 86.164 | 0.000 |
| AGxTD | MC | 2 | 2.418 | 1.209 | 5.818 | 0.004 |
| | OD | 2 | 0.002 | 0.001 | 1.360 | 0.260 |
| | BD | 2 | 0.002 | 0.001 | 1.395 | 0.251 |
| | TS | 2 | 0.270 | 0.135 | 12.012 | 0.000 |
| | RS | 2 | 0.558 | 0.279 | 94.915 | 0.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | LS | 2 | 0.023 | 0.012 | 13.657 | 0.000 |
| | VS | 2 | 0.516 | 0.258 | 13.805 | 0.000 |
| THxTD | MC | 4 | 7.314 | 1.829 | 8.801 | 0.000 |
| | OD | 4 | 0.006 | 0.001 | 1.999 | 0.098 |
| | BD | 4 | 0.003 | 0.001 | .975 | 0.423 |
| | TS | 4 | 1.085 | 0.271 | 24.151 | 0.000 |
| | RS | 4 | 0.942 | 0.235 | 80.152 | 0.000 |
| | LS | 4 | 0.031 | 0.008 | 9.115 | 0.000 |
| | VS | 4 | 2.097 | 0.524 | 28.025 | 0.000 |
| AGxTHxTD | MC | 8 | 11.034 | 1.379 | 6.639 | 0.000 |
| | OD | 8 | 0.008 | 0.001 | 1.465 | 0.175 |
| | BD | 8 | 0.003 | 0.000 | .358 | 0.941 |
| | TS | 8 | 1.446 | 0.181 | 16.094 | 0.000 |
| | RS | 8 | 2.254 | 0.282 | 95.927 | 0.000 |
| | LS | 8 | 0.038 | 0.005 | 5.486 | 0.000 |
| | VS | 8 | 2.037 | 0.255 | 13.613 | 0.000 |

[ns] is Not significant at p>0.1, * significant at p<0.05, ** significant at p<0.01, *** significant at p<0.001, '.' is significant at p<0.1, DF-degree of freedom. Where, TS is Tangential shrinkage, RS is Radial shrinkage, LS is Longitudinal shrinkage, and VS is Volumetric shrinkage

### 4.4 Shrinkages variation along tree height and across locations

There were significant ($p < 0.001$) variation in tangential (TS), radial (RS), longitudinal (LS) and volumetric (VS) within the tree height levels of *E. grandis* (**Table 4.1**). The results revealed that the tree height and diameter (heartwood & sapwood) had a significant ($p<0.05$) effect on the volumetric shrinkage; but not on tangential, radial and longitudinal shrinkages (**Table 4.1**). The interaction effect between tree height and tree diameter, tree height and tree age, and as well as the interactions of all factors tree height, tree age group and tree diameter had significant effects ($p<0.001$) on TS, RS, LS and VS (**Table 4.1; Figure 4.7**). The same results of (Artwel and Gonya, 2020) shows that shrinkage increased consistently with height. This is because the upper part of the tree had a lower extractive than bottom part. Therefore the result shows that there increasing shrinkage from base to height (**Figure 4.7**). This implies that the height of the tree had significant difference on shrinkage property of *E. grandis* south Africa country (Artwel and Gonya, 2020). Again, the same relationship observed for radial density variation holds for the height variation. According to their findings all the location of heights were significantly different from each other. This indicated that there is the variation of shrinkage along height of the *E. grandis* wood as the mean value of analysis of variance in the present study (**Table4.1**).

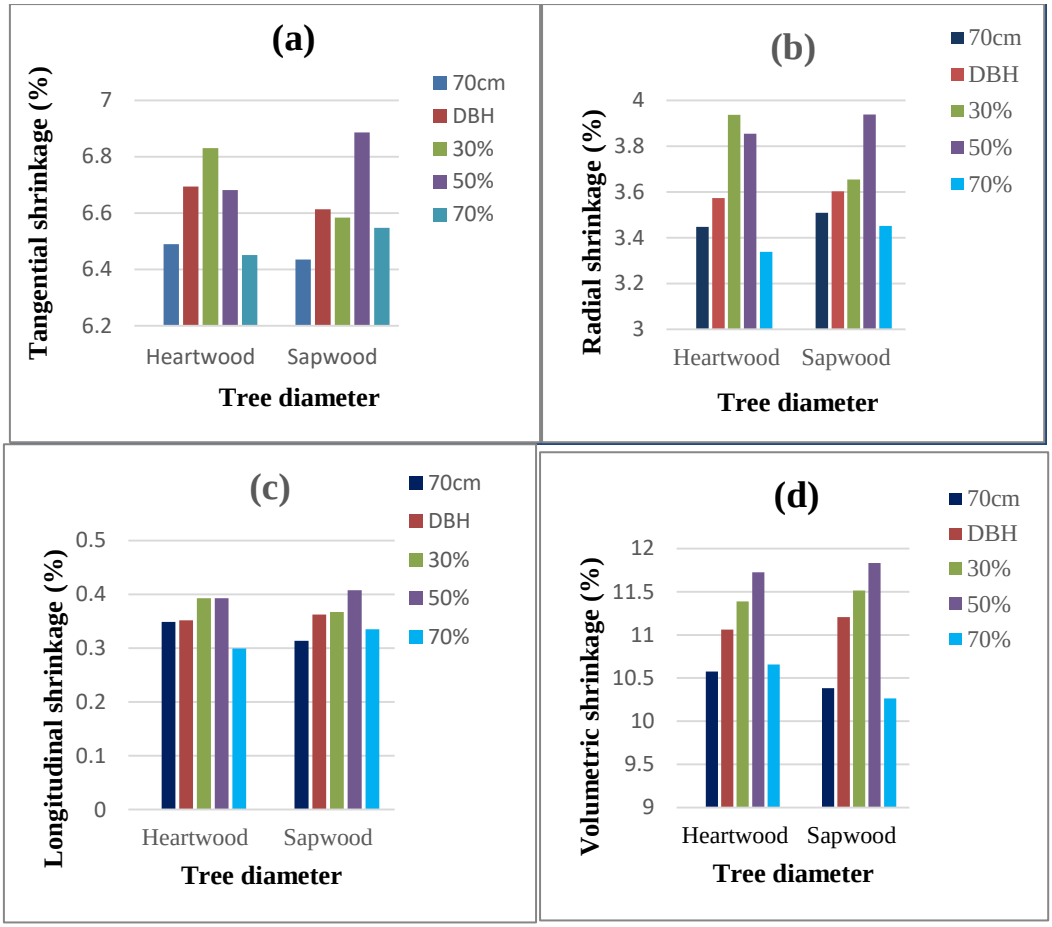



**Figure 4.7: Variations of Tangential (a), Radial (b), Longitudinal (c) and volumetric (d) shrinkages between heartwood and sapwood parts along the tree height levels of *E. grandis***

**Table 4.1** shows that the variation of tangential shrinkage, radial shrinkage, longitudinal shrinkage and volumetric shrinkage along the tree height levels of *E. grandis* wood. Accordingly, tangential shrinkage, radial shrinkage, longitudinal shrinkage and volumetric shrinkage mean values were increased from the base to DBH and then decreased to the top for 10-15 age groups; whereas for age groups 16-20 and 21-25 were decreased from the base (70cm) to the middle (50%) and then decreased to the top (70%) of the tree (**Table 4.1**). The results revealed that the tangential, radial and longitudinal shrinkages obtained in the heartwood part were increased from the base (70 cm) to 30% height level and then decreased to the top (70%) of the tree height level. While in the sapwood part of the tangential shrinkage, radial shrinkage, longitudinal shrinkage and volumetric shrinkage mean values were increased from the base to 50% of tree height level and then decreased to 70% of the tree height level (**Figure 4.7a, b, c, d**). The volumetric shrinkage mean values obtained in heartwood part was increased from the base to 50% of the tree height level and decreased to 70% tree height level (**Figure 4.7d**). The analysis of variance shows that the age group had significant effects on the tangential, radial, longitudinal and volumetric shrinkage (**Figure 4.8**). The results revealed that the tangential shrinkage, radial shrinkage, longitudinal shrinkage and volumetric shrinkage values were decreased with an increase of age groups (**Figure**

**4.7a, b, c, d**). Similar study by Emmanuel et al ( 2020) reported that shrinkage in all age groups had a decreased as age increase at the top of the trees without a consistent pattern for all age groups. Similarly, volumetric shrinkage follows a pattern that shows a lower value at the base of the tree, then increases in the middle portion and then reduces towards the top. The reduction of VS with tree height and age are similar to the findings of Wessels et al. (2016). The analysis shows that in all age groups, the longitudinal shrinkage is lower than tangential and radial shrinkage (**Figure 4.9a,b,c,d)**. Several studies are supported this result by reporting the lower average shrinkage of longitudinal direction (Wang et al., 2023; Gonya et al., 2022), they revealed that the shrinkage is lower at the direction of longitudinal. The average longitudinal shrinkage with age group (10-15 ,15-20 and 20-25years) 0.4%,0.36% and 0.3% respectively (**Figure 4.9** ). This result shows that as age increase the shrinkage tends to decrease due to the maturity of wood cell, because of its cell walls thicken and become more rigid. This increased rigidity that makes the wood less susceptible to dimensional changes when moisture is lost during drying (Li, 2024). Additionally, mature trees have lower moisture content compared to younger trees. This is because they have had more time to loss water through transpiration and aging processes. A lower moisture content means that there is a less water to be lost during drying, leading to less shrinkage (Gonya et al., 2022). Generally, *E. grandis* wood shrinkage is significantly less in the longitudinal direction (along the grain) compared to the radial or tangential directions (across the grain) in all age group due to the unique structure and arrangement of wood fibers (**Figure 4.9a,b,c,d)**. Because, the longitudinal direction of wood fibers has a strong, tightly packed structure that resists shrinkage due to the alignment of fibers and the strength provided by the helical arrangement of cell wall microfibrils (Li, 2024). This results in significantly less shrinkage along the grain compared to across the grain.

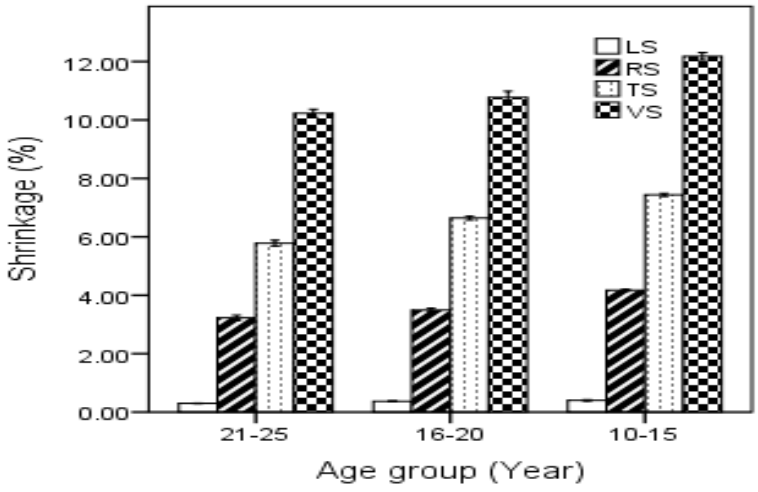



**Figure 4.8: Variations of shrinkages between age groups of *E. grandis***

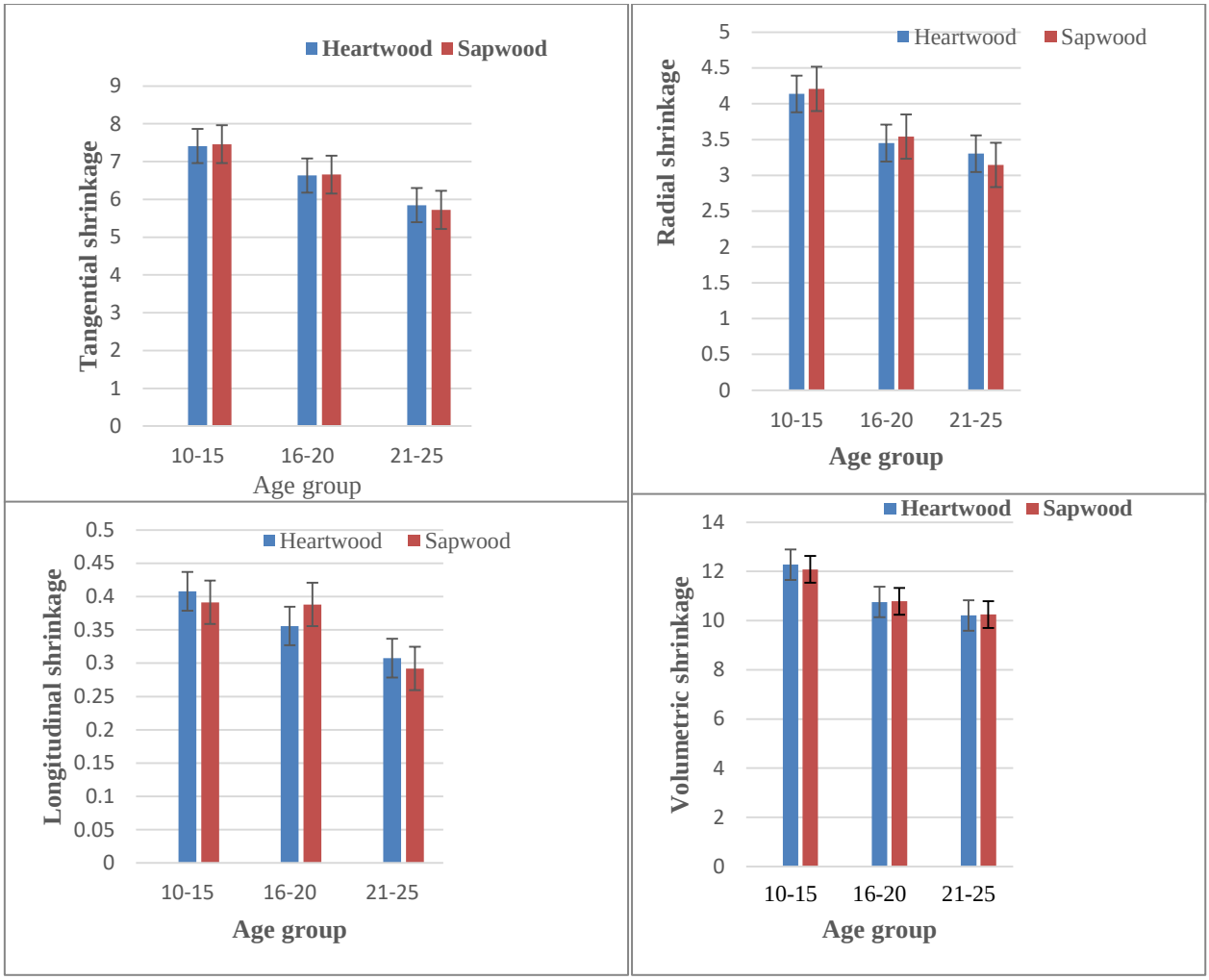



**Figure 4.9: Variations of Tangential, Radial, Longitudinal and volumetric shrinkages between heartwood and sapwood parts in the three age groups of *E. grandis***

# CHAPTER FIVE

## 5.1 Conclusion and Recommendations

### Conclusion

The results of the present study revealed that there are significant differences in the properties of *E. grandis* wood across different age groups, across diameter and tree height levels. According to the analysis of variance, the oven-dry and basic densities *of E. grandis* wood were significantly ($p<0.001$) impacted by the height of the tree. Tree diameter had a significant impact on the oven-dry density at $p<0.001$, while it had a significant impact on the basic density at $p<0.05$. While the oven-dry and basic densities exhibit a pattern of increase from the base to the middle sections and then a decrease towards the top of the tree, the moisture content decreases as age increases. Within the tree, the sapwood proportion tends to increase while the heartwood proportion decreases from base to top. Additionally, the study notes that for all age groups, the basic and oven-dry density mean values obtained in the sapwood part were marginally higher than the heartwood part, indicating variation in density in diameter. The decrease in basic density towards the top of the tree is attributed to the decrease in mature wood as one moves to higher portions of the tree with an increase in juvenile wood ratio. The statistical analysis conducted in this study demonstrated that tree age and height have a significant impact on the moisture content of *E. grandis* stem wood. The results indicated that as the tree age increased, the moisture content decreased, and there was a noticeable decrease in moisture content from the base to the top of the tree. Additionally, no significant difference was found in moisture content between heartwood and sapwood sections. These findings are consistent with previous research and suggest that age plays a key role in determining moisture content levels. The higher moisture content observed in younger trees at breast height compared to older trees may be attributed to the presence of extractives in the heartwood section, which affects water transportation within the tree. According to the findings, there were notable differences between various tree ages and height levels when tangential, radial, longitudinal, and volumetric shrinkage were analyzed along the height of *E. grandis* trees. This analysis of variance highlighted significant effects of age groups on shrinkage properties, with values generally decreasing as age and height increased.

Generally, the basic density and physical property mapping of *E. grandis* were significantly affected by age groups and tree height.

**Recommendations**

This study emphasizes the importance of considering age, tree height, density, moisture content, and shrinkage properties when selecting and utilizing *E. grandis* wood in Ethiopia. To optimize resource utilization, it is crucial to take into account the age of the trees during harvesting and processing activities. Age plays a significant role in determining moisture content and shrinkage properties. Future research should investigate the influence of environmental factors, genetic variations, and growth conditions on the basic density and physical properties of *E. grandis* wood. This will provide a more comprehensive understanding of wood quality and guide future management practices.

Generally, further study should be needed to discover more information on basic density and physical property of *E. grandis* for more utilization of forest management.

1. Consider Age and Density for Specific Applications: The research highlights the significant influence of age on density. When using *E. grandis* for various applications, consider the specific density requirements and select trees of appropriate age. Younger trees with lower density might be suitable for pulp production, while mature trees with higher density could be used for construction timber or furniture.
2. Optimize use of Sapwood and Heartwood: The study indicates that sapwood generally exhibits slightly less density than heartwood. This suggests that heartwood could be preferred for applications requiring greater strength, durability, or resistance to decay. For example, heartwood might be suitable for structural components or outdoor applications. sapwood, while less dense, could be used for applications where strength is not a primary concern, such as furniture or decorative elements.
3. Utilize Density Profile for Efficient Wood Use: The research demonstrates a consistent pattern of density variation along the tree height, with higher density in the middle portion and lower density at the base and top. This knowledge can be used to optimize wood utilization by prioritizing the denser portions of the tree for applications requiring high strength and durability, while using the less dense portions for other purposes.
4. Invest in Research on Density Enhancement: Further research should focus on exploring strategies to enhance the density of *E. grandis* wood, potentially through genetic selection, silvicultural practices, or post-harvest treatments. Increasing density could improve the overall strength, durability, and value of the wood, leading to more sustainable and efficient utilization.

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# APPENDIX

## 1. Summary of Data sheet for Density & Shrinkages of *Eucalyptus. grandis*

| Age group | Tree height | Tree diameter | Moisture content (%) | Basic density (g/cm3) | Ovendry density (g/cm3) | Tangential shrinkage (%) | Radial shrinkage (%) | Longitudinal shrinkage (%) | Volumetric shrinkage (%) |
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## 2. Summary of Data sheet for MC & Heart-sapwood Ratio

| TreeNo | Age group | Tree height | Moisture content (%) | Heart/Sap ratio |
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