MONITORING OF WOODY PLANT SPECIES COMPOSITION, DIVERSITY, STRUCTURE AND DYNAMICS IN KIHANSI GORGE FOREST, SOUTHERN UDZUNGWA MOUNTAINS, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOREST RESOURCES ASSESSMENT AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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EXTENDED ABSTRACT

Kihansi Gorge forest is located within the Udzungwa Mountains in the Eastern Arc Mountains in Tanzania. The Gorge has critically endangered and endemic plant species, hence has national and global significance. Kihansi hydropower project started to be constructed in 1990 and its operation commenced in 1999. The construction of the hydropower facilitated the establishment of baseline study to monitor the forest. The main objective of this study was to monitor trees' diversity using the established baseline study. Specifically this study intends (i) To assess changes of woody plant species composition and diversity for the period between 1997 and 2018 (ii) To assess changes in forest stand parameters between 1997 and 2018 (iii) To assess changes in tree species diversity and forest stand parameters along altitudinal gradients. Data were collected in 19 permanent sample plots established in year 1997 and 75 temporary sample plots installed in year 2018. The findings from statistical tests for all stand parameters for montane forest showed no significant differences ($p > 0.05$) throughout the study period. Basal area, volume and total carbon for miombo showed a significant difference ($p < 0.05$) for year 2006 and year 2009 and no significant difference ($p > 0.05$) for the year 2018. The study concludes that time to detect significant changes of forest stand parameters differ between vegetation types. Dynamic processes in the miombo woodlands are faster compared to montane forest. Based on altitude, tree species diversity in the Kihansi Gorge forest decreases as altitude increases. The study recommends monitoring to continue at Kihansi Gorge forest through the established permanent sample plots to ascertain the causes of the changes.

DECLARATION

I, **JESWALD GUSTAV UBISIMBALI** do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

The work is dedicated to my beloved father, the late Gustav Ubisimbali and my mother, the late Antonia Mayopa who gave me a good foundation for my life and education. The work is also dedicated to my beloved wife Martina Mberako, my daughters Jenifer, Stella, Avelina, Fransisca, Faustina and my son Joseph for their tolerance in my absence during the study period.

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LIST OF ABBREVIATIONS AND SYMBOLS

AGB	Above ground biomass
BGB	Below ground biomass
C	Circumference
Cm	Centimeter
DBH	Diameter at Breast Height (cm)
EACF	Eastern Arc and Coastal Forests
EAM	Eastern Arc Mountains
G	Basal area per ha (m^2/ha)
Ha	Hectare
ITCZ	Inter Tropical Convergence Zone
KCCMP	Kihansi Catchment Conservation Management Project
LKEMP	Lower Kihansi Environmental Management Project
M	Meter
M.a.s.l.	Meters above sea level
M^2	Meter squared
M^3	Cubic meter
MNRT	Ministry of Natural Resources and Tourism
N	Number of stems per ha
NAFORMA	National Forest Resources Monitoring and Assessment
NEMC	National Environmental Management Council
PAST	Paleontological Statistics
PSP	Permanent Sample Plots
URT	United Republic of Tanzania
V	Volume per ha (m^3/ha)

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background Information

The Eastern Arc Mountains (EAM) extend from Kenya to Southern Tanzania. They comprise one mountain block in Kenya and 12 blocks in Tanzania (Myers *et al.*, 2000; Platts *et al.*, 2013; Rovero *et al.*, 2014; Willcock *et al*., 2016). Udzungwa Mountains is the largest among the 12 Eastern Arc Mountains blocks in Tanzania and Kihansi Gorge forest is found within this block. The Gorge has an area of 197.3 ha and has national and global significance due to the presence of critically endangered and endemic plants species in a small area (Lovett *et al*., 1997; Zilihona *et al.*, 1998; World Bank, 2013; Rija, 2016).

Diversity in terms of tree species is the distribution and abundance of various tree species in a particular area (Bello *et al*., 2013). Species composition is the list of all tree species in a particular area (Kilawe, 2016). Species composition is a determinant for carbon storage or sink potential of a particular forest (Jibrin *et al.*, 2018) thus it is important to know the condition of a forest in terms of species composition. Closed natural forests have complex ecosystems (Munishi and Shear, 2004) and higher degree of biological diversity due to great variations in structure and tree species composition (Merino *et al.,* 2007).

Plant species composition together with diversity describe the condition, status and importance of a particular forest ecosystem for biodiversity conservation (Kent and Coker 1992; Janzen 1993; Smit *et al.,* 1993 cited by Chingonikaya, 2010). Information on vegetation and biodiversity helps to find solutions to ecological problems, monitor management practices and predict possible future changes of a particular forest (Chingonikaya, 2010; Kacholi, 2014).

Traditionally, diversity decreases with increasing altitude (Lieberman *et al*., 1996; Givnish, 1999). Tree density which is one of the parameters of forest structure is controlled by a major factor of elevation (Huang *et al*., 2003; Kumar *et al*., 2006). In tropical forests, tree density usually increases with increase in elevations (Kumar *et al*., 2006).

According to Raghubanshi and Tripathi, (2009), trees are the main structural component in forest ecosystem. Population structure of a forest has been widely used as a measure of regeneration pattern of a particular natural forest ecosystem (Rocky and Mligo, 2012) whereby diameter classes are arranged and observed their trend (Kigomo *et al*., 2015). Furthermore, the distribution of forest stand parameters to diameter class in a forest contributes to the structural pattern characteristic of the forest (Franklin *et al*., 2002; Huang *et al*., 2003).

The influence of forest structure of a particular forest may help to maintain biological diversity and facilitate regeneration (Nduwayezu *et al.*, 2015) and plan for long term biodiversity conservation (Suspense *et al.*, 2016). The need to quantify forest structure is very important since the information helps to identify the type of resources available and habitat for other species in a particular locality, predict future changes including recruitment and mortality of a forest and plan for conservation efforts (Philip, 1994; Chen and Bradshaw, 1999; Isango, 2007; Kacholi, 2014).

Forests are important carbon pools exchanging carbon dioxide with the atmosphere due to natural processes (photosynthesis) and human actions. Forest plays an important role in carbons sequestration and therefore act as carbon sinks when their area or productivity increases resulting into increased uptake of carbon dioxide from the atmosphere (Zahabu, 2008). However, the rate of carbon sequestration differs from one forest to another depending on the nature of the forest. Natural forests are more resilient to climate change disturbances because of their functional biodiversity. They are responsible for photosynthesis (Saxe *et al.,* 2001) and can store carbon as long as there is enough and solar radiation (Mackey *et al.*, 2008).

According to National Forest Resources Monitoring and Assessment (NAFORMA) carried out in year between 2010 and 2013 the amount of Above Ground Biomass (AGB) and Below Ground Biomass (BGB) in Tanzania is estimated to be 1060.8 million tonnes (URT, 2015). However, the reliability of NAFORMA data is low when used at levels lower than the regional level due to lower sampling intensity (Tomppo, 2010). It was recommended that there is a need for quantifying carbon for natural forests based on reliable estimation of current carbon stock for particular forest. Due to the increase of global concern on the efforts of mitigating climate change, forest conservation is an important concern. Inventories of natural forests are important to determine amount of carbon stored so as to have proper decision making on proper strategies for natural forest conservation (Munishi and Shear, 2004).

Recovery rate of vegetation after disturbance varies. The speed of recovery is a function of forest type (Ding *et al.,* 2012), site condition, type and the magnitude of disturbance (Syampungani *et al*., 2015). It has been reported by Slocum e*t al*. (2004) that montane forest can recover after anthropogenic disturbance at light and moderate intensity while intense disturbance to montane forest may result to vegetation change. However, Miombo woodlands have high ability to recover after cessation of disturbance. The recovery of miombo after disturbance among others, is the fact that most species are light demanding thus need sunlight to regenerate fast (Syampungani *et al.,* 2015). Nevertheless, other sort of forest disturbances such as selective cutting and fire are beneficial which activate overall growth of the forest.

1.2 Problem Statement and Justification

Previous reports for the monitoring of Kihansi Gorge woody vegetation showed that there were some changes of vegetation within the Gorge. It was recommended that since natural growth rates of woody species are low, which means slow response time of the forest ecosystem to stability, more time is required to demonstrate how changes in the woody vegetation take place (NORPLAN, 2002). According to Allen (1994) and Philip (1994) variations in forest vegetation can be revealed within a period of 5 to 10 years and for stable forest it can take longer period. Since there are some interventions on the conservation of Kihansi Gorge forest, there is a necessity to monitor the vegetation.

During environmental audit of Kihansi hydropower project in 2005 and 2011, it was noted that there were some changes on the surrounding vegetation within the Gorge. Due to this it was recommended that there should be further studies to determine changes on vegetation characteristics (URT, 2005; URT, 2011). Through this background, the study was undertaken to identify changes of woody vegetation in Kihansi Gorge forest. The results will be helpful for policy review, scientific monitoring and general management of Kihansi Gorge forest.

1.3 Objectives

1.3.1 Overall objective

To monitor temporal and spatial forest parameters and changes due to natural processes and human activities in Kihansi Gorge forest.

1.3.2 Specific objectives

Specific objectives of the study were as follows:

(i) To assess changes in woody plant species composition and diversity for the period between 1997 and 2018.

(ii) To assess changes in forest structure and carbon stock between 1997 and 2018.

(iii) To assess species composition, diversity and forest structure along altitudinal gradients.

1.4 Research Hypotheses

1.4.1 Null hypotheses

(i) There are no changes in tree species composition and diversity in Kihansi Gorge for the period 1997 to 2018.

(ii) There are no changes in forest structure and carbon stock in Kihansi Gorge for the period 1997 to 2018.

(iii) There are no differences in species composition, diversity and forest structure along altitudinal gradients.

1.4.2 Alternative hypotheses

(i) There are changes in tree species composition and diversity in Kihansi Gorge for the period 1997 to 2018.

(ii) There are changes in forest parameters and carbon stock in Kihansi Gorge for the period 1997 to 2018.

(iii) There are differences in species composition, diversity and forest parameters along altitudinal gradients.

1.5 Limitations of the Study

This study has the following limitations:

1. Kihansi Gorge forest is composed of two vegetation types namely montane and miombo woodlands and these two vegetation types have no clear boundary between them. This has resulted into the presence of a transitional zone having the mixture of montane and miombo tree species in some plots. This might result into overestimation or underestimation of stand parameters such as N, G, V and Carbon stock.
2. Lack of boundary demarcation for the permanent sample plots and loss of tags to some of the trees resulted to difficulties in identification of sample trees in the plots. In this case, some trees which were inside the plots might be unrecorded in the subsequent measurement and vice versa. Therefore, the error associated with this might be cancelled out. However, the error can only affect stand parameters such as basal area, volume and biomass but may not be affect trees species composition.

1.6 Dissertation Structure

This dissertation consists of five Chapters. Chapter one is a general introduction including background information, problem statement and justification and study objectives. Chapter two is manuscript one which presents changes of woody plant species composition, richness and diversity between 1997 and 2018 in Kihansi Gorge forest, Tanzania. Chapter three (Manuscript two) describes changes in forest stand parameters of the Kihansi Gorge Forest between 1997 and 2018 in Southern Udzungwa Mountains Block, Tanzania. Chapter four (Manuscript three) describes changes in tree species diversity and forest stand parameters along altitudinal gradients in the Kihansi Gorge forest, Southern

Udzungwa Mountains block, Tanzania. Chapter five gives key contributions of the study, general conclusions and recommendations.

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CHAPTER TWO

MANUSCRIPT 1

2.0 Changes of woody plant species composition and diversity between 1997 and 2018 in Kihansi Gorge forest, Tanzania

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2.1 Abstract

A study on changes of woody plant species in terms of tree species composition and diversity in Kihansi Gorge forest in Udzungwa Mountains for the period between 1997 and 2018 was carried out. Specifically, the study determined changes of woody plant species composition and abundances; assessed trees recruitment and mortality; and determined changes of forest diversity of Kihansi Gorge forest. The assessment was done using 19 Permanent Sample Plots (PSP) with dimension of 25 m x 25 m established in 1997. The study used inventory data re-measured in years 2006, 2009 and 2018. Trees included were those with diameter at breast height (dbh) ≥ 2.9 cm. Analysis was done using Microsoft Excel spreadsheet and PAST software version 2.17. Results showed changes in species composition and diversity for both montane forest and miombo woodlands. In montane forest, mean values during the study period for Shannon, Simpson and dominance were 3.73; 0.96; 0.04 respectively. In miombo woodlands, mean values for Shannon, Simpson and dominance were 2.75; 0.89 and 0.11 respectively. In montane forest, statistical t-test for individuals, Simpson, Shannon and dominance values showed no significant difference ($p > 0.05$) for years 2006 and 2009 and significant difference ($p < 0.05$) for year 2018. In miombo woodlands, statistical t-test showed significant difference ($p < 0.05$) for years 2006 and 2009 and no significant difference ($p > 0.05$) for the year 2018. *Rinorea ilicifolia* and *Englerophytum natalense* were among the topmost five recruited tree species for both montane and miombo woodlands. Tree species with high mortality for montane forest were *Rinorea ilicifolia,* and *Filicium decipiens* while for miombo woodland tree species were *Lagynias palidiflora*, *Englerophytum natalense* and *Garcinia semseii.* It is concluded that changes in miombo vegetation take short time compared to montane forest due to high ability of miombo woodlands to recover after disturbance. The study recommends the monitoring to continue to identify causes of the changes.

Keywords: Kihansi Gorge, montane forest, miombo woodlands, permanent sample plots.

2.2 Introduction

2.2.1 Background information

Eastern Arc Mountains (EAM) range from southern Kenya to southern Tanzania. There are 13 Mountain blocks which are Mahenge, Malundwe, Uluguru, Udzungwa, Rubeho, Ukaguru, Nguru, Nguu, East Usambara, West Usambara, South Pare, North Pare (Tanzania) and Taita Hills (Kenya). The Mountains contain high level of biodiversity and endemism of plants (Myers *et al*., 2000) due to moist climate and geographical isolation (Madoffe *et al*., 2005). The EAM have watersheds which are mixes of cropland, savanna, miombo woodlands and tropical forest (Wilckock *et al*., 2016). The Udzungwa Mountains block is the largest among the 12 EAM in Tanzania. The Mountains are exceptionally rich in species of restricted range.

Kihansi Gorge forest with an area of 197.3 ha (Lovett *et al.,* 1997) is located in the Udzungwa Mountains block. The forest is one of the biodiversity hotspots (Myers *et al*., 2000; Platts *et al.*, 2013; Rovero *et al.*, 2014; Willcock *et al.*, 2016). The Kihansi Gorge forest contains many of the Eastern Arc tree species which have national and global significance due to the fact that they are critically endangered, threatened and endemic (Lovett *et al.*, 1997; Zilihona *et al.,* 1998).

Kihansi Gorge forest has very steep slope which favored the establishment of Hydropower project in the area. When construction was ongoing, permanents sample plots (PSP) were established in year 1997 to monitor vegetation of the Kihansi Gorge forest. Based on the baseline data established in year 1997, a monitoring study by NORPLAN in year 2002 revealed that there was a decrease in tree species composition, richness and diversity of Kihansi Gorge forest and recommended further studies. Studies have shown that species composition in a forest can change over time due to various reasons like moisture contents resulting from unforeseen disturbances and environmental factors (Munishi *et al.*, 2007). According to Huang *et al*. (2003), tree species diversity in tropical forest varies from place to place, main reasons being variations in habitat and disturbance. Under natural setup where disturbance is null, forest structure is still not static. Trees die due to age/competition, new trees are coming up as recruitment and living tree grow and occupy more space (Mugasha *et al*., 2017).

2.2.2 Problem statement and justification.

Information on tree species composition, richness and diversity of a particular forest helps to understand the current status of a forest including endangered and/or rare tree species, forecasting possible future changes such as recruitments and mortality and plan for long term biodiversity conservation interventions (Philip, 1994; Chen and Bradshaw, 1999; Kent, 2012; Kacholi, 2014; Suspense *et al.*, 2016).

During the establishment of Kihansi hydropower, permanent sample plots were established in the gorge for monitoring the vegetation in the Kihansi Gorge forest. The aim of the monitoring was to gain knowledge on how disturbances disrupt tree species composition and diversity. Last monitoring report was prepared in year 2002 by NORPLAN. Data were collected in years 2006 and 2009 by the University of Dar-es-Salaam but no report was prepared. Data were collected in year 2018 and analyzed together with previous data to determine the trends of plant species composition and diversity.

Except for anthropogenic disturbances, climate and topography are the key natural drivers of the forest growth and health. Most monitoring studies have been focused on dry miombo woodlands (e.g. Mugasha *et al*., 2017; Njoghomi *et al*., 2020). Not much has been done on montane forest and adjacent miombo woodlands in Tanzania. Therefore this study intends to determine changes of the miombo woodlands and the montane forest for the years between 1997 and 2018. Dynamics of natural forest information is important input since will give feedback to forest managers, provision of appropriate management interventions and policy formulations and reviews for the management of Eastern Arc and similar forests.

2.2.3 Objectives

The main objective of this study was to assess the changes of woody plant species in Kihansi Gorge forest for the period between 1997 and 2018. Specific objectives of the study were as follows:

(i) to determine changes of woody plant species composition, richness and abundance for the period between 1997 and 2018.

(ii) to assess trees species recruitment and mortality for the period between 1997 and 2018.

(iii) to determine diversity changes of woody plant species in Kihansi Gorge forest for the period between 1997 and 2018.

2.3 Materials and Methods

2.3.1 Study area

Kihansi Gorge forest is located in Udzungwa Mountains block between latitudes 07^{o} 15' – 08^{o} 45' S and longitudes 35^{o} 00' – 37^{o} 00' E (Fig. 2.1) at the border of Kilombero and Mufindi districts in Morogoro and Iringa regions respectively. Distance from Iringa town to Kihansi Gorge forest is about 130 km. The Kihansi Gorge forest runs north – south (Plate 2.1) with the length of 2-4 km and width of 1 km in the North and 0.5 km in the South (Lovett *et al*., 1997; Hirji and Davis, 2009).

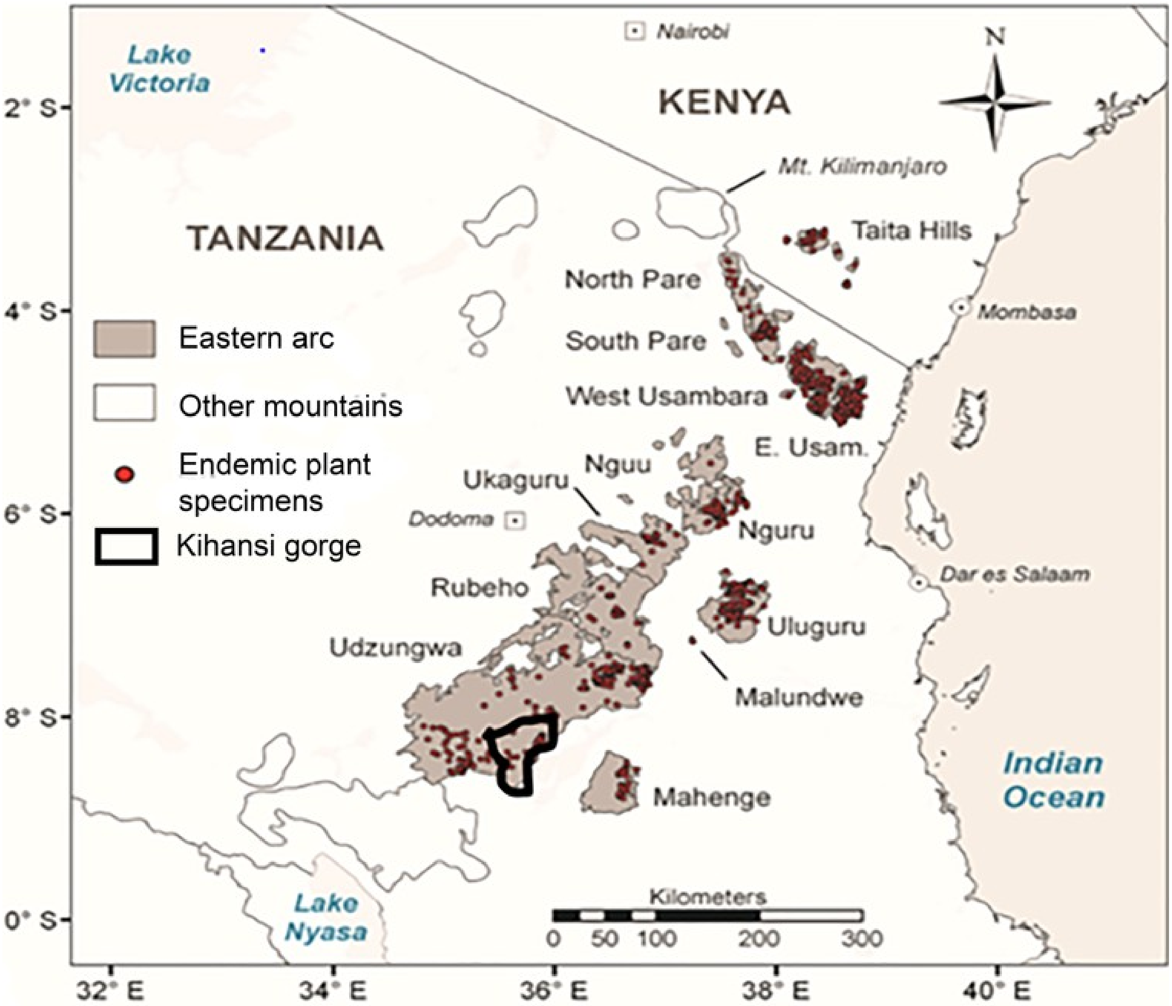

Figure 2.1: Map showing Kihansi Gorge forest within the Udzungwa Mountains block in the Eastern Arc Mountains blocks (Source: Platts *et al.,* 2013).

Plate 2.1: Kihansi Gorge forest in Udzungwa Mountains Block

Topography of Kihansi Gorge forest is very steep with rocky cliffs and its accessibility is very difficult especially during rainy season. It contains four waterfalls and an area of 2 ha which produce wetlands for natural habitat for Kihansi Spray Toads (Muamba, 2007). The area is mostly covered with moist forests probably partly due to sprays from the water falls (Vandvik *et al*., 2014). The altitude of Kihansi Gorge forest ranges from 310 m a.s.l where there is Hydropower plant and 1 141 m a.s.l at the dam site (Muamba, 2007). The climate of the area is influenced by the movement of Inter Tropical Convergence Zone (ITCZ) and the India ocean monsoon winds. Rainfall ranges from 1800 mm to 2000 mm and temperature ranges from 17.8 ^{o}C to 24.0 ^{o} C per annum (Lovett *et al.*, 1997).

Kihansi Gorge forest contains four major vegetation types (Lovett *et al*., 1997) rich in plant species (Shangali *et al.*, 1998). The vegetation types are miombo woodland (95 ha), montane forest (100 ha), *Filicium* forest (0.25 ha) and wetland grassland (2 ha) (Lovett *et al*., 1997) (Fig. 2.2). Forest occurs along the Kihansi River on both sides in the gorge (Lovett *et al*., 1997) (Plate 2.1). Wetland areas consist mostly herbaceous vegetation (Muamba, 2007). Dominating tree species in the montane forest include *Alphloia theiformis* and *Olea capensis* which are mainly found near waterfall (Lovett *et al*., 1997) and *Brachystergia* species in miombo woodlands zone at the lower side of the gorge. The height of the canopy decreases from the river to the edge of the forest where there are rocks. Near the River, where there is lowland forest, the canopy of trees ranges from 20 m to 30 m and sometimes reaches 60 m tall while in the edge of the forest where there is miombo woodland, the canopy fall to the range of 5 m to 15 m (Lovett *et al*., 1997; Zilihona *et al.*, 1998).

2.3.2 Sampling design and data collection

Field data collection (primary data) was done from November to December, 2018 in 20 permanent sample plots (PSP) which were established in the Gorge in year 1997 (Fig. 2.2). The shape of the plots were square with dimension of 25 m x 25 m in a continuous transect (NORPLAN, 2002). There were four plots in miombo woodlands and 16 plots in montane forest which include *Filicium* (6 plots) and wetland zone (2 plots) (Fig. 2.2). The PSP were identified in the field with a help of Global Positioning System (GPS) using coordinates recorded during plot establishment together with physical marking of trees in the plots through nails and tags. The GPS coordinates were also used to identify the center of the plots. Tree checklist of previous studies was used to identify trees in the plots since each tree had identity number (tag). Trees included in the study were those with diameter at breast height (dbh) $\geq$ 2.9 cm as used during baseline studies and recommended by NORPLAN (2002) to be used during re-measurement to observe trend of various parameters.

All trees with labels were included in the study and those without labels were considered to be recruitments and therefore identified and recorded. However, there were difficulties in identifying sample trees especially recruitments and other trees which their tags were lost at the borders of plots. In such cases, so as to minimize errors, a measuring tape was used to identify the border of the plot. Recruits were identified in the field by local tree identifier using local names. Trees forked above 1.3 m were treated as single tree and trees which forked below 1.3 m were considered as individual trees. All dead and live trees were identified and counted in the field.

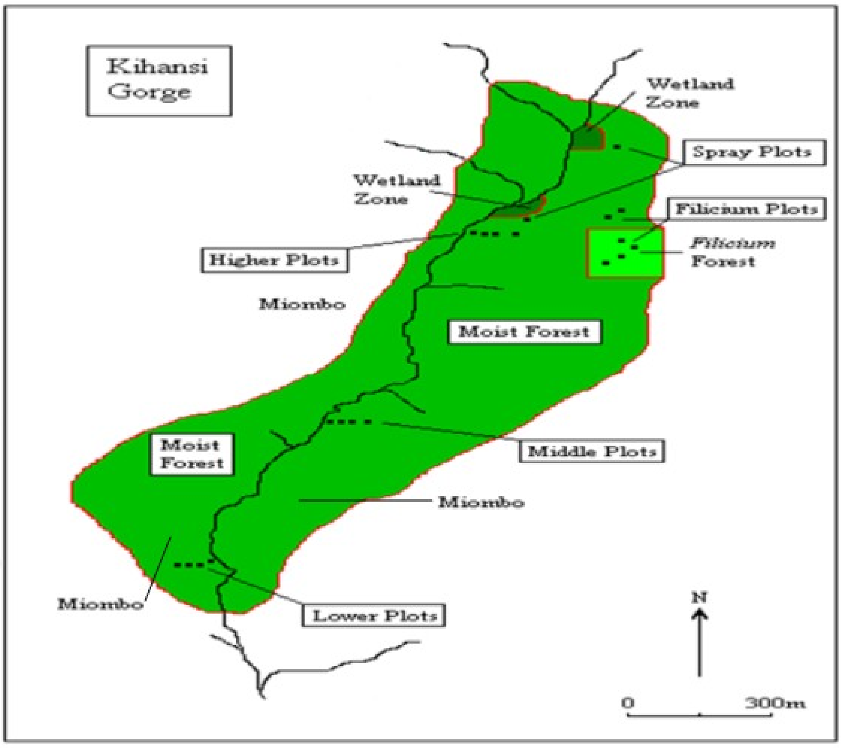

Figure 2.2: Permanent Sample Plots layout in Kihansi Gorge forest. (Source: NORPLAN, 2002).

2.4 Data Analysis

All field vegetation data were entered into Microsoft Excel spreadsheet and analyzed for different parameters according to vegetation types. Data analyzed were from 19 plots established during baseline survey in year 1997. One plot which was established in 1999 was not incorporated in the analysis since there were no data of 1997 to compare.

2.4.1 Species richness, recruitment and mortality

For the analysis of species richness, names used were the ones identified during previous inventories. For new species identified by local names, they were translated to scientific names using National Forest Resources Monitoring and Assessment (NAFORMA) species checklist (URT, 2010). Analysis for recruitment was done by sorting the counts of sampled trees which have attained diameter at breast height (dbh) of 2.9cm in the study period. Recruitment was considered to be a new tree emerged in the current and not present in the previous inventories (Mugasha *et al.,* 2017). The dbh of 2.9cm is the minimum diameter for recording trees suggested during establishment of the permanent sample plots in Kihansi Gorge forest. Mortality was considered to be a tree alive in previous measurement and found dead in next (Mugasha *et al.*, 2017).

2.4.2 Species diversity

Having sorted the data in Microsoft Excel spreadsheet, Paleontological Statistics (PAST) computer software version 2.17 was used for analysis. The software package is used in executing numerical analysis in ecological data basing on time series (Hammer *et al*., 2001). Trend of Shannon and Dominance diversity indices are among factors to consider when studying environmental issues (Magurran, 1998) thus were chosen for the analysis. Shannon diversity Index (H') was obtained by using the following equation:

$$H' = -\sum_{i=1}^{S} pi \ln pi \quad (1)$$

Where *S* is the number of species, *pi* is the proportion of individuals or the abundance of the *i*th species, and *ln* is the natural logarithm.

Simpson diversity index (1-D) was calculated using the following equation: (Rad *et al*., 2009; Hammer, 2012).

$$(1-D) = 1 - \sum ¿¿ \quad (2)$$

Where (1-D) = Simpson’s diversity index.

Dominance (D) was calculated by using the following equation:

D = 1 – (1-D) (3)

Whereby D = Dominance diversity index and (1-D) is Simpson’s diversity index.

2.5 Results and Discussion

2.5.1 Change of woody plant species richness

The current (2018) species composition per ha for montane forest and miombo woodland in Kihansi Gorge forest are 78 and 34, respectively. Based on baseline data of the year 1997, tree species richness and abundance for montane forest increased in year 2006 then decreased to years 2009 and 2018 (Fig. 2.3).

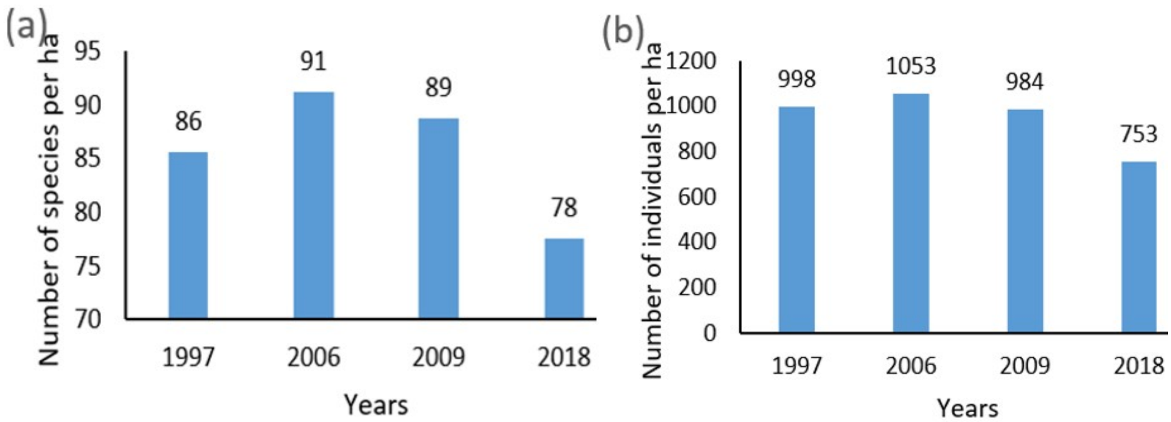

Figure 2.3: Trend of species richness in montane forest Kihansi Gorge (a) species richness (b) abundance

For miombo woodland, species richness increased in the year 2006 then decreased to years 2009 and 2018 while for the abundance there was a general decrease from year 1997 up to the year 2018 (Fig. 2.4).

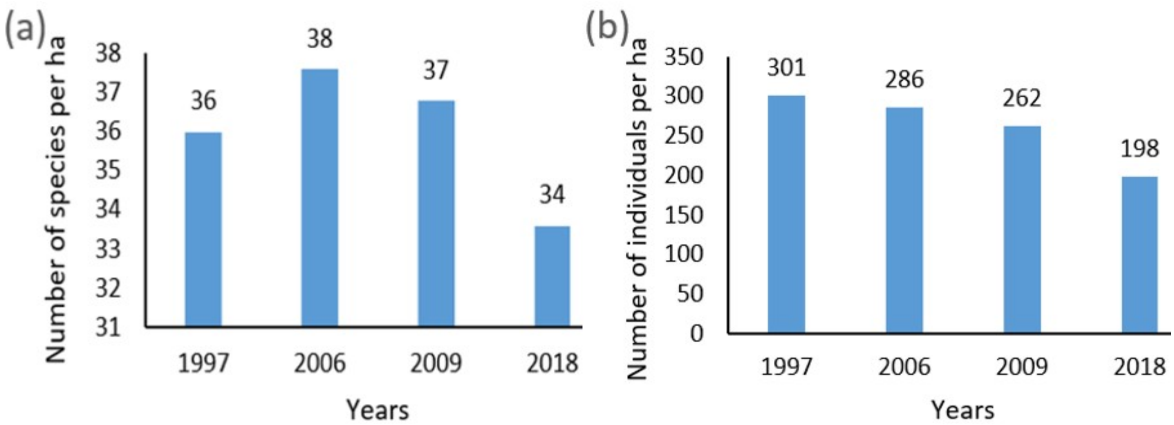

Figure 2.4: Trend of species richness in miombo woodlands Kihansi Gorge (a) species richness (b) abundance

The decrease of species richness and abundance might be due to natural mortality of trees due to competition wildfires (Herwitz, 1994 and Mountford *et al*., 1999). These could be some of the reasons for the decrease of number of species and abundance in the Kihansi Gorge forest especially in the montane forest where there was high competition, wild fires and fall of trees due to landslides (URT, 2011; URT, 2016). The list of tree species in Kihansi Gorge forest is in Appendix 1 and 2 for montane forest and miombo woodlands respectively.

Statistical t-test for individuals in montane forest based on baseline data showed no significant difference for years 2006 and 2009 ($p > 0.05$) while for the year 2018 there was a significant difference ($p < 0.05$) (Table 2.1). Possible reasons for the drop of individuals for the year 2018 could be long term natural dynamics of the forest such as mortality and natural disturbances (Crausbay and Martin, 2016) and human interference (John, 2018).

Table 2.1: Comparison of abundance of tree species among years in montane forest, Kihansi Gorge

Category	Parameter	Years			
		1997	2006	2009	2018
Individuals/ abundance	Mean	62	66	77	62
	Variance	1232.99	1366.47	1146.9	484
	***p* - value**		**0.4032**	**0.8485**	**0.0069**

Statistical t-test for miombo woodland revealed significant difference ($p < 0.05$) for year 2006 compared to the baseline, revealed marginal ($p = 0.05$) for year 2009 and no significant difference ($p > 0.05$) for year 2018 (Table 2.2). This indicates that changes in miombo woodland take short time (less than 10 years). Due to observed results, it was difficult to consider the observed changes were partly caused by diversion of water for hydropower production. It was expected that the effect of diverting river would have been observed within a short time. This justifies the argument of Philip (1994) and Allen (1994) that changes of species composition within forest vegetation can occur within a period of 5 to 10 years but for some stable forest it can take longer time.

Table 2.2: Comparison of abundance of tree species among years in miombo woodland, Kihansi Gorge

Category	Parameter	Years			
		1997	**2006**	**2009**	**2018**
Individuals/ abundance	Mean	74	70	65	49
	Variance	49.00	37.58	58.91	453.66
	***p* - value**		**0.023**	**0.053**	**0.085**

2.5.2 Recruitment and mortality

Species types recruited in montane forest was higher in year 2006 compared to years 2009 and 2018 which was constant (Fig. 2.5a) while number of individuals recruited was higher in year 2006, decreased in year 2009 then increased in the year 2018 (Fig. 2.5b). It is natural that the large load of recruitment is expected at the beginning and drop later specifically due to competition. It reached a point where the recruitment drops significantly or remain constant at lower level (Mugasha *et al.*, 2017).

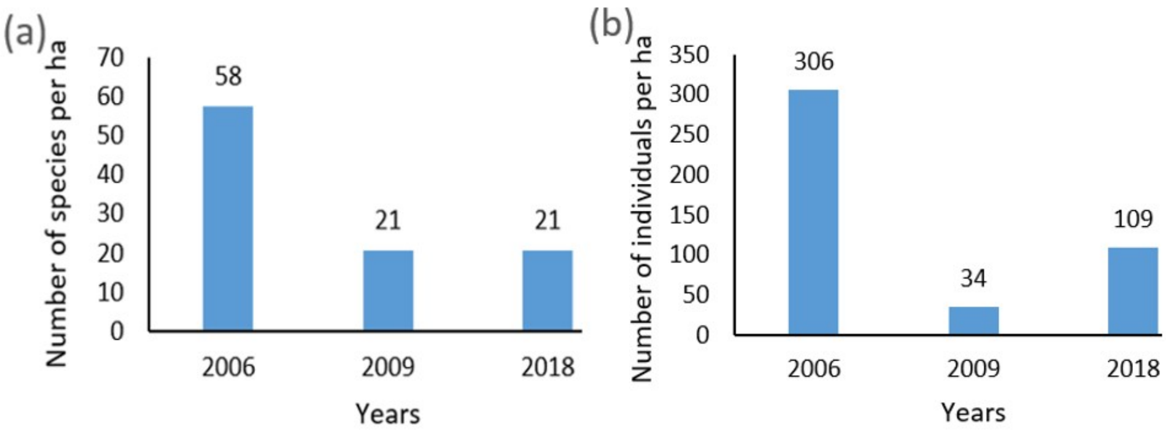

Figure 2.5: Tree recruitment trend for montane forest in Kihansi Gorge (a) Species types (b) Abundance

In miombo woodland, both species types and individuals recruited decreased from year 2006 to year 2009 then increased in the year 2018 (Fig. 2.6).

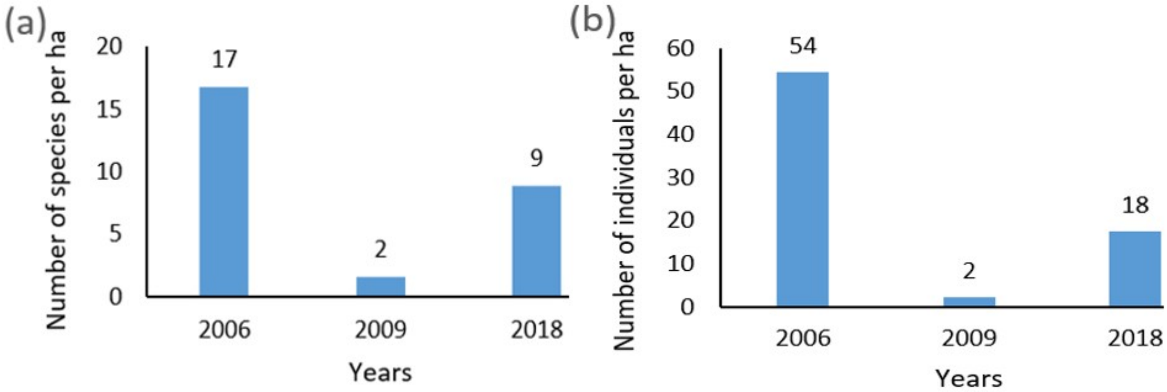

Figure 2.6: Tree recruitment trend for miombo woodland in Kihansi Gorge (a) Species types (b) Abundance.

Tree species mostly recruited during the study period were *Rinorea ilicifolia* and *Englerophytum natalense* which were among topmost five for both montane forest and miombo woodland. Other tree species for montane forest were *Cephalosphaera usambarensis*, *Sorindeia madagascariensis*, *Rinorea ferruginea* while other species for miombo woodland were *Lagynias palidiflora*, *Drypetes usambarica*, *Garcinia semseii*.

Trend of mortality for species types and individuals during the study period revealed general decrease for both montane forest (Fig. 2.7) and miombo woodland (Fig. 2.8). One of the possible reasons for the decrease of mortality rate during the study period could be reduction of competition. There was high regeneration in the year 2006 and thus high competition (survival for the fittest) compared to years 2009 and 2018. Improvement of Kihansi Gorge forest is another reason for the decrease of mortality of trees within the forest since wildfire incidences have been reduced significantly (URT, 2016; URT, 2011).

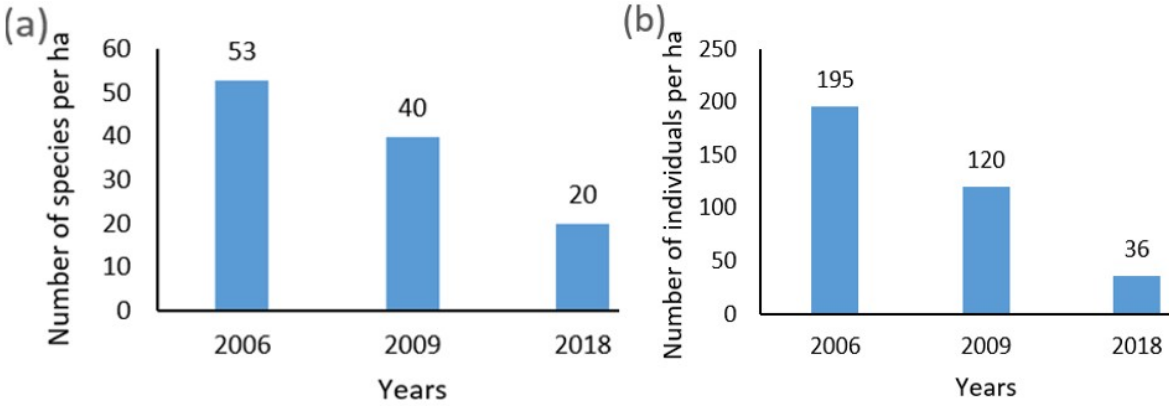

Figure 2.7: Tree mortality trend for montane forest in Kihansi Gorge forest (a) Species types (b) Abundance

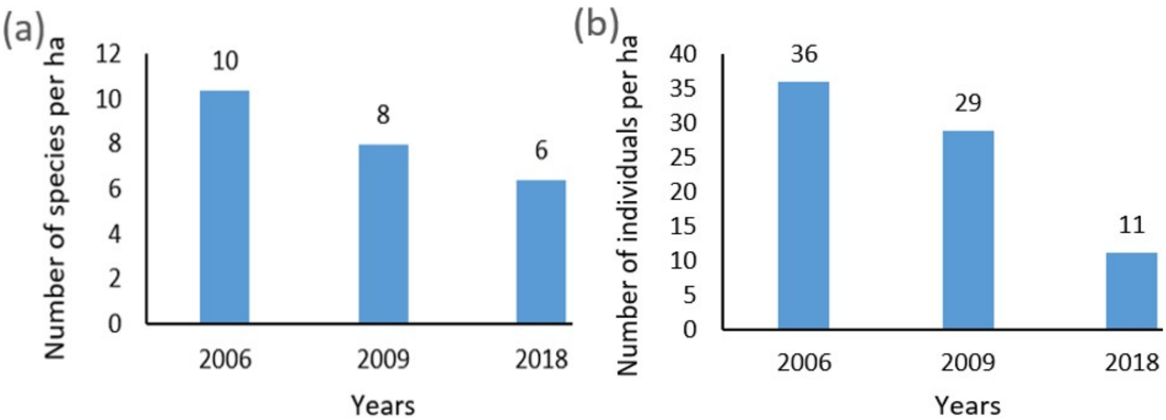

Figure 2.8: Tree mortality trend for miombo woodland in Kihansi Gorge forest (a) Species types (b) Abundance

Tree species which were at the top five in mortality during the study period for montane forest were *Rinorea ilicifolia*, *Filicium decipiens*, *Cephalosphaera usambarensis*, *Sorindeia madagascariensis* and *Strombosia scheffleri* while for miombo woodland tree species were *Lagynias palidiflora*, *Englerophytum natalense*, *Coffea sp*., *Garcinia semseii* and *Monodora grandidieri*. Big trees were observed in the field as dead naturally and others fallen due to wind and soil erosion. Most of dead small trees were those affected by fallen big trees (also reported by Lovett *et al*., 1997) and others were found washed out by water during high level of water for plots close to the river.

2.5.3 Species diversity

2.5.3.1 Shannon wiener index

Results showed that Shannon's diversity index in Kihansi Gorge for montane forest was 3.777 in 1997 and was almost maintained up 2009 then dropped to 3.635 in 2018 (Fig. 2.9a). Miombo woodland revealed Shannon diversity value increased from 2.740 in year 1997 to 2.809 in year 2009 then dropped to 2.680 in year 2018 (Fig. 2.9b). This indicates that

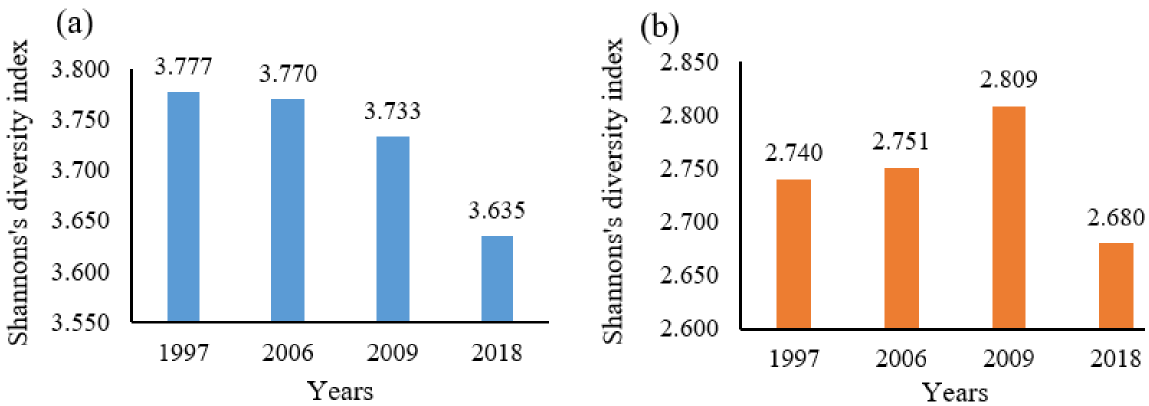

Figure 2.9: Shannon diversity indices trend in Kihansi Gorge (a) montane forest (b) miombo woodland

Usually, an ecosystem with H value greater than 2 has been regarded as medium to high species diversity (Rands *et al.*, 2010). According to Kent and Coker (1992) as cited by Gaines *et al.* (1999); Japhet (2011) the value of Shannon Wiener index lies between 1.5 and 3.5 although occasionally exceeds 4.5. The index tells about species richness which is the number of species together with species evenness which implies species distribution (Magurran, 1998). Species diversity increases as the number of individuals increases in the community. The larger the value of H the greater the diversity of the forest (Giliba *et al.*, 2011). Though there was a decrease in Shannon diversity index, the findings show that Kihansi vegetation has high vegetation diversity since Shannon diversity indices for both montane and miombo woodlands had values greater than 2.

Shannon statistical t-test for montane forest showed no significant difference ($p > 0.05$) for year 2006 and year 2009 and showed significant difference ($p < 0.05$) for year 2018 (Table 2.3).

Table 2.3: Comparison of diversity of tree species among years in montane forest Kihansi Gorge

Category	Parameter	Years			
		1997	**2006**	**2009**	**2018**
Dominance	Mean	0.0168	0.0161	0.016	0.0169
	Variance	0.0001	0.0001	0.0001	0.0001
	***p* - value**		**0.293**	**0.863**	**0.020**
Simpson	Mean	0.9832	0.9839	0.98308	0.97996
	Variance	0.0001	0.0001	0.0001	0.0001
	***p* - value**		**0.304**	**0.857**	**0.020**
Shannon	Mean	4.2415	4.2925	4.2325	4.0025
	Variance	0.2864	0.3018	0.2795	0.1726
	***p* - value**		**0.329**	**0.873**	**0.007**

Miombo woodland revealed significant difference ($p < 0.05$) for year 2006 and no significant difference ($p > 0.05$) for year 2009 and year 2018 (Table 2.4).

Table 2.4: Comparison of diversity of tree species among years in miombo woodland, Kihansi Gorge

Category	Parameter	Years			
		1997	**2006**	**2009**	**2018**
Dominance	Mean	0.0107	0.0113	0.0124	0.0188
	Variance	0.0001	0.0001	0.0001	0.0001
	***p* - value**		**0.024**	**0.065**	**0.209**
Simpson	Mean	0.9893	0.9887	0.9876	0.9812
	Variance	0.0001	0.0001	0.0001	0.0001
	***p* - value**		**0.032**	**0.071**	**0.210**
Shannon	Mean	4.5360	4.4842	4.3942	4.0567
	Variance	0.0056	0.0047	0.0088	0.1935
	***p* - value**		**0.023**	**0.059**	**0.138**

Species which have contributed to high diversity by frequency (five top most) with their percentages for montane forest include *Cephalosphaera usambarensis* (18%), *Drypetes usambarica* (11%), *Garcinia semseii* (10%), *Englerophytum natalense* (8%) and *Filicium decipiens*. For miombo woodlands, the five top most tree species with their percentages were *Drypetes usambarica* (20%), *Lagynias palidiflora* (16%), *Garcinia semseii* (12%), *Englerophytum natalense* (11%) and *Rinorea ilicifolia* (8%). This study has high Shannon diversity indices as compared to previous studies with similar vegetation type. Lovett (1996) documented Shannon index mean value of 1.97 in montane forest of Mwanihana in Sanje within Udzungwa Mountain block while Shirima *et al*. (2011) documented Shannon diversity index values of 1.05 and 1.25 for miombo woodland in EAM of Nyangaje and Kitonga respectively. The findings of the current study show higher mean Shannon values of 4.2 and 4.4 for montane forest and miombo woodlands, respectively. These results are complemented by the observed mixture of tree species of the so called miombo woodlands dominated by montane forest tree species. This implies that the forest is in transition.

2.5.3.2 Simpson Index (1-D)

Results showed that Simpson diversity index (1-D) for montane forest was higher (0.964) and for miombo woodland (0.891) in 1997 before river diversion. General trend showed a slight decrease for both montane forest (Fig. 2.10a) and miombo woodland (Fig. 2.10b) throughout the study period.

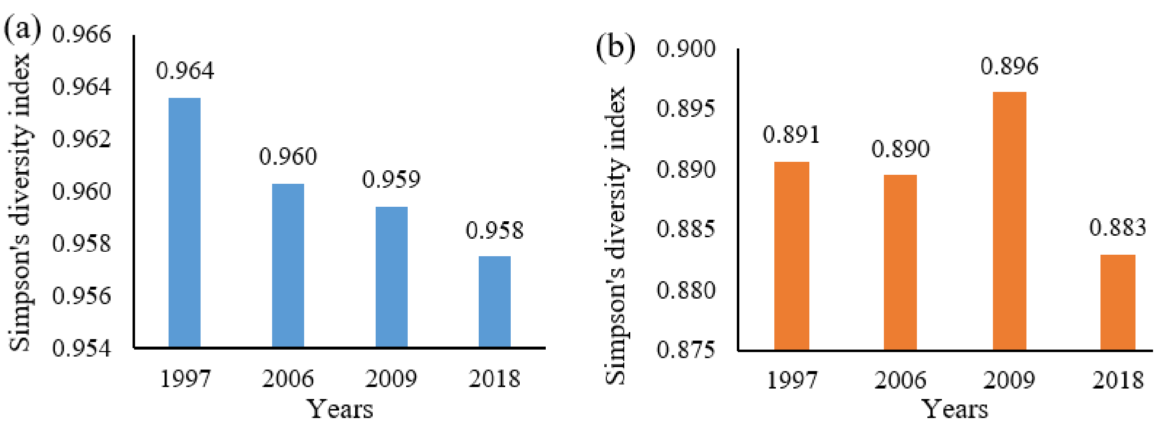

Figure 2.10: Simpson's diversity indices for Kihansi Gorge (a) montane forest (b) miombo woodland.

However, statistical test for montane forest revealed no significant difference ($p > 0.05$) for year 2006 and year 2009 while there was significant difference ($p < 0.05$) for year 2018 (Table 2.3). Statistical t-test for miombo woodland showed significant difference ($p < 0.05$) for years 2006 and year 2009 while there was no significant difference ($p > 0.05$) for year 2018 (Table 2.4).

Simpson diversity index of 0.96 means that if 100 trees are taken randomly, 96 pairs of trees are composed of different species (Elouard *et al*., 1997). This indicates that the forest has high diversity. A study done by Lovett (1996) in other EAM forests obtained 0.17, 0.15 and 0.10 Simpson diversity index at Udzungwa, Usambara and Nguru forest respectively.

2.5.3.3 Dominance

Results showed that montane forest had lower dominance index compared to miombo woodland in Kihansi Gorge forest during the study period. The dominance index values for montane forest ranged between 0.036 and 0.042 (Fig. 2.11a) while for miombo woodland the values ranged between 0.109 and 0.104 (Fig. 2.11b).

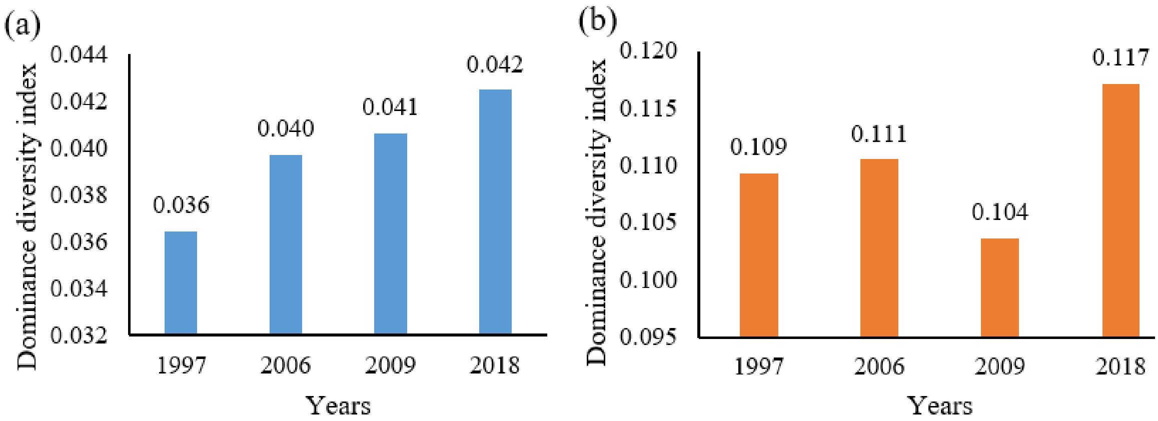

Figure 2.11: Dominance diversity indices for Kihansi Gorge (a) montane forest (b) miombo woodland

According to Magurran (1988) and Kent (2012), the value of dominance index ranges from 0 to 1, the greater the value the lower the species diversity. The lower the Dominance index value, the lower the dominance of a single or few species (Eward, 1996) as cited by Giliba *et al*. (2011). However, Lovett *et al*. (1997) reported average dominance value of 0.73 at Kihansi Gorge forest.

Dominance diversity index statistical test for montane forest revealed no significant difference ($p > 0.05$) for year 2006 and year 2009 while there was significant difference ($p < 0.05$) for year 2018 (Table 2.3). Statistical t-test for miombo woodland showed significant difference ($p < 0.05$) for year 2006 while there were no significant differences ($p > 0.05$) for years 2009 and 2018 (Table 2.4). The trend of the results indicate that changes in vegetation composition differs between vegetation types (Ding *et al.*, 2012). Changes in montane forest need longer time compared to miombo woodlands due to the characteristics of the vegetation.

2.6 Conclusion and Recommendations

The study has revealed that there are changes in species composition and diversity in the Kihansi Gorge forest. However, the period in which the changes took place differ among vegetation type. Changes in miombo woodlands took short time compared to montane forest due to natural characteristics of the vegetation types. Moreover, mortality and recruitment of trees for both montane and miombo woodlands decreased as time goes during the study period which was attributed by the reduction of anthropogenic activities. However, it was further observed that the so called miombo woodlands seems to be in transition to montane forest attributed by domination of montane tree species in miombo woodlands.

The study recommends continuous monitoring of plant diversity at Kihansi Gorge forest through the established permanent sample plots to ascertain if the observed changes are due to diversion of the river or natural dynamics. Furthermore, availability of long term forest monitoring data will enhance development of tree mortality and recruitment models using permanent sample plots in Kihansi Gorge forest.

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CHAPTER THREE

MANUSCRIPT 2

3.0 Changes in forest stand parameters of Kihansi Gorge Forest between 1997 and 2018 in Southern Udzungwa Mountains, Tanzania.

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3.1 Abstract

The study assessed changes in forest structure and carbon stock in the Kihansi Gorge forest for the period from 1997 to 2018. Data on the diameter at breast height and height for sample trees were collected in 19 permanent sample plots established in 1997. Trees included for the study were those with dbh ≥ 2.9 cm. Descriptive statistics were used in data analysis to calculate diameter class distribution, stem density, basal area (m^2), volume (m^3) and total carbon (tonnes) per ha basis for montane forest and miombo woodland. Diameter class distribution against stem density revealed an inverted "J" shape which indicate good forest condition. Statistical tests for all parameters for montane forest and stem density for miombo woodland showed no statistically significant differences ($p > 0.05$) throughout the study period. Basal area, volume and total carbon for miombo showed a statistical significant difference ($p < 0.05$) for year 2006 and year 2009 and no significant difference ($p > 0.05$) for the year 2018. The study concludes that time to observe significant changes of a forest vary according to vegetation type. Further studies are recommended for development of models to predict changes of various parameters in Kihansi Gorge.

Keywords: Kihansi Gorge, Udzungwa Mountains block, permanent sample plots.

3.2 Introduction

3.2.1 Background information

Kihansi Gorge forest is one of the global biodiversity hotspots. It is located in the Eastern Arc Mountains (EAM) which comprises of 13 mountain blocks that extend from Southern Kenya (one block) to southern Tanzania (12 blocks). The Eastern Arc Mountains have mixed vegetation including savanna, miombo woodland and tropical forest (Willckock *et al.,* 2016). In Tanzania, the Eastern Arc Mountains contain high amount of plant biodiversity which are endemic (Platts *et al.,* 2013; Rovero *et al.,* 2014; Willcock *et al.,* 2016).

The Kihansi Gorge forest has an area of 197.3 ha with many Eastern Arc endemics plant species such as *Garcinia semseii* and *Allanblackia stuhlmannii* (Lovett *et al.,* 1997). The forest has both national and global significance. This is due to the presence of plants which are critically endangered and endemic in a small area (Zilihona *et al.,* 1998; Rija, 2016).

Tropical forests are sinks of carbon throughout the year (Malhi *et al.,* 1999). The structure of a forest has a great effect on the above ground biomass (Imani *et al.,* 2017) and hence carbon stock (Wekesa *et al.,* 2016). The amount of carbon present in a particular forest depends on the variation in the forest structure (Jibrin *et al.,* 2018). Carbon stock of forests has an effect on climate change (Lopez-gonzalez *et al.,* 2011) thus it is important to know the trend of carbon stocking.

3.2.2 Problem statement and justification

Assessment of the structure of a particular forest may help to plan for long term biodiversity conservation (Nduwayezu *et al.,* 2015; Suspense *et al.,* 2016). Information generated from the forest structure assessment helps to understand the type of resources available and habitat for other species in a particular locality (Kacholi, 2014), hence predict future changes of vegetation in terms of recruitments and mortality of a forest (Philip, 1994; Chen and Bradshaw, 1999).

Forest structure has been widely used as a measure of regeneration pattern of a particular natural forest ecosystem (Rocky and Mligo, 2012) whereby diameter classes are arranged and observed for their trend (Kigomo *et al.*, 2015). Changes in forest structure are normally due to natural processes such as mortality, recruitment and natural disturbances (Crausbay and Martin, 2016). To some extent, human interference has also caused change of forest structure (John, 2018) as it could be in the Kihansi Gorge forest. Permanent sample plots are useful for studying and detecting changes in the structure of a forest (Elouard *et al.*,1997).

Studies which were done in the Kihansi Gorge forest revealed that the forest had important biodiversity which have national and global importance (Lovett *et al.*, 1997). Following this realization, permanent sample plots (PSP) were established to have Long Term Environmental Monitoring Plan (LEMP) of the vegetation in the Gorge (URT, 2004). A study done by NORPLAN (2002a) revealed that there were changes of vegetation in Kihansi Gorge forest in terms of forest structure and ultimately carbon storage. The study recommended continuous monitoring of vegetation of the Kihansi Gorge. This could be because changes in forest vegetation sometimes take quite a long time to be detected (Allen, 1994; Philip, 1994).

Continuous monitoring was necessary because forest stand parameters are indicators for forest health and productivity and key attributes used when developing utilization of forest resources such as harvesting plan. The information provided will be helpful to improve management of the ecosystems of the Kihansi Gorge and general management of similar ecosystems in Tanzania and globally. The same information can be used for policy formulation and reviews.

3.2.3 Objectives

The main objective of this study was to assess changes in the forest structure and carbon stock for the period between 1997 and 2018.

The specific objectives were:

(i) to assess changes in stem density, basal area and volume for the period between 1997 and 2018.

(ii) to examine changes in total carbon stock of the Kihansi Gorge woody plant species for the period between 1997 and 2018.

3.3 Materials and Methods

3.3.1 Study area

The study was conducted in Kihansi Gorge forest located in the southern Udzungwa Mountains block between latitudes 07º81´50´´ and 08º84´50´´ S and between longitudes 35º80´00´´37º80´00´´ E (Mangosongo and Griffiths, 2019). The Kihansi Gorge is about six km long running from north to south. Maximum and minimum elevation of the Gorge is 1100 m and 300 m above sea level respectively (Mangosongo and Griffiths, 2019).

Kihansi Gorge comprises of two main vegetation types. Montane forest with trees such as *Aphloia theiformis* together with *Olea capensis* are found mainly near the waterfall. Miombo woodland dominated by *Brachystergia* species is found on the sides of the Kihansi Gorge escarpment (Lovett *et al*., 1997).

There are 19 permanent sample plots (PSP) established in the Kihansi Gorge forest in the year 1997. Among the 20 plots, 16 plots were in montane forest and 4 plots in miombo woodlands (Fig. 3.1). The topography of the Kihansi Gorge is very steep with rocky cliffs and its accessibility is relatively difficult (Zilihona *et al.*, 1998).

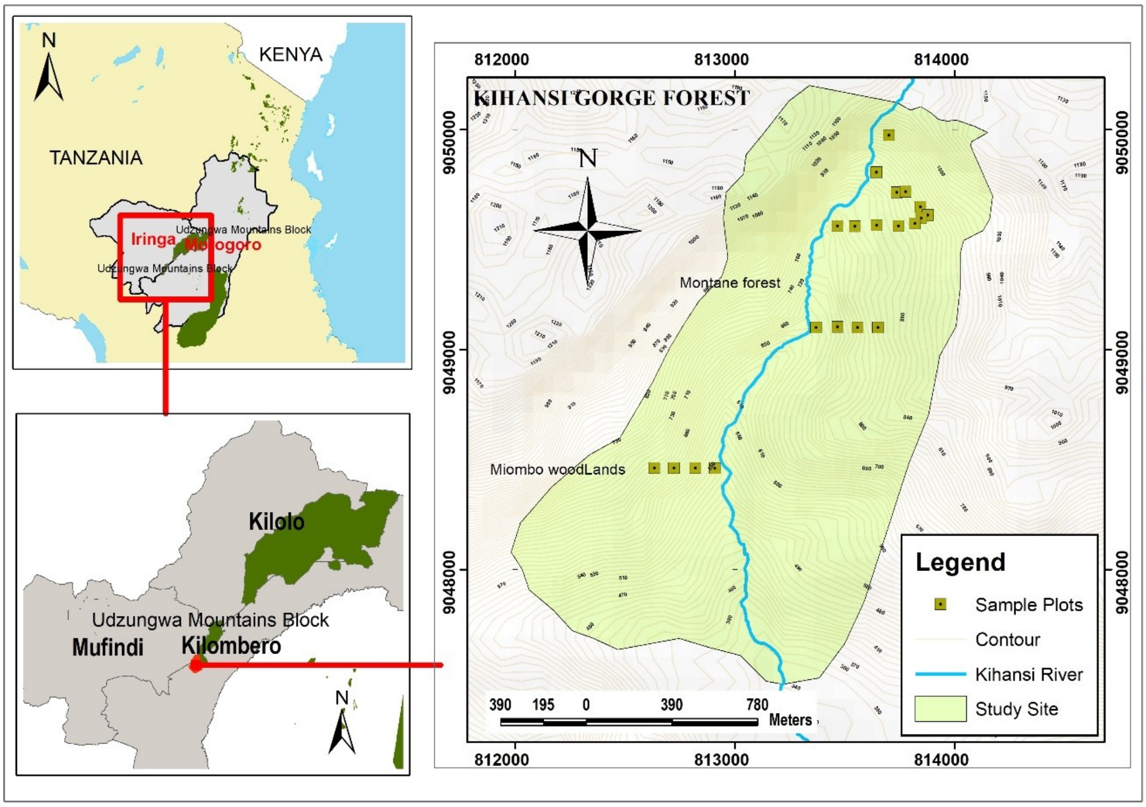

Figure 3.1: Map showing location of Kihansi Gorge forest with permanent sample plots in the Udzungwa Mountains block.

3.3.2 Vegetation Sampling and data collection

Data collection was done in 19 PSP laid in the Gorge in year 1997. The plots were of 25 m x 25 m located in a continuous transect with reference from the River (NORPLAN, 2002a) (Fig. 3.1). Global Positioning System (GPS) was used to identify plots in the field. In each plot, each tree measured in the previous years was labeled with identity number. Trees measured were those with diameter at breast height (dbh) ≥ 2.9 cm. Variables measured in the field were diameter at breast height (dbh) of each tree for both montane forest and miombo woodland. Height of three trees in each plot for montane forest were measured for volume calculation since model for volume in montane forest needs tree height.

3.4 Data Analysis

Data analysis was done basing on vegetation types which are montane forest and miombo woodland. Descriptive statistics using Excel Spreadsheet, a Microsoft office software, window 2013 was used for analysis. Parameters analyzed were establishment of diameter and height relationship, stem density by diameter classes, basal area by diameter classes, volume and total carbon per hectare basis for years 1997, 2006, 2009 and 2018. Trends for each parameter were shown in histograms and t-test were done with reference to 1997 as baseline data to detect changes statistically.

3.4.1 Diameter–height relationship

Relationship of tree diameters and tree heights of measured trees in 1997 during baseline data establishment were used to fit an equation for the estimation of tree heights for the data of 2006, 2009 and 2018 years. This was done due to the fact that measurement of tree height in tropical forest is very difficult, time consuming and costly (Larjavaara and Muller, 2013; Masota *et al.*, 2014) since most of the areas are mountainous with steep slopes thus difficult to see the top of tree crowns (Mugasha *et al.*, 2013). The equation was used to estimate height of unmeasured trees for montane forest. The regression equation obtained was as follows: $Y = -0.0034x^2 + 0.5767x + 2.1069$ Where Y = tree height (m) and x = tree dbh (cm). R^2 for the equation was 0.87. However, it was found that the equation was very poor, thus the recently developed height diameter equations for both miombo woodlands and montane forests developed by Mugasha *et al.* (2019) were used. The equations were as follow:

$H_{montane} = 1.3 + 25.6752 \times ¿$ (1)

Where H = tree height (m) and D = tree dbh (cm).

$H_{miombo} = 1.3 + 24.3701 \times \left(1 - \exp\left(-0.0405 \times D^{0.8070}\right)\right)$ (2)

3.4.2 Diameter class distribution

In order to determine diameter class distribution, Sturge's rule was used by first determining the number of classes. The equation was as follows:

K = 1+3.22*logn (3)

Whereby K= number of classes and n = number of observations

Thus 1+3.22*log1.257 = 11 dbh classes. The number of observations (1,257) was obtained by taking the average of observations for the years 1997, 2006, 2009 and 2018. Class interval was determined using the formula: W= (L-S)/K whereby W= class interval, L = the largest observation, S = the smallest observation and K= number of classes. Thus, W = (131.8-2.9)/11 = 11.7 dbh class interval. The largest observation was taken by observing data set for all years. A total of 11 tree dbh classes with class interval of 11.7 were obtained. However, 14 diameter classes with class interval of 5 cm were used for good observation of health status of Kihansi Gorge forest.

3.4.3 Stem density

The following formula was used to determine stem density;

$$N = \frac{1}{n} \sum \frac{n_i}{a} \quad (4)$$

Where: N = Number of stems per hectare, n_i = Number of trees counted in a plot, a = Plot area in hectare and n = Total number of plots measured.

3.4.4 Basal area

Basal area (m^2) is the cross-sectional area of each tree. Basal area (m^2) per ha (G) was obtained by summing basal area of each tree in a plot divided by plot size (ha). The formula used for the calculation was as follows:

$$G = \frac{\sum \frac{n_{i=1}}{a_j}}{N} \tag{5}$$

Where: G = Basal area per ha (m^2/ha), *a* = Area in hectare of the plot *j* and *n* = the number of trees in the plot *i*; N = the number of plots in forest type *j*.

3.4.5 Volume

Volume for montane forest was obtained using model for lowlands and humid montane forest developed by Masota *et al.* (2016) and volume for miombo woodland was obtained using model developed by Mauya *et al.* (2014). The models were as follow;

$$V = \exp\left(-8.12477 + 1.653497 \times \ln(D) + 0.852048 \times \ln(H)\right) \tag{6}$$

$$V = 0.00011\, x \left(D \text{¿¿¿} 2.133\, x\, H\right)^{0.5758} \tag{7}$$

Where: V = volume (m^3), D = diameter at breast height (cm), H= total tree height (m).

3.4.6 Total carbon

Total carbon (tonnes per ha) is the sum of Above Ground Biomass (AGB) and Below Ground Biomass (BGB) multiplied by a factor of 0.47 which has been used in other similar studies (URT, 2015).

AGB and BGB for montane forest were obtained using Biomass models for lowlands and humid montane forest developed by Malimbwi *et al*. (2016) as follows:

$$AGB = 0.9635 \text{ x } dbh^{1.9440} \tag{8}$$

$$BGB = 7.5811 \text{ x } dbh^{1.16801} \tag{9}$$

Biomass for miombo woodland was obtained using model developed by Mugasha *et al.* (2013) as follows:

$$AGB = 0.1027 \times dbh^{2.4798} \quad (10)$$

$$BGB = 0.2113 \times dbh^{1.9838} \quad (11)$$

Where: AGB = Above Ground Biomass (kg), BGB = Below Ground Biomass (kg) and dbh = diameter at breast height (cm)

3.5 Results and Discussion

3.5.1 Forest structure

Number of trees

The mean stem densities for the period 2018 in the Kihansi Gorge forest for montane forest and miombo woodland were 1 026 ± 134 and 1 191 ± 77 stems per ha, respectively. General trend for both montane forest and miombo woodland showed a decrease in the period from year 1997 to year 2018 (Fig. 3.2).

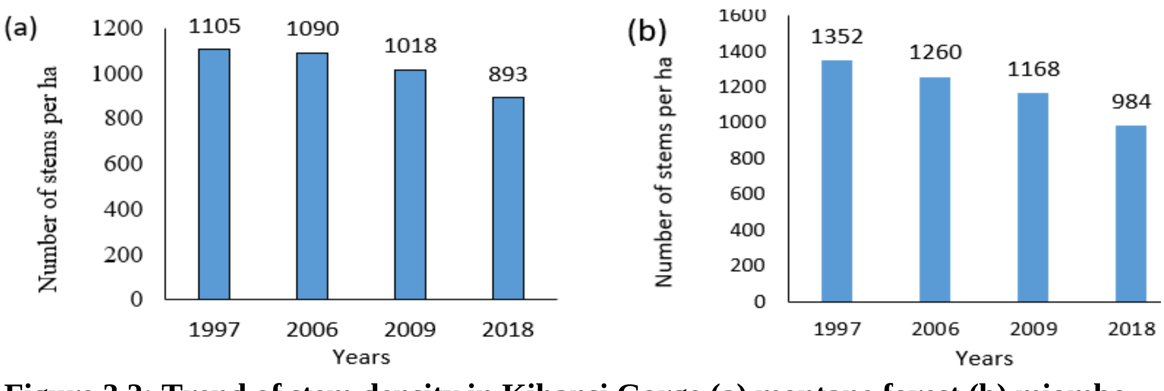

Figure 3.2: Trend of stem density in Kihansi Gorge (a) montane forest (b) miombo woodland

Possible reasons for the decrease of number of stems as observed in the plots include fall of big trees due to wind which also destroy small trees. Additionally, some trees were washed away by water for the plots located close to Kihansi River bank. This was observed by presence of dead trees along the river banks during the data collection.

Statistical t-test for stem density for both montane forest and miombo woodlands based on base line data of 1997 showed no significant difference (p > 0.05) throughout the study period (Table 3.1). This implies detection of changes on stem density needs more than 20 years.

Table 3.1: Comparison of stand parameters among years in the Kihansi Gorge forest

Forest type	**Category**	**Stand parameter**	**Years**			
			1997	**2006**	**2009**	**2018**
Montane forest		Observations	15	15	15	15
	Stem density	Mean	1105	1090	1018	893
		p - value		0.839	0.232	0.075
	Basal area	Mean	30.198	28.052	27.787	29.068
		p - value		0.157	0.285	0.606
	Volume	Mean	344.278	322.616	311.079	324.012
		p - value		0.455	0.299	0.529
	Total carbon	Mean	218.011	202.860	200.184	201.906
		p - value		0.128	0.196	0.210
Miombo woodlands		Observations	4	4	4	4
	Stem density	Mean	1352	1260	1168	984
		p - value		0.192	0.098	0.135
	Basal area	Mean	22.696	26.839	28.277	27.142
		p - value		0.004	0.030	0.356
	Volume	Mean	244.609	301.770	322.068	322.758
		p - value		0.004	0.019	0.226
	Total carbon	Mean	106.011	129.448	137.732	136.698
		p - value		0.003	0.020	0.248

Stem density may remain constant if there are no disturbances. Studies have found stem density ranging from 650 to 1161 for Montane forest and 618 to 980 for miombo woodland (Japhet, 2011). Stem density for montane forest in the Kihansi Gorge is within the range of other forests, whereas, stem density for miombo woodland is higher than other forests. Possible reason for high stem density in miombo woodland in the Kihansi Gorge forest is awareness of the community around the forest on environmental conservation since miombo woodland borders Udagaji village. The awareness is being done through Kihansi Catchment Conservation Management Project (KCCMP) formerly called Lower Kihansi Environmental Management Project (LKEMP) coordinated by the National Environmental Management Council (NEMC).

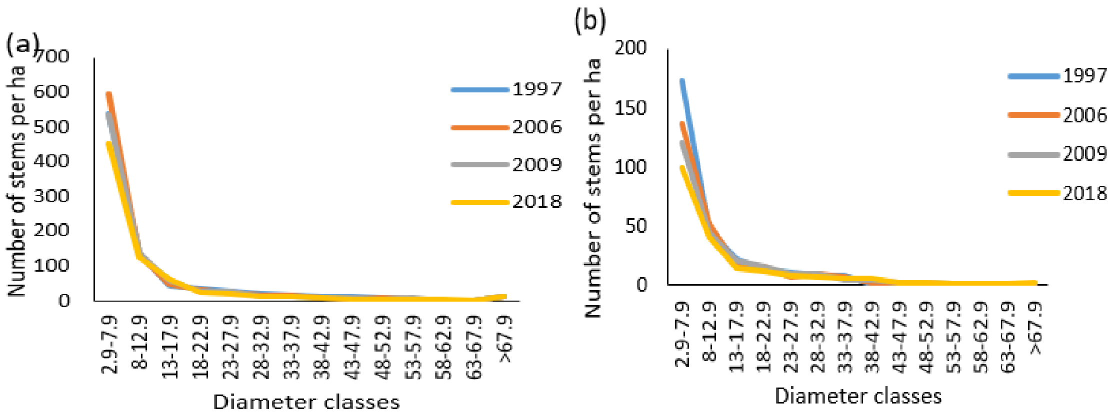

Figure 3.3: Diameter class distribution against number of stems per ha for Kihansi Gorge (a) montane forest (b) miombo woodland.

Results of stem density distribution in diameter class in both montane forest and miombo woodlands in Kihansi Gorge revealed an inverted “J” shaped trend along the study period (Fig. 3.3). The inverse “J” shape, which is a normal situation in natural forests, indicates high recruitment potential. This is important to offset the high mortality rate often occurring to small trees (Philip, 1994; Luoga *et al*., 2005; Isango, 2007; Shirima *et al.*, 2011; Mugasha *et al*., 2017).

Basal area

Basal area per ha in the Kihansi Gorge in 2018 for montane forest and miombo woodland were 28.776 ± 4.092 and 26.238 ± 9.036 m^2 per ha respectively. The values between montane forest and miombo woodlands are almost similar because the forest seems to be in transition. Another reason is that montane forest in the Kihansi Gorge forest has high organic matter (NORPLAN, 2002b) and miombo woodlands which is at the lower part there is deposition of soil which also supports growth of big trees. For montane forest, there was a decrease of basal area from year 1997 to year 2009 then there was an increase for the year 2018 (Fig. 3.4a). There was an increase of basal area for miombo woodland from year 1997 to year 2009 then there was a decrease in year 2018 (Fig. 3.4b).

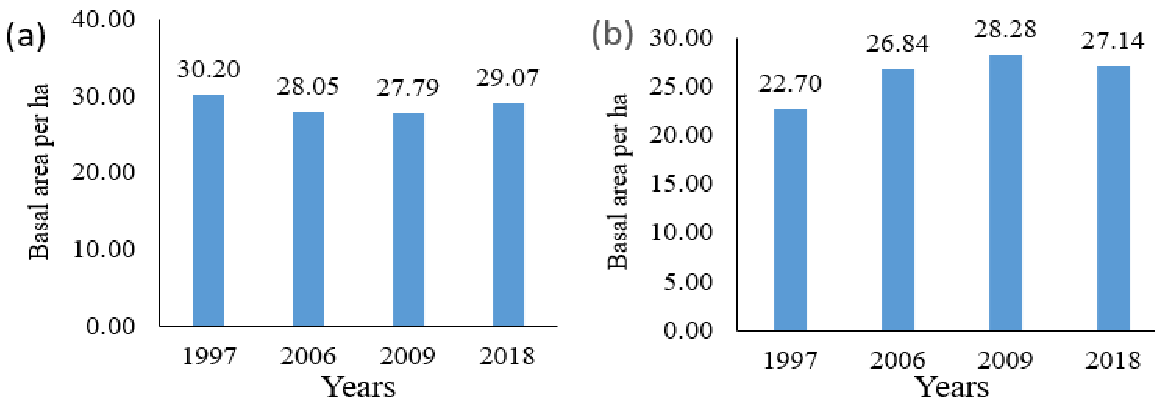

Figure 3.4: Trend of basal area per ha in Kihansi Gorge (a) montane forest (b) miombo woodland

The increasing trend of basal area for both montane forest and miombo woodlands (Fig. 3.4) is due to decrease in number of trees as shown in Fig. 3.3, the competition is reduced and therefore allow the remaining trees to grow quite well. However, statistical t-test for the montane forest showed no significant difference ($p > 0.05$) for all years. Statistical test for miombo woodland showed a significant difference ($p < 0.05$) for the year 2006 and year 2009 and no significant difference ($p > 0.05$) for the year 2018. This implies miombo woodlands has fast growth rate compared to montane forest.

Other studies indicate that basal area for montane forest and miombo woodland range from 17 to 59 m^2 (Malimbwi *et al*., 2018) and 7 to 25 m^2 per ha, respectively (Zahabu, 2001). Basal area obtained in the Kihansi Gorge for montane forest is within the range obtained by other researchers while for miombo woodland the result was slight higher. This was attributed by presence of montane tree species within miombo woodland as there was no clear boundary between the two vegetation types. Another possible reason for high basal area is that, there a possibility of the called miombo woodland in the Kihansi Gorge to be a transitional zone between lowland and montane forest. This assumption is due to high amount of rainfall (1800 mm to 2000 mm) documented by various researches in the Kihansi Gorge forest which is not normal in miombo woodlands. In addition, presence of species such as Sterculia and Rinorea tree species indicate that the area could be lowland forest rather than miombo.

Diameter class distribution against basal area per ha revealed a “J” shaped trend for montane forest in the Kihansi Gorge (Fig. 3.5a). There was no clear pattern for the distribution in miombo woodland (Fig. 3.5b).

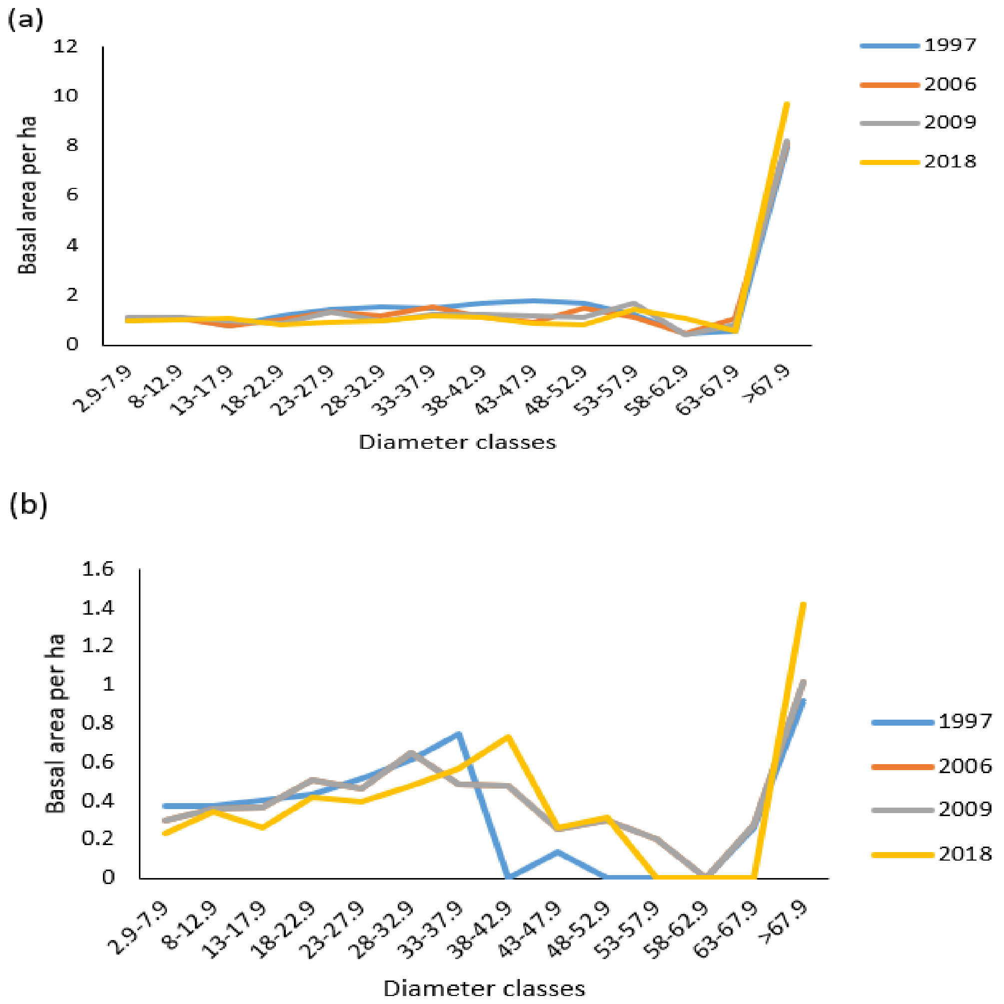

Figure 3.5: Diameter class distribution against basal area per ha for Kihansi Gorge (a) montane forest (b) miombo woodland

Volume

Results for volume per ha for montane forest and miombo woodland in 2018 were 325.496 ± 47.724 m^3 per ha and 297.801 ± 139.835 m^3 per ha respectively. The volume for montane forest decreased from year 1997 to year 2009 then increased in the year 2018 (Fig. 3.6a). On the other hand, volume for miombo woodland increased throughout the study period (Fig. 3.6b). The general trend for both vegetation types indicate that at the beginning there was competition, as time goes competition was reduced which facilitate trees to grow better thus increase of volume.

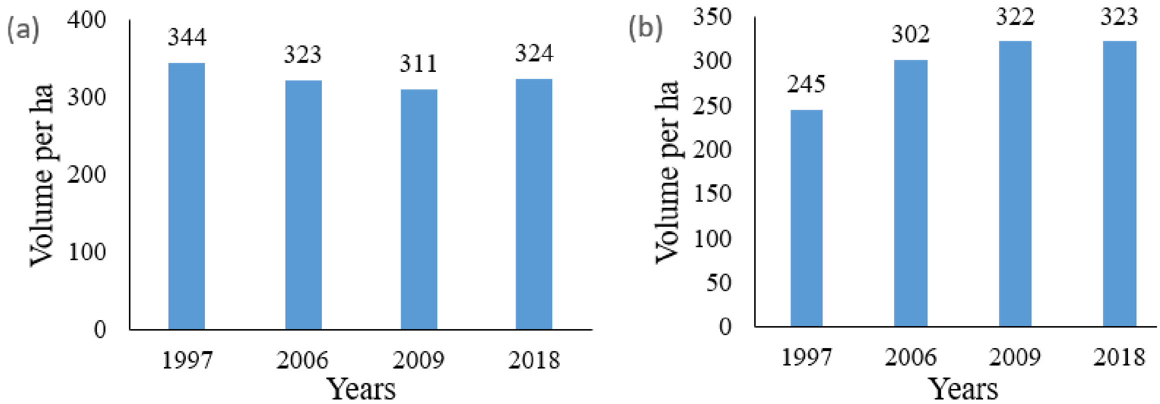

Figure 3.6: Trend of Volume per ha for Kihansi Gorge (a) montane forest (b) miombo woodland.

A statistical t-test for montane forest showed no significant difference ($p > 0.05$) throughout the study period. For miombo woodland there was a statistically significant difference ($p < 0.05$) for years 2006 and 2009 and no significant difference ($p > 0.05$) for the year 2018.

The volume in the montane forest obtained in the Kihansi Gorge was almost similar to results by Luoga *et al.* (2005) of 310 m^3 per ha in Nkweshoo Forest, Kilimanjaro. Volume for miombo woodland in the Kihansi Gorge forest was higher compared to the results obtained by John (2018) who reported 88.07 ± 25.61 m^3 per ha for Mkulanzi forest and

155.9 ± 72.4 m^3 per ha for Haitemba forest (Zahabu, 2008). Possible reason for high volume in miombo woodland in Kihansi Gorge forest is the presence of montane tree species within the miombo woodland as no clear boundary between the two vegetation types.

3.5.2 Total carbon stock

In this study, total carbon storage for montane forest and miombo woodland in the Kihansi Gorge (mean ± SE) was 205.740 ± 26.060 tonnes per ha and 127.472 ± 56.185 tonnes per ha respectively. The trend for total carbon in montane forest showed a decrease from year 1997 to year 2009 and then increased in the year 2018 (Fig. 3.7a). Trend for the carbon in miombo woodland revealed an increase from year 1997 to year 2009 then decrease in year 2018 (Fig. 3.7b).

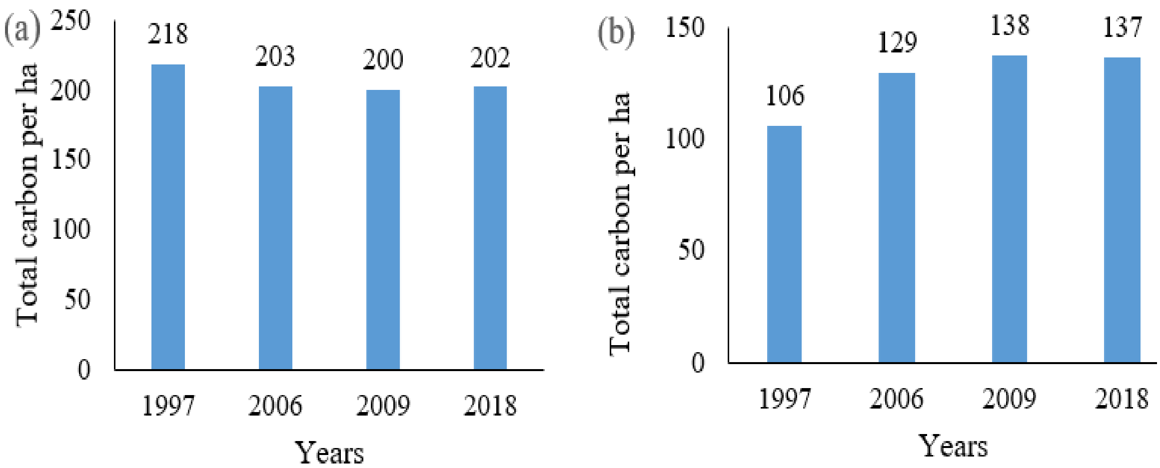

Figure 3.7: Trend of total carbon (tonnes) per ha in Kihansi Gorge (a) montane forest (b) miombo woodland

Statistical t-test for total carbon in montane forest showed no significant difference ($p > 0.05$) throughout the study period. Statistical t-test for miombo woodland revealed a significant difference ($p < 0.05$) for years 2006 and 2009 and no significant difference ($p > 0.05$) for the year 2018.

Studies by Munishi and Shear (2004) in other montane forest in the EAM revealed a total carbon of 388 ± 10 tonnes per ha in Uluguru mountains. The amount of carbon in the montane forest of Uluguru Mountains is higher than that in the Kihansi Gorge forest. This is indicative of the difference in size of tree species as suggested by Munishi and Shear, (2004). However, the amount of carbon obtained in miombo woodland in the Kihansi Gorge forest is higher than the amount reported by Shirima *et al*. (2011) who documented miombo woodlands to store carbon of 13 – 30 tonnes per ha. Difference in methodological approaches and procedures may be responsible for amount difference.

3.6 Conclusion and Recommendations

The current study revealed differences in responses of studied parameters in montane forest and miombo woodlands. Stem density, basal area, volume and total carbon stock for miombo woodlands decreased significantly during the study period while for montane forest the parameters did not show significant changes. Therefore, dynamic processes in the miombo woodlands are faster compared to montane forest due to natural characteristics of the vegetation types.

It is recommended monitoring to continue so as to identify changes and/or ascertain causes of the changes in the Kihansi Gorge forest. Further studies are recommended for development of models to predict changes in various parameters in the Kihansi Gorge forest. The models could cover volume, basal area and carbon stock.

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CHAPTER FOUR

MANUSCRIPT 3

4.0 Changes in Tree Species Diversity and Forest stand Parameters along Altitudinal Gradients in Kihansi Gorge Forest, Southern Udzungwa Mountains, Tanzania

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4.1 Abstract

This study assessed tree species composition, diversity and forest structure along altitudinal gradients in the Kihansi Gorge forest, Udzungwa Mountains. The evaluation used a total of 87 plots (75 temporary and 12 permanent sample plots) distributed equally at the higher, middle and lower altitudes. Trees with dbh ≥ 2.9 cm were identified, measured, counted and recorded. Analysis was done by using Microsoft excel spreadsheet and PAST software version 2.17. Diversity was determined using Shannon's and Simpson's diversity indices. The total number of tree species identified in the forest is 173. Most of the species were found in all altitudes (27%), Lower altitude (24%), species found in double altitudes (22%), Higher altitude (19%) and Middle altitude 8%. Tree species diversity decreased as altitudes increases. Stem density decreased with increasing altitude while basal area and volume decreased with decreasing altitude. Further researches elsewhere are recommended on variations of tree species diversity and forest structure along different altitudinal ranges since the parameters may differ with locations.

Keywords: Kihansi Gorge, altitude, tree species diversity, structure, Eastern Arc forest, Udzungwa Mountains.

4.2 Introduction

4.2.1 Background information

Kihansi Gorge forest is found within the Udzungwa Mountains block which is the largest among the 12 Eastern Arc Mountain (EAM) blocks in Tanzania. The EAM of Tanzania have a characteristic of having high level of species endemism, severe threat as well as exceptional diversity of plant communities of restricted range size (Gereau *et al*., 2016). *Coffea kihansiensis* is one of plant species which is endemic to Kihansi Gorge forest (Rija, 2016). Kihansi Gorge is characterized by two vegetation types which are montane forest found in the higher and middle altitudes and miombo woodlands in the lower altitude.

The debate on the variation on tree species diversity along gradients is ongoing (Givnish, 1999; Currie and Francis, 2004; Gonzalez-Espinosa *et al*., 2004; Qian and Riclefs, 2004). There is an assumption that species diversity peaks up at intermediate part of an altitude due to transition of lowland to montane zone (Lomolino, 2001; Rahbeck 2005) which may result into overlapping ranges of species distributions due to conducive growth condition for multiple tree species. This assumption has brought a debate to various scholars (Hamilton and Perrott, 1981; Zapata *et al*., 2003).

Traditionally, it is viewed that there is a positive relationship diversity to decrease with increasing altitude (Lieberman *et al*., 1996; Givnish, 1999). This is due to the fact that as altitude increases from the ocean or coast to the top of the mountain, temperature decreases and thus productivity decreases leading to lowering biotic interaction. This is according to the theory of standard ecology of diversity and environmental gradients, though the pattern is not uniform (Lovett *et al*., 2006).

According to Givnish (1999), elevation is one of the factors which affect tree species diversity. The reason for this effect is moisture and nutrient availability which vary along altitudinal gradient. Thus, results for diversity differ from one study location to another.

4.2.2 Problem statement and justification

Studies carried out in the EAM forests on altitudinal change concluded that there was no relationship between altitude and diversity. The study was done using data from Eastern Arc forest of five different localities of West Usambara, East Usambara, South Nguru, Malundwe, Northern Udzungwa and Southern Udzungwa by involving trees with diameter at breast height (dbh) $\geq$ 20 cm (Lovett, 1998; 1999). The areas have mean elevation of 1 295 meters above sea level (m.a.s.l) (Lovett, 1996) and Kihansi Gorge forest has mean elevation of 725.5 m.a.s.l (Muamba, 2007). The information from the results will increase our understanding on the change of forest stand parameters along altitudinal gradients in the Kihansi Gorge forest and other similar forests.

4.2.3 Objectives

The main objective of the study was to assess changes in tree species diversity and forest stand parameters along altitudinal gradients in the Kihansi Gorge forest.

The specific objectives were:

(i) to assess changes of tree species composition along altitude in Kihansi Gorge forest.

(ii) to assess changes of tree species diversity along altitude in Kihansi Gorge forest.

(iii) to assess changes of forest stand parameters in terms of density, basal area and volume along altitudinal gradient in the Kihansi Gorge forest.

4.3 Materials and Methods

4.3.1 Study area

The study was conducted in Kihansi Gorge forest which is located in southern Udzungwa Mountains block at the border of Kilombero and Mufindi districts (Fig. 4.1). The Kihansi Gorge forest is very steep with rocky cliffs which make accessibility difficult. The altitude of the Kihansi Gorge forest ranges between 310 m a.s.l and 1 141m a.s.l (Muamba, 2007). The area is mostly covered with moist forests probably due to sprays from the water falls (Vandvik *et al*., 2014). Kihansi Gorge has montane forest which is found in the higher altitudes (776 m.a.s.l) and middle altitudes (710 m.a.s.l) and miombo woodlands in the lower altitude (483 m.a.s.l).

The climate of Kihansi Gorge forest is influenced by the movement of Inter Tropical Convergence Zone (ITCZ) and the India ocean monsoon winds (Lovett *et al.*, 1997). Kihansi Gorge forest is found in the leeward side. The area receives rainfall of about 1800 mm a year and temperature ranges between 13^{o}C and 25^{o} C (Cordeiro *et al*., 2006). Rainfall falls off rapidly to the rain shadow with the vegetation changing to woodland (Lovett *et al.*, 1997).

4.3.2 Sampling and data collection

Data were collected from 87 plots whereby 12 were permanent and 75 temporary sample plots. The plots were distributed equally at the higher (H), middle (M) and lower (L) altitude of the forest whereby there were 29 sample plots (4 permanent and 25 temporary) in all altitudes (Fig. 4.1). The average altitudes of the location of plots were 483, 710 and 776 m.a.s.l at the lower, middle and higher altitude respectively. The 12 permanent sample plots (25 m x 25 m) were laid down in the year 1997. The plots were identified in the field using a hand held Global Positioning System (GPS). The 75 temporary sample plots were added so as to have enough data along altitudinal gradient which require numerous samples as recommended by Vazques and Givnish (1998). The temporary sample plots were circular with radius 15 m. This plot design was chosen since it is easy to lay in the field compared to square plot particularly in difficult terrain found in the study site. This design was also adopted during National Forest Resources Monitoring and Assessment (NAFORMA) carried out between 2009 and 2014. Distances between plots was 50 m and between transects was 100 m.

In each plot, all trees with dbh ≥ 2.9 cm were identified, counted and measured their dbh and recorded in field data form (Appendix 3). Three trees in each plot for montane forest (higher and middle altitude plots) were measured their heights so as to find their relationship with dbh for the estimation of heights of the remaining trees. This was done because model for volume estimation for montane forest requires height parameter.

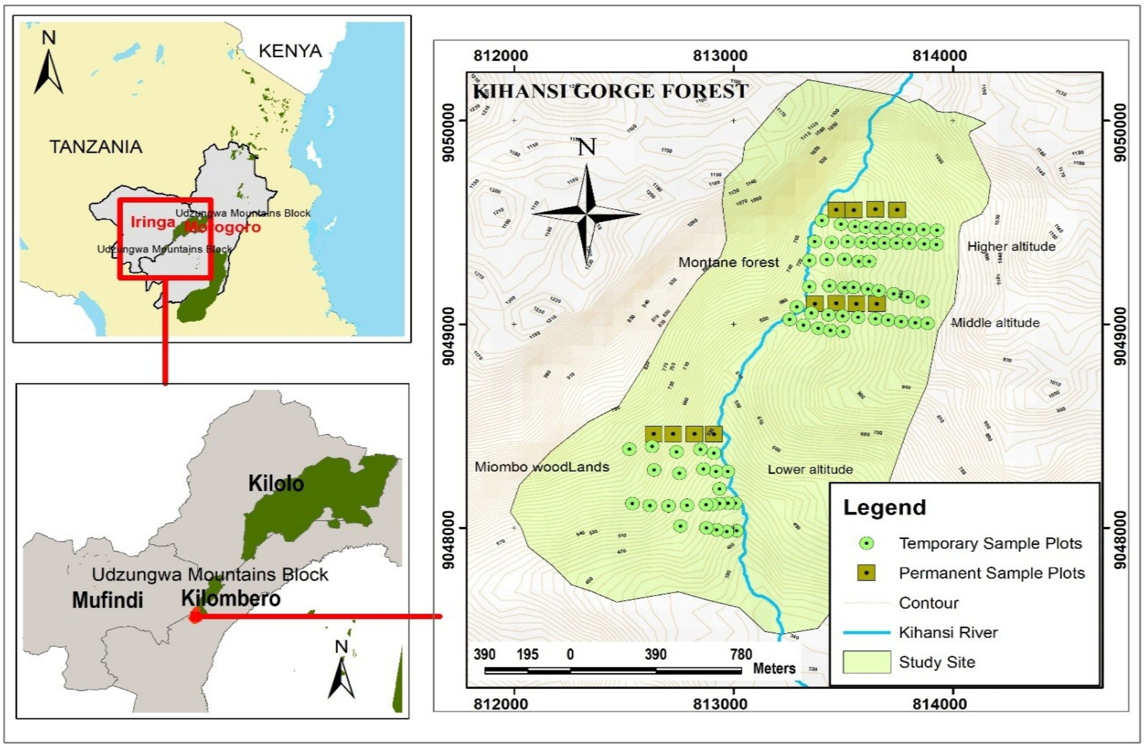

Figure 4.1: Map showing layout of sample plots in the Kihansi Gorge forest, Udzungwa Mountains block

4.4 Data Analysis

Field data was cleaned and sorted in Microsoft excel spreadsheet and analyzed through Descriptive statistics and Paleontological Statistics (PAST) software version 2.17. Data analysis was done for higher, middle and lower altitudes for each parameter separately. The parameters were then presented in histograms and statistical tests were done to find their significances altitudinally.

4.4.1 Species composition

Analysis for species composition was done by arranging the identified list in an alphabetical order in a Microsoft excel spreadsheet and thus the list and number of species for Kihansi Gorge forest for all altitudes was obtained.

4.4.2 Species Diversity

Diversity was measured by Shannon's and Simpson's diversity indices. The diversity indices were chosen because Shannon's diversity index considers both abundance and evenness and Simpson's diversity index is a measure of dominance (Magurran, 1988).

Shannon diversity Index (H') was obtained by using the following equation:

$$H^{'} = -\sum_{i=1}^{S} pi \in pi \quad (1)$$

Where H' = Shannon' diversity Index, S = number of species, pi = proportion of individuals or the abundance of the *i*th species, and In = the log base$_n$.

Simpson diversity index (1-D) was calculated using the following equation: (Rad *et al*., 2009; Hammer, 2012).

$$(1-D) = 1 - \sum ¿¿ \quad (2)$$

Where (1-D) = Simpson's diversity index and p_i is the proportion of individuals of species *i* in the community.

4.4.3 Forest structure

Forest stand parameters analyzed for forest structure were number of stems per ha (N), basal area per ha (G) and volume per ha (V). Since measurement was done using different plot designs i.e permanent sample plots were 25 m x 25 m and temporary sample plots were circular with radius of 15 m, the measured values were divided to the respective plot area to convert the values into the same unit. However the estimated forest parameters was obtained as the mean value from all plots measured. The dbh – height relationship for measured trees was done so as to estimate heights of unmeasured trees. The tree heights were then used to estimate tree volumes for montane forest and miombo woodlands. Regression equation obtained for estimating unmeasured tree height was $Y = -0.0033x^2 + 0.5813x + 2.267$ where Y = tree height (m) and x = tree dbh (cm). The equation was poor, thus recently developed height-diameter equation models developed by Mugasha *et al.* (2019) for montane forest (equation 3) and miombo woodlands (equation 4) were used instead. The equations were as follows:

$$H_{montane} = 1.3 + 25.6752 \times ¿ \qquad (3)$$

Where H = tree height (m) and D = tree dbh (cm).

$$H_{miombo} = 1.3 + 24.3701 \times \left(1 - \exp\left(-0.0405 \times D^{0.8070}\right)\right) \qquad (4)$$

Stem density is the total number of individuals in each plot divided by the total plot area (plants per ha). Stem density was computed by using the formula;

$$N = \frac{1}{n} \sum \frac{n_i}{a}$$

(5)

Where: N = Number of stems per hectare, n_i = Number of trees counted in a plot, a = Plot area in hectare and n = Total number of plots measured.

Basal area (m^2) is the cross sectional area of each tree. Basal area (m^2) per ha (G) was obtained by summing the basal area of each tree divided by plot size. The formula used for basal was as follows:

$$G=\frac{\sum \frac{n_{i=1}}{a_j}}{N} \qquad (6)$$

Where: G = Basal area per ha (m^2/ha), *a* = Area in hectare of the plot *j* and *n* = the number of trees in the plot *i*; N = the number of plots in forest type *j*.

The volume for the montane forest utilized the model developed by Masota *et al.* (2014) for tropical rainforest (equation 7) and volume for miombo woodland was obtained using model developed by Mauya *et al.* (2014) (equation 8). The models were as follows:

$$V=\exp\left(-8.12477+1.653497\times\ln\left(D\right)+0.852048\times\ln\left(H\right)\right) \qquad (7)$$

$$V=0.00011\,x\left(D¿¿¿2.133\,x\,H\right)^{0.5758} \qquad (8)$$

Where: V = volume (m^3), D = diameter at breast height (cm), H= total tree height (m).

Forest structure parameters (N, G and V) were tested by comparing Higher vs Middle, Higher vs Lower together with Middle vs Lower for all parameters.

4.5 Results and Discussion

4.5.1 Species composition

Results showed that the number of species was higher at the lower altitude followed by higher altitude and the least was middle altitude (Fig. 4.2).

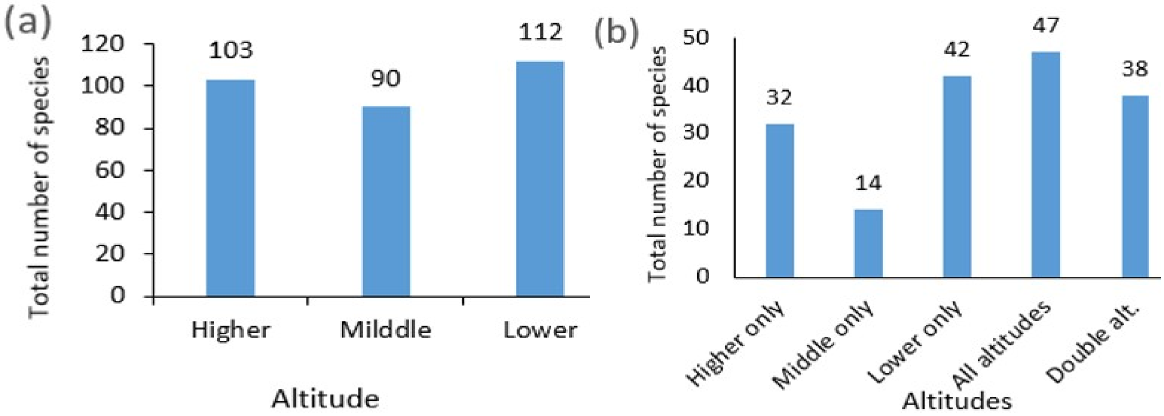

Figure 4.2: Distribution of tree species composition at Higher, Middle and Lower altitudes in the Kihansi Gorge forest (a) number of species (c) exclusive number of tree species

Species distribution showed that among 173 species, 42 (24%) were found only in the lower altitude, 14 species (8%) found only in the middle altitude, 32 (19%) found only in the higher altitude, 47 (27%) found in all altitudes and 38 (22%) species were found in double altitude (either H and M, H and L or M and L) (Fig. 4.2b). The list of tree species is in Appendix 4.

The study reveals that 47 tree species which is 27 percent of all tree species occurred in all altitudes in the Kihansi Gorge forest. The same trend of results were obtained by Lovett (1998; 1999) in other forests within the Eastern Arc Mountains of Tanzania. However, five top most tree species localized only in specific altitude in the Kihansi Gorge forest include *Rinorea ferruginea*, *Clausena anisata*, *Erythrina abyssinica*, *Croton macrostachys* and *Myrianthus arboreus* in the higher altitude; *Afzelia quanzensis, Teclea trichocarpa*, *Polyscias fulva, Thespesia garckeana* and *Olea europea* in the middle altitude together with *Erythrococca atrovirens*, *Ehretia cymosa*, *Diplorhynchus condylocarpon*, *Zanthoxylum chalybeum and Macaranga kilimandscharica* in the lower altitude.

4.5.2 Species diversity

Results showed that tree species diversity in the Kihansi Gorge forest decreases as altitude increases as shown by both Shannon (Fig. 4.3a) and Simpson (Fig. 4.3b) diversity indices.

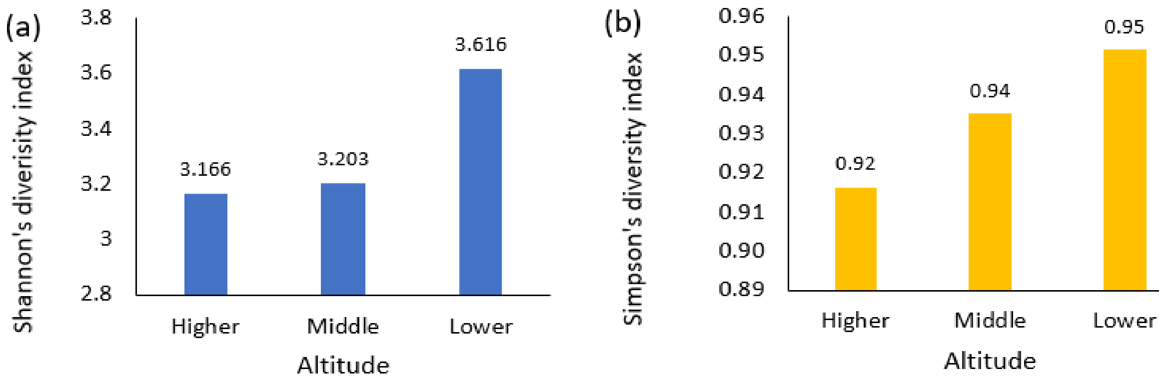

Figure 4.3: Diversity indices in Kihansi Gorge forest at higher, middle and lower altitudes (a) Shannon's diversity index (b) Simpson's diversity index

This study revealed that diversity at Kihansi Gorge forest decreases at an increasing altitude. The results support the traditional theory that diversity decreases with increasing altitude. The same trend of results were obtained by Lieberman *et al.* (1996) in Costa Rica; Lovett (1996) in Eastern Arc Mountains specifically in Mwanihana Forest Reserve, Tanzania; Vazquez and Givnish (1998) in Mexico; Givnish (1999) in tropical forests and Wenjun *et al*. (2012) in China. Rahbek (1995) documented that decline in species richness with increasing altitude is widely accepted as a general pattern. However, Tallents *et al.* (2005) documented that species diversity decreases with decreasing elevation or at least remains constant as it is in some of the Eastern Arc Mountains.

The decline of diversity at an increasing altitude has been explained by various mechanisms including the isolation nature of montane forests which prevent migration of forest (Lieberman *et al.*, 1996; Vazquez and Givnish, 1998). On the other hand, low diversity at the higher altitude may be contributed by limited land area at the top compared to lowland area (Vazquez and Givnish, 1998). This scenario is the one which is at Kihansi

Gorge forest whereby at the higher altitude the width of the gorge is 500 m while at the lowland area the width extends up to 1000 m.

These results contradict with other studies done in other EAM forests which revealed that diversity does not decrease with increasing altitude (Lovett, 1998; 1999; Tallents *et al*., 2005). One of the reasons for the differences is study site characteristics including variation in elevations.

Higher diversity at the Lower altitude of Kihansi Gorge forest, could be contributed by favorable soil condition for the growth of trees. This is due to the fact that temperature decreases with decreasing altitude thus microbial activity in lower part of the Kihansi Gorge forest might also increase as consequence of higher temperatures (NORPLAN, 2002).

4.5.3 Forest structure

Results for physical structure for Kihansi Gorge forest revealed that number of stems per ha was higher at the lower altitude followed by higher altitude and the least was middle altitude (Fig. 4.4a). Basal area per ha was higher at middle altitude followed by higher altitude and the least was at the lower altitude (Fig. 4.4b). Volume per ha decreased as altitude decreases (Fig. 4.4c). These results show that lower altitude has many smaller trees while middle and higher altitudes have fewer but bigger trees. The same trend was also reported by Lieberman *et al.* (1996) in Costa Rica and Lovett *et al*. (2006) at Manihana forest in Udzungwa Mountains. Possible reason for low basal area and volume per ha at the lower altitude of Kihansi Gorge forest could be former cultivation in the area. The former cultivation in the area has made the area to have many but small trees.

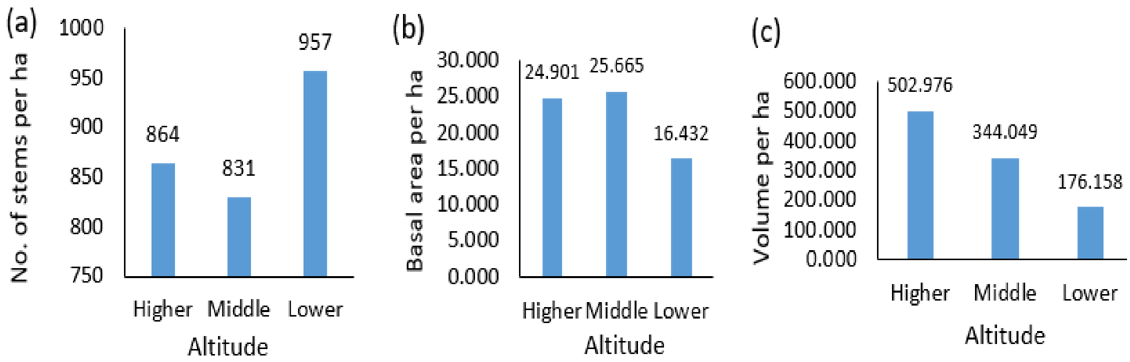

Figure 4.4: Physical structure trend at higher, middle and lower altitudes (a) Number of stems per ha (b) Basal area per ha (c) Volume per ha

Statistical t-test for number of stems per ha for all altitudes (higher vs middle, higher vs lower and middle vs lower) showed no significant difference ($p > 0.05$) (Table 4.1). Statistical t-test for basal area (m^2) per ha revealed no significant difference ($p > 0.05$) for higher vs middle altitudes, significant difference for higher vs lower altitudes as well as middle vs lower altitude ($p < 0.05$). Statistical t-test for volume revealed marginal ($p = 0.05$) for higher vs middle altitudes and significant difference ($p < 0.05$) for higher vs lower together with middle vs lower altitudes. The observed differences for basal area and volume per ha when comparing with lower altitude is contributed by vegetation type. The trend of results for number of stems per ha was also reported by Swamy *et al*. (2000) and Marshall (2007) i.e higher number of stems per ha at the lower altitude followed by higher altitude and the least at the middle altitude.

Table 4.1: Comparison of parameters among altitudes in the Kihansi Gorge forest

Parameter	Altitude	p value
	Higher vs Middle altitude	0.6703
Number of stems per ha (N)	Higher vs Lower altitude	0.2969
	Middle vs Lower altitude	0.0826
	Higher vs Middle altitude	0.8334
Basal area per ha (G)	Higher vs Lower altitude	0.0186
	Middle vs Lower altitude	0.0049
	Higher vs Middle altitude	0.0460
Volume per ha (V)	Higher vs Lower altitude	0.0001
	Middle vs Lower altitude	0.0006
	Higher vs Middle altitude	0.6634
Number of individuals	Higher vs Lower altitude	0.2832
	Middle vs Lower altitude	0.0754
	Higher vs Middle altitude	0.4830
Number of species	Higher vs Lower altitude	0.3695
	Middle vs Lower altitude	0.8189

The statistical results from this study do not show a clear trend on forest structure especially on Basal area and Volume per ha. This lines with the conclusion done by Lovett *et al.* (2006) that it is difficult to generalize about forest structure in terms of altitude in tropical forests.

4.6 Conclusion and Recommendations

In Kihansi Gorge forest, tree species diversity decreases as altitude increases. It is difficult to generalize forest structure. This is due to the fact that there was no significance difference on stem density along the elevation. Both basal area and volume per ha showed no significance difference for the Higher and Middle altitude, on the other hand, there was a significant difference for the Higher and Lower altitudes together with the Middle and Lower altitudes.

Further research is recommended on variations of tree species diversity and forest structure along different altitudinal ranges since the parameters may differ with locations.

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CHAPTER FIVE

5.0 KEY CONTRIBUTIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides key contributions of the study to increase knowledge on temporal and spatial changes of forest parameters in the Kihansi Gorge forest. The chapter highlights general conclusions of the study and recommendations.

5.2 Key Contributions of the Study

The first objective which is chapter two provided results from monitored vegetation for changes of woody plant species composition and diversity within a period of 20 years in the Kihansi Gorge forest, Tanzania. The study revealed that there are changes in vegetation, however time for the changes differ between vegetation type i.e montane forest and miombo woodlands.

The second objective provides (chapter two) provided the results from the monitored forest for 20 years showing the changes in forest parameters of the Kihansi Gorge forest between 1997 and 2018. The study revealed that the montane forest is more stable as the forest stand parameters did not differ significantly during the study period and therefore more time is required to observe changes. However, for miombo woodlands, forest parameters changed significantly within time of 10 years.

The third objective which is chapter four provided the trend of changes in tree species diversity and forest stand parameters along altitudinal gradients in the Kihansi Gorge forest. The study revealed that as going up the mountain, number of trees, species composition and diversity decreases.

5.3 Conclusions

The study on the monitoring of woody plant species shows that there are changes in tree species composition, diversity, forest structure and carbon stock in the Kihansi Gorge forest. The study has revealed that changes in montane forest take more time compared to miombo woodlands due to natural characteristics of the vegetation types. Based on altitude, tree species diversity and number of trees in the Kihansi Gorge forest decrease as altitude increases. However, it was observed that the so called miombo woodlands seems to be in transition to montane forest. This might be associated by enhanced conservation efforts to the forest.

5.4 Recommendations

The study recommends monitoring of various stand parameters to continue in the Kihansi Gorge forest through the established permanent sample plots to identify changes and ascertain possible causes of the changes. More studies are recommended for development of site specific models to predict changes in various parameters in the Kihansi Gorge forest since the area has national and international importance. The models could cover tree mortality and recruitment, volume, basal area and carbon stock. Further researches are recommended on variations of tree species diversity and forest structure along different altitudinal ranges since the parameters may differ with locations. Based on study limitations, there is a need to maintain the permanent sample plots especially boundary demarcation together with relabeling and labelling of the recruited trees to enable further monitoring of the vegetation.

APPENDICES

Appendix 1: List of tree species in montane forest, Kihansi Gorge, forest from 1997 to 2018

Scientific Name	Years				Scientific Name	Years			
	1997	2006	2009	2018		1997	2006	2009	2018
Albizia gummifera	0	1	1	0	*Drypetes arguta*	4	10	11	7
Allablanckia stuhlmannii	1	1	1	1	*Drypetes usambarica*	87	91	83	60
Allophylus abyssinica	0	1	1	1	*Englerophytum magalismontanum*	2	3	2	2
Allophylus congolanus	2	1	1	0	*Englerophytum natalense*	53	54	55	57
Antiaris toxicaria	7	6	5	4	*Erythrina abyssinica*	6	7	7	9
Baphia wollastonii	1	1	1	1	*Erythroxylon emarginatum*	6	8	6	5
Bersama abyssinica	0	1	1	1	*Fernandoa magnifica*	1	2	1	1
Blighia unijugata	3	2	3	7	*Ficus cyathystipula*	0	2	0	0
Bombax rhodognaphalon	13	11	10	5	*Ficus exasperata*	1	2	2	2
Bridelia micrantha	0	0	0	0	*Ficus ingens*	1	0	0	0
Brucea tenuifolia	3	3	3	2	*Ficus lutea*	2	2	2	2
Carpolobia goetzei	48	50	49	25	*Ficus sp.*	4	5	4	5
Cassipourea molasana	2	2	2	2	*Ficus sur*	4	4	4	2
Celtis zenkeri	1	2	1	0	*Ficus thonningii*	1	0	0	0
Cephalosphaera usambarensis	109	155	148	99	*Filicium decipiens*	69	51	47	37
Chrysophyllum gorungosanum	3	3	3	3	*Galiniera saxifraga*	0	2	2	1
Chyranthus prieurianus	9	10	9	6	*Garcinia buchananii*	3	4	1	2
Clausena anisata	8	6	6	7	*Garcinia semseii*	76	73	71	52
Clerodendrum schweinfurthii	2	2	1	1	*Haplocoelopsis africana*	1	1	1	3
Coffea sp.	7	2	1	0	*Harungana madagascariensis*	4	9	2	0
Cola discoglypremnophylla	30	18	16	13	*Heinsenia diervilleoides*	1	1	0	0
Cola microcarpa	1	1	0	0	*Isolona heinsenii*	10	10	9	5
Cola scheffleri	1	1	1	1	*Lagynias palidiflora*	24	25	26	27
Cordia monoica	0	1	1	0	*Lasiodiscus usambarensis*	0	1	1	1
Cremaspora triflora	24	27	29	28	*Lecaniodiscus fraxinifolius*	2	2	2	2
Croton macrostachys	1	1	1	1	*Leptactina platyphylla*	2	2	2	1
Cussonia zimmermannii	1	1	1	1	*Leptaulus holstii*	0	4	4	5
Cylicomorpha parviflora	3	1	0	0	*Leptonychia usambarensis*	5	4	5	2
Cynometra sp.	32	40	41	47	*Lettowianthus stellatus*	2	0	0	0
Diospyros greenwayi	3	3	3	3	*Lindackeria bukobensis*	1	0	0	0
Diospyros sp.	16	17	18	13	*Ludia mauritiana*	21	25	26	11
Dracaena laxissima	0	2	2	0	*Macaranga capensis*	0	1	1	1

Appendix 1: continues

Scientific Name	Years				Scientific Name	Years			
	1997	2006	2009	2018		1997	2006	2009	2018
Maesa lanceolata	1	0	0	0	*Psychotria capensis*	5	4	2	1
Manilkara sansibarensis	1	1	1	0	*Psychotria goetzei*	10	7	4	1
Manilkara sanzibarensis	2	2	2	0	*Psychotria megalopus*	16	12	10	4
Margaritaria sp.	0	0	1	1	*Psychotria sp.*	7	3	3	2
Markhamia lutea	1	0	0	0	*Pterocarpus tinctorius*	3	2	2	0
Markhamia obtusifolia	0	0	0	1	*Rauvolfia rosea*	6	7	5	2
Maytenus acuminata	0	1	1	1	*Ricinodendron heudelotii*	1	0	0	0
Maytenus undata	1	0	0	0	*Rinorea ferruginea*	40	39	35	23
Maytenus undatus	2	3	3	1	*Rinorea ilicifolia*	57	61	48	26
Memecylon myrtilloides	2	2	2	2	*Rothmannia urcelliformis*	31	37	33	19
Memecylon cogniauxii	6	6	4	1	*Sorindeia madagascariensis*	70	75	68	73
Memecylon schliebenii	16	18	17	9	*Sphaerocoryne gracilis*	2	0	0	0
Memecylon sp.	0	0	0	8	*Sterculia sp.*	0	1	1	0
Milicia excelsa	1	1	1	1	*Strombosia scheffleri*	58	49	43	29
Millettia oblata	22	21	19	19	*Strophanthus*	0	1	1	0
Mimusops kummel	18	16	15	10	*Strychnos mitis*	3	3	2	1
Monanthotaxis buchananii	1	3	3	1	*Strychnos spinosa*	1	1	1	1
Monodora grandidieri	6	8	7	3	*Synsepalum cerasiferum*	10	11	10	10
Multidentia crassa	4	7	7	1	*Tabernaemontana pachysiphon*	7	9	9	3
Myrianthus arboreus	4	9	9	5	*Tapiphyllum floribundum*	0	0	0	2
Neoboutonia macrocalyx	1	1	1	1	*Teclea nobilis*	9	8	6	7
Newtonia buchananii	2	2	1	1	*Tetrapleura tetraptera*	4	3	2	1
Ochna oxyaphylla	1	2	3	3	*Tricalysia allocalyx*	8	6	6	3
Olax gambecola	0	1	1	1	*Tricalysia pallens*	11	11	11	8
Olea capensis	18	29	40	52	*Tricalysia sp.*	0	0	1	0
Oxyanthus haerdii	3	2	2	0	*Trichilia dregeana*	4	4	4	1
Paramacrolobium coeruleum	1	1	1	1	*Trilepisium madagascariense*	3	4	4	3
Parinari excelsa	5	7	7	3	*Uvariodendron gorgonis*	19	21	19	14
Pavetta pocsii	0	1	3	0	*Vangueria acutiloba*	1	3	2	1
Phyllanthus sepialis	0	0	0	1	*Vangueria infausta*	2	2	2	0
Polysphaeria braunii	8	2	2	0	*Vangueria madagascariensis*	0	1	1	0
Pouteria alnifolia	3	3	2	2	*Vernonia subuligera*	3	0	0	0
Prunus africana	0	1	0	0	*Zanha africana*	1	1	1	1
					Zanthoxylum usambarense	1	2	2	2

Appendix 2: List of tree species in miombo woodlands, Kihansi Gorge, from 1997 to 2018

Scientific Name	Years				Scientific Name	Years			
	1997	2006	2009	2018		1997	2006	2009	2018
Blighia unijugata	1	2	2	2	*Ludia mauritiana*	1	1	1	1
Carpolobia goetzei	8	7	7	0	*Millettia oblata*	12	10	9	7
Chrysophyllum gorungosanum	2	2	2	2	*Monodora grandidieri*	5	4	3	1
Chyranthus prieurianus	3	3	3	2	*Newtonia buchananii*	1	1	2	1
Clerodendrum glabrum	1	1	1	1	*Olea capensis*	2	2	2	2
Coffea sp.	11	4	4	5	*Pavetta pocsii*	0	0	2	1
Cola greenwayi	1	1	1	1	*Pouteria alnifolia*	3	3	3	2
Cola microcarpa	2	2	2	1	*Psychotria goetzei*	1	1	0	0
Combretum sp.	0	1	1	1	*Psychotria megalopus*	1	1	1	1
Cordia monoica	1	2	2	1	*Pterocarpus tinctorius*	3	1	1	1
Cordyla africana	0	0	0	1	*Rhus longipes*	3	3	3	1
Cremaspora triflora	4	5	5	0	*Ricinodendron heudelotii*	1	1	1	0
Diospyros sp.	2	2	2	2	*Rinorea ilicifolia*	28	28	28	24
Dombeya shupangae	0	0	0	0	*Sorindeia madagascariensis*	19	15	16	18
Drypetes usambarica	66	70	69	60	*Synsepalum cerasiferum*	2	2	2	2
Englerophytum natalense	41	39	37	24	*Tapiphyllum burnetii*	2	1	0	0
Ficus lutea	1	1	1	1	*Teclea nobilis*	4	4	3	3
Ficus sp.	3	3	3	2	*Terminalia sambesiaca*	1	1	1	0
Ficus vallis-choudae	3	3	3	2	*Tetrapleura tetraptera*	2	2	2	1
Filicium decipiens	1	1	1	1	Unknown 1	2	2	2	1
Garcinia semseii	39	41	38	39	*Tricalysia acidophylla*	2	1	1	0
Haplocoelopsis africana	3	3	3	2	*Tricalysia allocalyx*	2	3	3	4
Lagynias palidiflora	79	68	47	21	*Tricalysia pallens*	2	2	2	2
Leptonychia usambarensis	0	1	1	1	*Trilepisium madagascariense*	2	3	2	1
Lettowianthus stellatus	1	1	1	1					

Appendix 3: Field data collection form

Category………………Transect No…… Plot no……….... Date……………………….

Tree No.	Local Name	Other Names	Dbh (cm)	Height (m)	Remarks

Appendix 4: Altitudinal species composition at Kihansi Gorge forest. Letters at the end of species represent area where the species is found. H = Higher altitude, M = Middle altitude, L = Lower altitude. Blank species means the species is found in double altitudes that is HM, HL or ML. * indicate globally threatened in EAM and Coastal forest of Tanzania and Kenya

SN	Scientific name	Higher	Middle	Lower
1	*Afzelia quanzensis* [M]	0	3	0
2	*Albizia gummifera* [HML]	1	1	4
3	*Allablanckia stuhlmannii* [H]	1	0	0
4	*Allophylus abyssinica*	1	0	1
5	*Annona senegalensis* [L]	0	0	9
6	*Anthocleista grandiflora* [L]	0	0	1
7	*Antiaris toxicaria* [HML]	5	1	2
8	*Antidesma sp.* [L]	0	0	7
9	*Azanza garckeana* [L]	0	0	2
10	*Baphia wollastonii* [H]	1	0	0
11	*Bersama abyssinica* [HML]	10	2	6
12	*Blighia unijugata* [HML]	29	12	41
13	*Bombax rhodognaphalon* [HML]	13	4	1
14	*Brachystegia microphylla*	0	2	1
15	*Brachystegia sp.* [HML]	6	1	10
16	*Brucea tenuifolia* [H]	2	0	0
17	*Bussea massaiensis*	0	3	17
18	*Canthium luillense* [HML]	8	11	108
19	*Carpodiptera africana* [L]	0	0	2
20	*Carpolobia goetzei* [HML]	224	140	121
21	*Cassipourea molasana* [H]	2	0	0
22	*Celtis gomphophylla* [M]	0	2	0
23	*Cephalosphaera usambarensis* *	34	167	0
24	*Chrysophylum gorungosanum* [H]	1	0	0
25	*Chrysophylum lanceolatum* [HML]	9	16	17
26	*Chyranthus prieurianus* [HML]	8	11	10
27	*Drypetes reticulata*	5	1	0
28	*Drypetes usambarica* [L *]	0	0	1

SN	Scientific name	Higher	Middle	Lower
31	*Clausena anisata* [H]	7	0	0
32	*Clerodendrum glabrum* [L]	0	0	3
33	*Clerodendrum schweinfurthii* [H]	1	0	0
34	*Coffea sp.* [L]	0	0	5
35	*Cola discoglypremnophylla*	12	1	0
36	*Cola greenwayi* [L]	0	0	1
38	*Cola microcarpa* [L]	0	0	1
37	*Cola scheffleri* [M *]	0	1	0
38	*Combretum sp.* [HML]	6	18	43
39	*Cordia monoica* [L]	0	0	3
40	*Cordyla africana* [L]	0	0	1
41	*Cremaspora triflora* [HML]	572	249	81
42	*Croton macrostachys* [H]	3	0	0
43	*Croton scheffleri* [L]	0	0	2
44	*Cussonia zimmermannii* [H]	0	6	2
45	*Cylicomorpha parviflora*	5	0	1
46	*Cynometra sp.* [HML] *	79	29	29
47	*Diospyros abyssinica*	1	0	0
48	*Diospyros greenwayi* *	19	3	0
49	*Diospyros mespiliformis* [L]	0	0	1
50	*Diospyros sp.* [HML]	21	5	31
51	*Diospyros whyteana* [L]	0	0	1
52	*Diplorhynchus condylocarpon* [L]	0	0	24
53	*Dracaena steudneri*	1	3	0
54	*Drypetes arguta*	5	2	0
55	*Drypetes natalensis* [L]	0	0	5
56	*Khaya anthotheca*	1	1	0
57	*Kigelia africana*	0	5	18

SN	Scientific name	Higher	Middle	Lower
29	*Drypetes usambarica* HML	28	41	61
30	*Ehretia cymosa* L	0	0	35
60	*Ekebergia benguelensis* L	0	0	1
61	*Englerophytum magalismontanum* H	2	0	0
62	*Englerophytum natalense* HML	266	216	211
63	*Erythrina abyssinica* H	9	0	0
64	*Erythrococca atrovirens* L	0	0	37
65	*Erythroxylon emarginatum* HML	5	9	7
66	*Fagoropsis angolensis* L	0	0	9
67	*Fernandoa magnifica* M	0	1	0
68	*Ficus exasperate* H	2	0	0
69	*Ficus lutea*	2	0	1
70	*Ficus sp.* HML	11	62	120
71	*Ficus stuhlmannii*	0	5	8
72	*Ficus sur* H	2	0	0
73	*Ficus vallis-choudae* L	0	0	2
74	*Filicium decipiens* HML	80	34	5
75	*Flacourtia indica* L	0	0	5
76	*Galiniera saxifraga* H	1	0	0
77	*Garcinia buchananii* HML	10	2	2
78	*Garcinia semseii* HML *	137	174	111
79	*Hallea rubrostipulata*	0	1	17
77	*Haplocoelopsis Africana* HML	13	2	7
78	*Haplocoelum inoploeum* L	0	0	1
79	*Isolona heinsenii* *	4	1	0
80	*Multidentia crassa* H	1	0	0
81	*Myrianthus arboreus* H	5	0	0
82	*Myrianthus holstii* L	0	0	1
83	*Neoboutonia macrocalyx* H	4	0	0
84	*Newtonia buchananii* HML	2	8	7
85	*Ochna oxyaphylla* H	3	0	0
86	*Ocotea usambarensis*	0	1	4
87	*Olax gambecola* H	1	0	0
88	*Olea capensis* HML	178	29	28
89	*Olea europea- ssp curpidata* M	0	1	0

SN	Scientific name	Higher	Middle	Lower
58	*Lagynias palidiflora* HML	134	121	31
59	*Lannea stuhlmannii* L	0	0	1
91	*Lasiodiscus usambarensis* H	1	0	0
92	*Lecaniodiscus fraxinifolius* M	0	2	0
93	*Leptactina platyphylla* M *	0	1	0
94	*Leptaulus holstii*	5	1	0
95	*Leptonychia usambarensis* HML	2	1	4
96	*Lettowianthus stellatus* L	0	0	1
97	*Lonchocarpus sp.*	0	5	2
98	*Ludia mauritiana* HML	10	1	1
99	*Macaranga capensis* H	1	0	0
100	*Macaranga Kilimandscharica* L	0	0	16
101	*Margaritaria sp.* HML	8	34	28
102	*Markhamia obtusifolia* HML	2	4	8
103	*Maytenus acuminata*	9	8	0
104	*Maytenus undatus* H	1	0	0
105	*Memecylon myrtilloides*	2	0	0
106	*Memecylon cogniauxii* H *	1	0	0
107	*Memecylon schliebenii* H	6	3	0
108	*Memecylon sp.*	10	1	0
109	*Milicia excelsa* HML	1	3	20
110	*Millettia oblata* HML *	111	171	285
111	*Mimusops kummel* HML	12	11	9
112	*Monanthotaxis buchananii* H	1	0	0
113	*Monodora grandidieri* HML	12	35	17
114	*Psychotria megalopus*	4	0	1
115	*Psychotria sp.* HML	4	3	2
116	*Pterocarpus angolensis* L	0	0	5
117	*Pterocarpus tinctorius* L	0	0	1
118	*Rapanea pulchra* L	0	0	1
119	*Rauvolfia rosea*	2	0	4
120	*Rhus longipes*	0	4	19
121	*Rinorea ferruginea* H	23	0	0
122	*Rinorea ilicifolia*	24	0	25
123	*Ritcheia albersii* H	2	0	0

SN	Scientific name	Higher	Middle	Lower	SN	Scientific name	Higher	Middle	Lower
90	*Olinia rochetiana* [L]	0	0	1	124	*Rothmannia macrosiphon* [L *]	0	0	1
91	*Pappea capensis* [L]	0	0	2	125	*Rothmannia urcelliformis* [HML]	15	19	15
125	*Paramacrolobium coeruleum* [M]	0	1	0	146	*Scolopia zeyheri* [HML]	4	19	18
126	*Parinari excelsa* [HML]	11	1	5	147	*Sorindeia madagascariensis* [HML]	148	116	181
127	*Pavetta pocsii* [L]	0	0	1	148	*Strombosia scheffleri*	24	5	0
128	*Phyllanthus reticulatus*	0	3	13	149	*Strychnos mitis* [M]	0	1	0
129	*Phyllanthus sepialis* [HML]	1	2	7	150	*Strychnos spinosa* [H]	1	0	0
130	*Podocarpus milanjianus* [M]	0	5	0	151	*Synsepalum cerasiferum* [HML]	59	35	21
131	*Polyathia oliveri* [HML]	1	14	18	152	*Syzygium cordatum* [HML *]	4	4	20
132	*Polyscias fulva* [M]	0	3	0	153	*Tabernaemontana pachysiphon*	8	2	0
133	*Pouteria alnifolia* [HML *]	1	1	2	154	*Tapiphyllum floribundum* [H]	2	0	0
134	*Pseudolachnostylis maprouneifolia* [L]	0	0	5	161	*Teclea nobilis* [HML]	53	33	57
135	*Psidium guajava*	0	1	7	162	*Teclea trichocarpa* [M]	0	2	0
136	*Psorospernum febrifugum* [L]	0	0	1	163	*Terminalia sambesiaca*	0	4	4
137	*Psychotria capensis* [H]	1	0	0	164	*Terminalia sericea* [L]	0	0	3
138	*Psychotria goetzei* [H]	1	0	0	165	*Tetrapleura tetraptera*	1	0	1
139	*Psychotria mahonii* [L]	0	0	1	166	*Uvariodendron gorgonis* [HML]	15	1	2
140	*Thespesia garckeana* [M]	0	3	0	167	*Vangueria acutiloba* [H]	1	0	0
141	*Tricalysia allocalyx*	0	3	4	168	*Vangueria infausta*	0	1	28
142	*Tricalysia pallens*	8	0	2	169	*Vernonia subuligera*	5	0	12
143	*Trichilia dregeana* [M]	0	1	0	170	*Zanha africana* [HML]	5	11	6
144	*Trilepisium madagascariense* [HML]	10	13	12	171	*Zanthoxylum chalybeum* [L]	0	0	12
145	*Turraea stuhlmanni* [L]	0	0	1	172	*Zanthoxylum usambarense*	2	1	0
146	*Scolopia stolzii* [L]	0	0	3	**Total**		**2628**	**2001**	**2240**