MSc in Biodiversity Conservation and Natural Resources Management

EVALUATION OF SOIL MACRONUTRIENTS, TREES BIOMASS AND VEGETATION VARIATION ALONG ALTITUDINAL GRADIENT IN TROPICAL MONTANE FOREST.

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Declaration

I, Germaine HIRWA with reference number 217240771 declare that the research Project entitled: "**EVALUATION OF SOIL MACRONUTRIENTS, TREES BIOMASS AND VEGETATION VARIATION ALONG ALTITUDINAL GRADIENT IN TROPICAL MONTANE FOREST**" is the result of my own work and has not been submitted for any other degree at the University of Rwanda or any other institution.

Germaine HIRWA

Signature..................Date................

Declaration from the main supervisor that He is approving the submission of dissertation

Prof. Elias BIZURU

Signature……………….Date………..

Dedication

To my lovely family, friends, supervisors, mentors I dedicate this dissertation. Without your love, encouragement, affection and moral support, this work could not be accomplished.

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ABSTRACT

Soil nutrients are predominant elements determining the status of biomass. Shortage of soil nutrients can result in severe low forest productivity, plant regeneration, decrease in tree species distribution and biodiversity shortage. Nyungwe is considered as the most important site for biodiversity in Rwanda, it is considered also as one of the big preserved central African rainforests. A lot of studies have been conducted in Nyungwe forest but the variation of soil nutrients along different altitude were not investigated yet. Understanding the variation in nutrients status and nutrient dynamics along altitudinal gradients in Nyungwe forest shall improve our understanding about spatial distribution of biomass and shall also enhance our ability to predict how terrestrial ecosystems will respond to global warming. The distribution of vegetation along Nyungwe vegetation can be assumed to be affected by soil nutrient variation in addition to chemical variables. The Current study is investigating soil nutrients content and spacial distribution of biomass along elevation gradient in Nyungwe forest. Twelve permanent Sample plots of (50x50m) were established in three altitudinal locations (Karamba 1900m, Uwagashihe 2500m, Bigugu 2700m) randomly. The density and richness of trees together with their DBH were quantified and correlated to soil nutrients status experimented in laboratory. The soil texture showed that the more you increase in altitude the texture change. Karamba is generalized by silt clay, Uwagashihe has sandy loam and where Bigugu is characterized by sand clay. Soil macronutrients (N, P and K) vary with altitudinal gradient in Nyungwe forest but with low significance. The results showed that with increasing the altitude total TN increased. The results from DBH measurement > 10cm from different plots in three sites along elevation gradients were taken. More you get in high altitude the more tree species differs, decreased in numbers and biomass. Plant communities change with respective altitude: *Syzygium guineense* ssp. *Parvifolium* and *Bridelia bridelifolia* at 1900m, *Macaranga kilimandscharica* and *Ocotea kenyensis* at 2500m, and *Podocarpus latifolius* and *Syzygium guineense* ssp. *Parvifolium* at +2700m.

Keywords: Biomass, plant vegetation, Nyungwe forest, Soil nutrients.

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1.0 GENERAL INTRODUCTION

1.1 Background

The study of quantity and quality of vegetation provides all prerequisites to understand the overall structure and function of any ecosystem (Kate A. Brauman et al.,2007). With the purpose to perform productive conservation and effective management, several studies have been conducted on plant species composition and diversity (Sudam, et al.2019; Andel, 2001, Nobel et al, 2001). The contribution of tropical forest to the global biodiversity is widely acknowledged. However, most of these forests are threatened by huge anthropogenic disturbances, which require interactive interventions in management to retain overall biodiversity for sustainability of natural ecosystem (Kumar et al., 2006). Among tropical forest, Nyungwe is considered as the most important site for biodiversity in Rwanda. Extensive studies have been conducted in Nyungwe forest but the correlation of soil nutrients with special distribution of vegetation along different altitude were not investigated yet. The vegetation of any place is the results of interaction of various factors such as soil composition, gradient mesotopographic, elevation, species composition and biotic interferences (Sudam Charan Sahu et al., 2019).

The distribution of vegetation along Nyungwe forest can be assumed to be affected by soil nutrient variation in addition to chemical variables. Transformation of forest to grassland results in the reduction of soil nutrients and organic carbon (Laurance et al., 1999). Soil genesis and its composition are influenced with the variation in elevation and climate ((Sudam Charan Sahu et al., 2019).). Current study is aiming to investigating the correlation between soil nutrients and spatial distribution of biomass along elevation Gradient in Nyungwe forest while also assessing the vegetation variation along altitudinal gradient.

1.2 Main objective

The main objective of this research is to evaluate the soil macro nutrients content biomass distribution and vegetation variation along elevation gradient in Nyungwe forest.

1.3 Specific objectives

To determine the concentration of soil macro nutrients at different altitudinal gradients, to evaluate the correlation between the spatial distributions of biomass aligned with soil nutrients along elevation in tropical montane forest and to evaluate the vegetation variation along altitudinal gradient.

1.4 Hypothesis

The hypothesis was verified. Because this study showed that the soil macronutrients are there in Nyungwe forest, the correlation between soil and biomass distribution has low significance value and vegetation varied clearly on different altitudinal gradient.

2.0 LITERATURE REVIEW

Extensive research on the relationship between soil nutrients, gradient and aboveground biomass have been conducted and the yielded results are well documented. Recent literature review is highlighting the documented findings on various soils nutrients and their relationship with the spatial distribution of above ground biomass along elevation and the vegetation variation along elevation gradient in tropical montane forest.

2.1 Tropical forest

A meaning of tropical forest implies its components; tropical, geographic aspect or climatic and forest as land cover type. The word tropical indicates the geographic location between the tropic of Capricorn, that of Cancer and tropical belt. On other hand the Climatic characterization designates the region where certain long-term meteorological conditions are fulfilled (Pascal et al., 2016). By definition, 'the tropics' lie between 238N and 238S latitude, the place where the sun lies directly overhead at some point in its seasonal progression. In this area the flux of solar energy is high due to incoming sunlight which is perpendicular to the earth surface (J. Pokorný et al., 2010). Referring to cover to the land cover type a number of definitions of forest is available in the literature; forest is a land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ (FAO, 2005). It does not include land that is predominantly under agricultural or urban land use. According to Food and Agriculture Organization, Global forest Resources Assessment in 2015 tropical forest covers 44% of the global forest area.

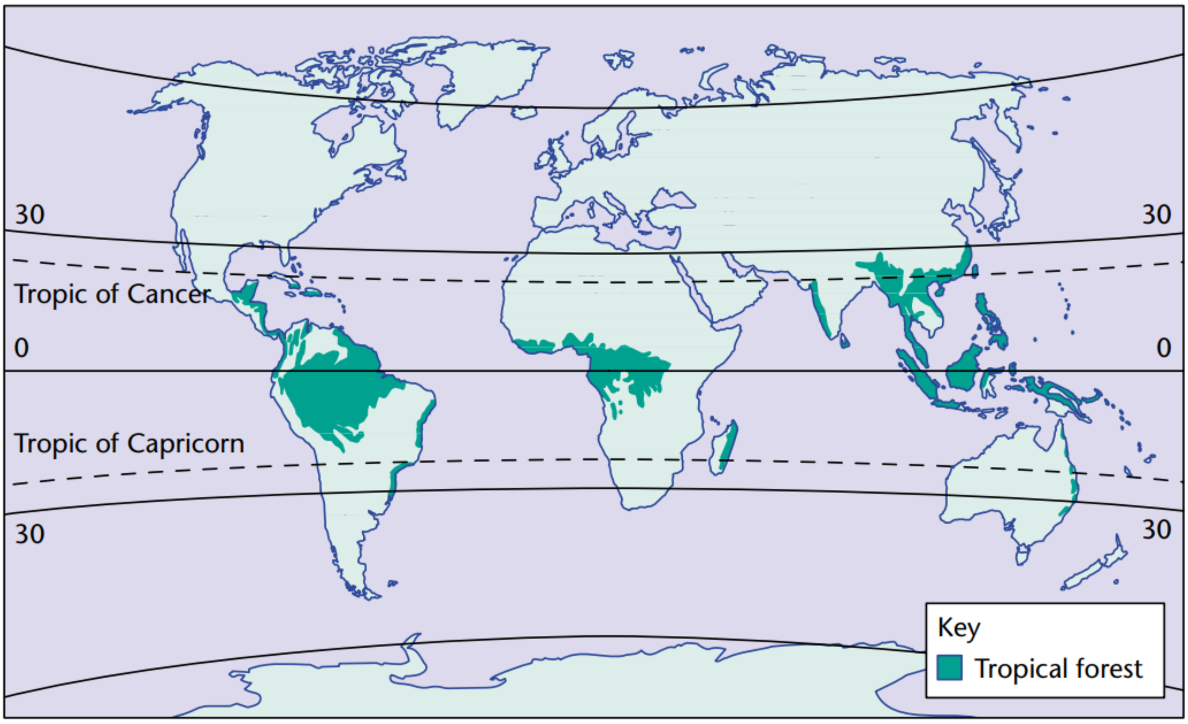

Figure 1. Global distribution of tropical forests (adapted from Sean et al, 2002).

The major value of tropical forests is their Biodiversity. Gardener et al. (2010), estimated the tropical forest species to lay between one-half to two-thirds of the Earth's terrestrial biodiversity. While Sean et al. (2002), estimate it over half of all the species on the planet. Tropical forest trees is estimated to lay between 40,000 to 53,000 (Slik et al.,2015). The additional value of Tropical forest is further heightened by its ecosystem services. The latter is the direct and indirect contributions of ecosystems that benefit human wellbeing. Generally, the services ecosystems provided are the supporting services, provisioning services, regulating services and cultural services. An example of the regulating services provided by Tropical forest on local and global level is the climate regulation via carbon sequestration. Regardless of the positive services delivered by the tropical forest, there is noticeable decrease of the tropic forest area from 1966 M ha in 1990 to 1770 M ha in 2015 as declared by (Keenan et al., 2015). In addition, the tropical forest is getting undermined by forest degradation which is difficult to quantify but is also responsible for most of biodiversity and carbon stock losses. Tropical forests have therefore received attention both for their high importance in biodiversity and the speed at which they are being destroyed.

Tropical forest is subdivided into two parts with respect to the altitude; Tropical lowland forest and tropical montane forest (Fjeldså Jon et al., 2011).

The latter is poorly researched compared to lowland tropical forest (Bubb et al., 2004). Malhi et al. (2010) investigated the major reasons for investing effort in conducting research on the tropical montane forests. Tropical elevations are the proper sites for better understanding past climate change in the tropics and tropical mountains are potentials arks in a century of rapid warming. In addition, environmental responses to global change drivers in Tropical mountain forests may show in advance what will happen on the World's ecosystems (González et al.,2013). The important characteristic of Mountain forest is the altitudinal zonation. The latter is classified with respect to various elements, but the most obvious recurrent distinction is the elevation. Most of Climatic factors such as humidity, temperature, incoming solar radiation and the presence and frequency of clouds and fog are influenced by elevation. And these factors are in its turn responsible for a lot of botanical characteristics of the forest. Altitudinal zonation phenomenon indicates the variation of vegetation zones along the elevation. Ashton, 2003 provided four general forest zones on tropical mountain; lowland, lower montane, upper montane and subalpine. The dependence on altitude of some physiognomic or structural features such as the tree height and leaf size, are quite straightforward whereas others such as the number of strata (vegetation layers) are much more discussable (Pascal et al., 2016).

Table 1.Characters of structure and physiognomy of the four general altitudinal forest zones (adopted from Ashton (2003)

Formation	Tropical lowland evergreen rain forest	Tropical lower montane rain forest	Tropical upper montane rain forest	Tropical sub-alpine forest
Canopy height, emergent trees	24-45m	15-33m	1.5-18m	1.5-9(15)m
Number of strata	3	2	1	(1)
Principal leaf size- class of woody plants	Mesophyll	Notophyll	Microphyll	Nanophyll
Pinnate leaves	Frequent	Rare	Very rare	Very rare
Buttresses	Usually frequent& large	Uncommon or small	Usual absent	None
Cauliflory	Frequent	Rare	Absent	(Absent)
woody climbers	Abundant	Usually none	None	None
Bole climbers	Often abundant	Frequent to abundant	Very few	Few
Vascular epiphytes	Frequent	Abundant	Frequent	Frequent
Non- vascular epiphytes	Occasional	Occasional to abundant	Often abundant	Abundant

Other factors such as rainfall and edaphic soils conditions can be of major importance as well. Soil conditions and altitudinal nutrient shifts possibly responsible for vegetation changes as discussed.

The decrease of above ground biomass and tree stature with increasing altitude in tropical montane forests is poorly understood and many researchers have provided various explanations for low growth and stature trees at high altitude: Bruijnzeel et al. 1998 attributed this to low photosynthesis due to persistent cloudiness and thus low radiation input while Kitayama and Aiba 2002 attribute this to low temperatures. Other reasons provided in the literature are; direct impact of low temperatures on growth (Hoch&Korner 2003); exposure to strong winds (Timothy J. Fahey et al., 2016).

Low nutrient availability due to water-saturated soils, low temperatures and high concentrations of phenolic compounds in soils leading to low decomposition and mineralization rates (Bruijnzeel et al. 1993, Edwards & Grubb 1977, Tanner et al. 1998); low nutrient uptake capacity due to reduced root respiration or transpiration (Bruijnzeel & Veneklaas 1998)

2.2 Soil nutrients

Soil nutrients are important elements that support plant growth and crop productivity (Rusell, 1973). The availability of soil nutrient for macro and micro remains essential in ensuring sustained plants growth (Kumar et al., 2016).

2.2.1 Macronutrients

The essential macronutrients N, P, potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) are involved in numerous metabolic processes and are crucial for plant growth and development of biomass (Drollinger et al.,2017). Generally, macronutrients, required in large quantities, are the focus of many interventions, unlike micronutrients that are required in small quantities (Mowo et al., 1993).

2.2.2 Micronutrients

Soil micronutrients are important elements for plant growth despite being required in small quantities (Mathayo et al., 2016).

Table 2. Nutrients content distribution in different forest ecosystem (Foster and Bhatti, 2006).

	Vegetation(Mg/ha)	Forest floor (Mg/ha)	soil (Mg/ha)	Residence time/Year
Nitrogen				
Boreal coniferous	0.3-0.5	0.6-1.1	0.7-2.87	200
Temperate deciduous	0.1-1.2	0.2-1.0	2.0-9.45	6
Tropical rain forest	1.0-4.0	0.03-0.05	5.0-19.2	0.6
Phosphorus				
Boreal coniferous	0.033-0.060	0.075-0.15	0.04-1.06	300
Temperate deciduous	0.060.08	0.20-0.10	0.91-1.68	6
Tropical rain forest	0,2-0.3	0.001-0.005	0.06-7.2	0.6
Potassium				
Boreal coniferous	0.15-0.35	0.3-0.75	0.07-0.8	100
Temperate deciduous	0.3-0.6	0.050-0.15	0.01-38	1
Tropical rain forest	2,0-3.5	0.020-0.040	0.05-71	0.2

2.3 Albertine rift montane forests

The Albertine Rift's unique beautiful landscapes, biodiversity and diversity of its people make it one of the most attractive transboundary ecosystems in East Africa and in the world. According to World Wildlife Fund (WWF) The area is a priority ecoregion and it supports many endangered species such as the mountain gorilla (Gorilla beringei) and the eastern lowland gorilla (Gorilla beringei graueri). The Albertine rift is amongst the most important regions for conservation in Africa due to its highest number of vertebrate species on the African continent (Plumptre et al., 2007). Rwanda is covering 6% of these Afromontane forests. Given that the region is one of the most densely populated areas in Africa and therefore suffers from a high degree of direct and indirect threats to the entire ecosystem, such as unsustainable timber extraction, general forest clearance and conversion to agricultural land, grazing, hunting and firewood collection (WWF, 2011).

Table 3. Top priority sites for conservation in the Albertine Rift based upon the paper by Plumptre et al. (2007); NP=National Park

Priority site	Country
Virunga NP	Democratic Republic of Congo
Itombwe Massif	Democratic Republic of Congo
Kahuzi Biega NP	Democratic Republic of Congo
Nyungwe NP	Rwanda
Bwindi Impenetrable NP	Uganda

2.4 Soil Nutrients and Gradients

The common responses of nutrient status to changes in altitude across different regions are generally thought to be driven by changes in temperature with altitude (Sundqvist, et al.1998). Precipitation affects soil nutrient availability through its influence on erosion and nutrient cycling (Eric C. Brevik, 2013).

Additional research is needed to clarify how the nutrient status of key ecosystem components responds to altitude gradients, because such studies can help us understand how changes in climate may alter nutrient cycling and ultimately plant growth.

In tropical regions some findings are showing that foliar and litter nitrogen (N) together with foliar and litter Phosphorus (P) concentrations decrease with the increase in altitude (Sundqvist et al.1998). The studies are attributing the limited development of plants in high montane forest to lack of N in the humid tropical Peruvian Andes (Fisher et al.,2013). Nathalie et al., 2008 investigated the nutrients availability at different altitudes in tropical montane forest in Ecuador and found that N, P and K, increased markedly with increasing altitude in this tropical montane forest

The Stocks of extractable nutrients in different depths of mineral soil at three altitudes, Nathalie et al., 2008 have described how the major nutrients N, P and K differs in the soil. The Nitrogen (N) vary with altitude, it was high at 1900m low at 2400m then increased again at 3000m. The Phosphorus (P) increased with increasing altitude the same as Potassium (K).

However, Van de Weg et al.,2011 and Giesler et al., 2011 noticed a lack of significant change or even an increase in foliar and/or litter N concentrations along altitudinal gradients.

Martin et al., 2015 studied the correlation between soil fertility and plant biodiversity in tropical forest and their findings are that tree species richness of pristine tropical forests decrease as K and P increased. According to Gary et al., 2008 soil P and K are the measure candidate nutrients limiting the density of emergent trees.

3. METHODOLOGY

3.1 Description of the study area

This research was conducted in the Nyungwe Forest in south-western of Rwanda (2°15′–2°55′S, 29°00′–29°30′E), part of the Albertine Rift montane forests ecoregion. Nyungwe is one of the biologically most important montane rainforests in central Africa, Elevations range from 1600 to 2950 m above sea level and the forest has diverse topography (Figure 1). Annual rainfall in Nyungwe is between 1800 and 2500 mm, with a major dry season in July–August and a minor dry season in December–January, and the mean annual temperature is 15 to 17°C (Rutting et al., 2015). Samples were taken at Bigugu (Nyamasheke district) located at +2700m altitude, Uwagashihe (Nyamagabe district) 2500m and Karamba (Nyamasheke district) 1900m.

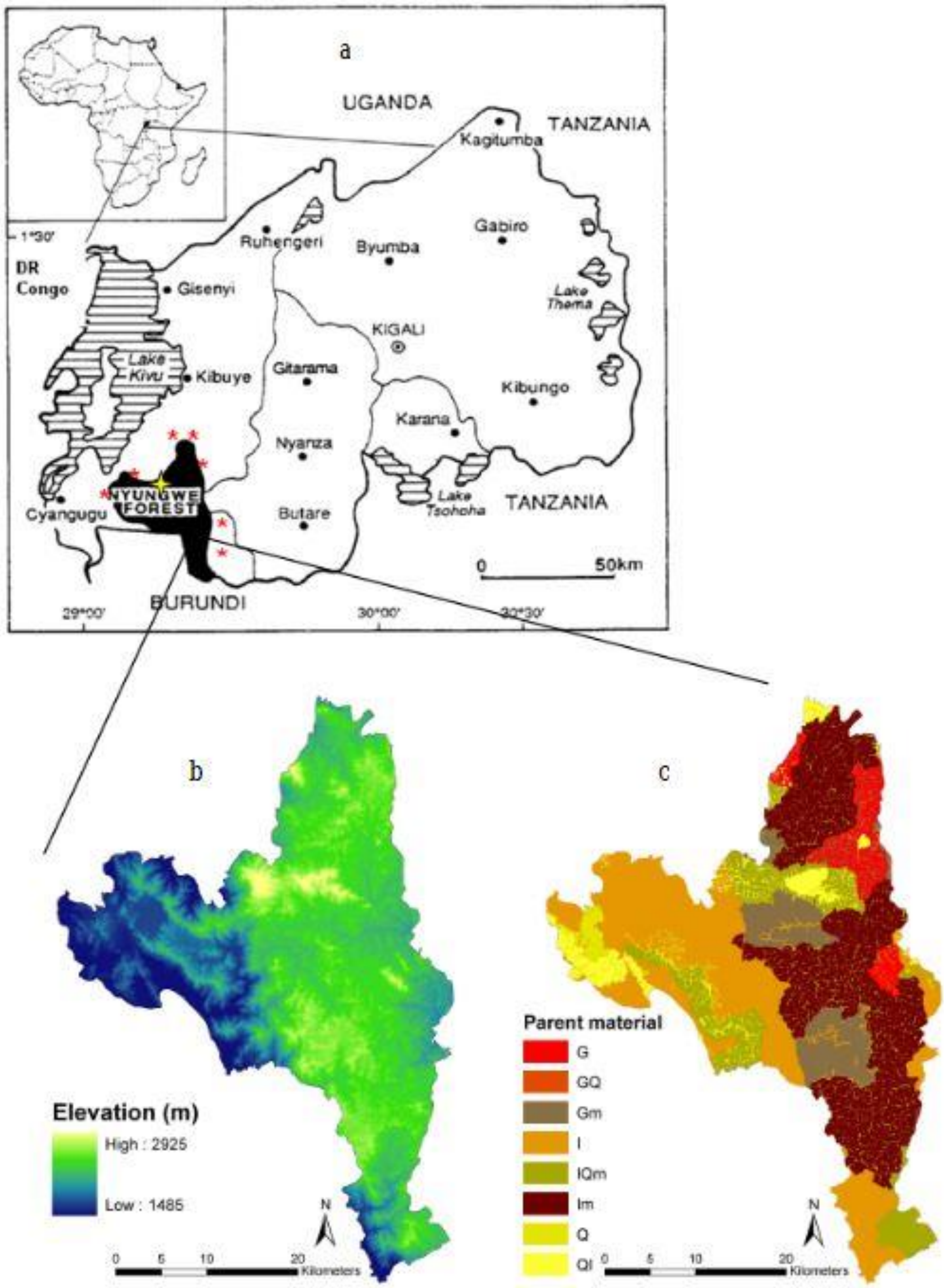

Figure 2. Location of Nyungwe forest in Southwestern Rwanda.

Seven climate stations around the forest are shown by red stars; the recent climate station in the Nyungwe forest is shown by a yellow star (a), elevation map (b) and parent material map of the Nyungwe forest: Q = quartzite; QI = quartzite intercalated with schists; IQm = quartzite intercalated with micaschists; GQ = granitic and quartzitic rocks; G = acid rocks (granite); Gm = micaceous acid rocks (granitoide); Im = micaschists; I = schists (Figure adopted from Gharahi Ghehi et al. (2012))

3.2 Research equipment and sampling procedures

Hand driven auger (soil probe) to drill in order to get soil samples, we drilled into 21cm of depth, Plastic bags helped to pack the soil samples. To clean up the auger for next plot we used brush to clean sampling tools after every sample collection, Labels includes samples collection dates, Field location, contact of laboratory. After labelling the soil samples were carried in appropriate bags. GPS for locating sites, altitude gradient and plots. As the aim of this project was also to measure and evaluate plant diversity, Calibrated diameter tape (d-tape) to measure the Diameter at Breast Height (DBH > 10cm) and plant of Nyungwe book helped us to verify species scientific name and local names. Reader field protocol to identify soil texture

Twelve plots were established for 800m long preselected transect running from 1900 to 2700 m; four plots in the upland at Bigugu, four in the midland at Uwagashihe, and four in the lowland at Karamba and five soil samples were taken at each plot from all those plots at each site. Samples were taken at the depth from 5-26cm from top soil, to mean that the samples were taken from 21cm of length per each. Auger and sampling plate were used to dig soil samples in randomized quadrates plot of 50m by 50m each (see figure 3) at all three sites chosen. Climate, temperature and precipitation variables were described as the influence to soil nutrients because they help the movement of soil particles into soil and facilitate their cycling and transmission in plant to facilitate plant growth (K.Tamai, 2010). The methodology used to evaluate and study the distribution of biomass aligned with soil nutrients was harmonized with reference to biomass data existed and to the new findings on the field using observation method.

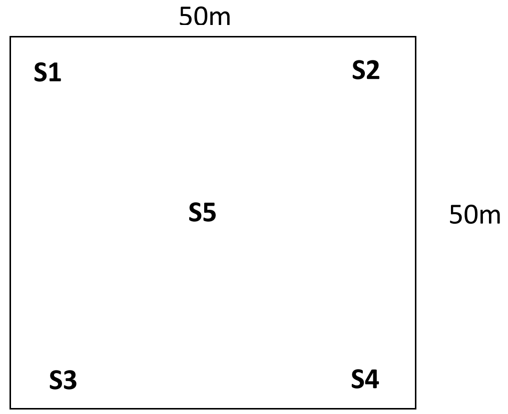

Figure 3. Plot where samples were taken; S=Sample (Sample one to sample five) and plant identification was done in the same plot size together with DBH

3.4 Laboratory soil test

The soil nutrients analysis was conducted in the chemical laboratory located in the University of Rwanda, Nyarugenge campus. The lab materials and protocols used were available for experimentation and determination of major macronutrients like soluble Phosphorus (P), Nitrogen (N) and Potassium (K) were examined. The laboratory test included also the analysis of availability of Soil physics; texture: sand, silt, clay differences along Nyungwe elevation using field protocol soil test. Soil experiment was conducted using a working manual, the second edition by J.Robert Okalebo et al., 2002. Sixty soil samples from all sites each one with around 500g were well conserved in the lab. Twenty samples from each site were mixed going to the resemblance of plot numbers. For example for Bigugu site, we took five samples from each plot, 100g of soil were weighted 100g from each plot and mix plot one by taking sample one, two, three, four and five ,we had in total 500g in order to get one sample which represent the whole plot. The representation plots soil samples were dried in oven at 70^{o}C for about five hours.

Total Nitrogen and total Phosphorus: the content of TN and TP was experimented in a digest obtained by treating soil sample with hydrogen peroxide (H_2O_2), Sulphuric acid (H_2SO_4), Selenium (Se) and Salicylic acid ($C_7H_6O_3$). The principle takes into account the possible omission of nitrates by coupling them with salicylic acid in an acid media to form 3-nitrosalicylic or 4- nitrosalicylic ($C_7H_5NO_5$). The compounds are reduced to their corresponding amino acid forms by the soil organic matter. The analysis of total nutrients requires complete oxidation of organic matter.

The hydrogen peroxide oxidises the organic matter while the selenium compound acts as catalyst for the process and the sulphuric acid completes the digestion at elevated temperatures 400^{o}C using an electric hot plate and conical flasks for digestion. The Principe here is that in laboratory where no block digester is available, one alternative is to carry out wet sample digestion using suitable Pyrex glassware on an electric hot plate in a fume hood.

0.3 g of dry soil sample from each plot and each site was weigh in a 125ml conical flask, 4ml of Sulphuric acid were added and we swirl the flask careful to make sure that the entire sample is wetted. The next steps were alternatively hitting and cooling (J. Okalebo et al., 2002). The solution we used to determine N and P was the digested cooled and transferred into 50ml volumetric flask, using distilled water.

K (potassium), In 1:2 soil water extract, 25 mg of soil were weighed in a 100ml beaker add 50ml of distilled water, use a control shaker IKA ® KS 130 in order to mix well the solution, thirty minutes each in conical flask shaker. To facilitate the read of Potassium concentration three standards were prepared: Sodium chloride AR, Potassium nitrate LR and concentrated Sulphuric acid (J. Okalebo et al., 2002).

3.3 Plant species identification

To identify plant, we have used the famous method of analyzing the structure of the tree species on the field. Looking the steam color shape and size, leaves shape and their position on the steam all helped to describe which family and specie to categorize those trees.

Morphological characteristics of tree species shown in drawings of G. Troupin 1982" Flore of Rwanda", contributed much in this research. We have used the revised book published in 2009 of U. Bloesch, G. Troupin+ & N.Derungs "Les plantes ligneuses du Rwanda" helped us to identify tree species diversity in Nyungwe forest together with the "Illustrated Field guide to the plants of Nyungwe National Park Rwanda" written by Prof. Eberhard Fischer and Dr. Dorothee Killmann.

3.4 Data analysis

The statistical analyses of all data from plots was conducted using Multivariate Statistical Package (MVSP) and excel. We analysed Plant diversity communities, Biomass distribution and nutrients content along altitudinal gradient in Nyungwe forest. The results are shown and interpreted in this study.

4. RESULTS AND DISCUSSION

4.1 Soil nutrients content, spatial distribution of biomass and plant diversity communities along elevation gradient in Nyungwe forest.

4.1.1 Soil Nutrients content along elevation gradient in Nyungwe forest

Evaluation of macronutrients (N, P, and K) content in altitudinal gradient in Nyungwe forest was analysed and the results are shown here below.

Total Nitrogen content in Soil

The calculations of TN content in the soil (see in appendix Table 8) shows that the more the altitude increase the TN increase too. Karamba site (1900m) is seen to have a low concentration of TN than two other sites. The concentration of TN content in the soil is increasing with altitude as shown in figure 4.

The low concentration of TN at Karamba may be coming from the disturbance or the presence of a young forest there. The nutrients content in the soil is resulting in organic matter which is low at karamba than Uwagashihe and Bigugu sites.

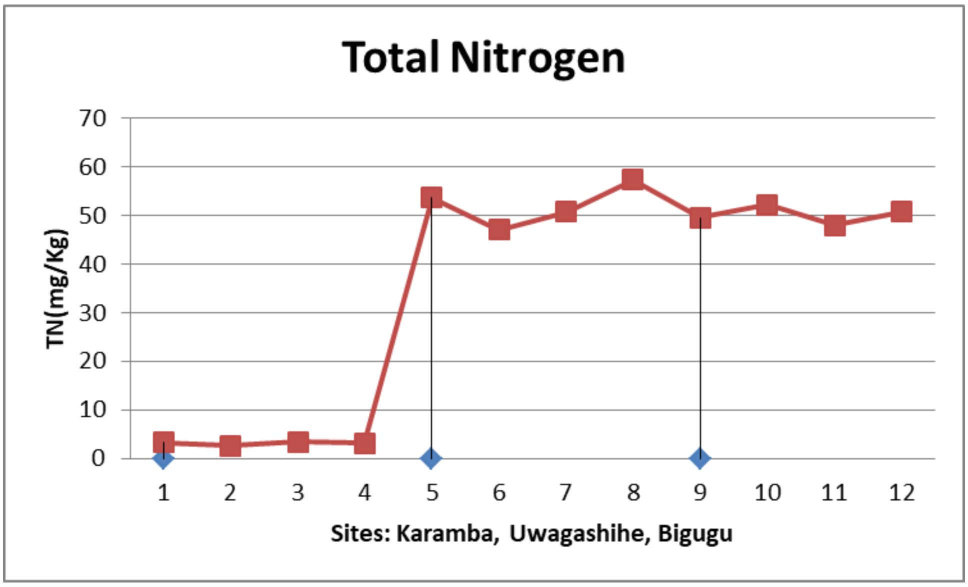

Figure 4. TN along altitudinal gradient in Nyungwe forest

Total Phosphorus content in Soil

The concentration of Total Phosphorus in the soil was interesting because the calculations did not increase or decrease with a significance difference, but neither they were not equal at all sites as shown in appendix table 9.

The figure 5 is showing how the trend of TP tends to be linear. TP is not changing with altitude. Phosphorus is known to play a role in making important biological molecules like ATP, DNA and RNA.

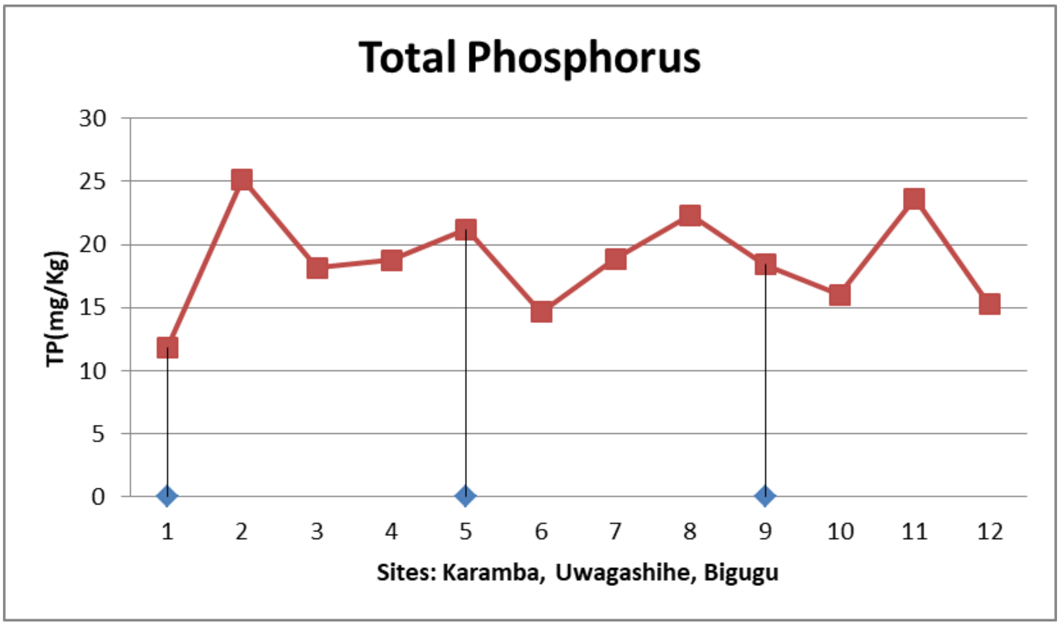

Figure 5. Concentration of Total Phosphorus in Soil

Potassium content along elevation gradient

Potassium concentration in the soil is represented in appendix table 10. The calculations indicated that low altitude (1900m) has a low concentration of Potassium equal to (8.5, 11.5,8.5 and 11.5) mg/kg for four plots at Karamba. The more we increase in altitude potassium content increase too. In tropical soil nutrient cycling K is playing a role of water uptake, photosynthesis and respiration.

The more altitude increase the trend of potassium concentration in the soil is increasing as shown in figure 6. Bigugu is very rich in Potassium(K) content in the soil than Karamba site.

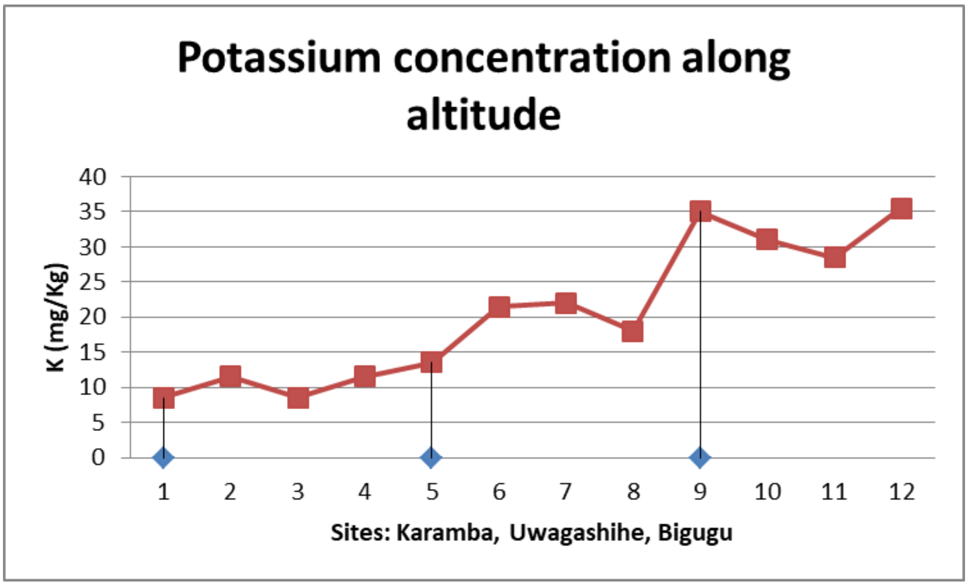

Figure 6. Concentration of Potassium in the soil

4.2 Biomass along elevation gradient in Nyungwe forest

The Diameter at Breast Height (DBH) > 10cm was measured in three different altitudinal gradient in Nyungwe forest together with the canopy cover we have been able to present the spatial distribution of biomass here below as follow:

Karamba site (1900m) has high rate of biomass distribution (Figure 7) more than two other site with high altitude, Uwagashihe (2500m) and Bigugu (2700m). However, 1900m of altitude found to have young trees of (10-20) cm of DBH measurement than other DBH class intervals. The results show that, we have 51% of trees species are between 10cm and 20cm of DBH, 24.8% of trees species are between 20cm to 30cm followed by 8.1% of trees species from 30cm to 40cm and then 6.7% are from 50cm to 60cm; the lowest percentage of 0.7% are from trees species of 70cm to 80cm of DBH measurement.

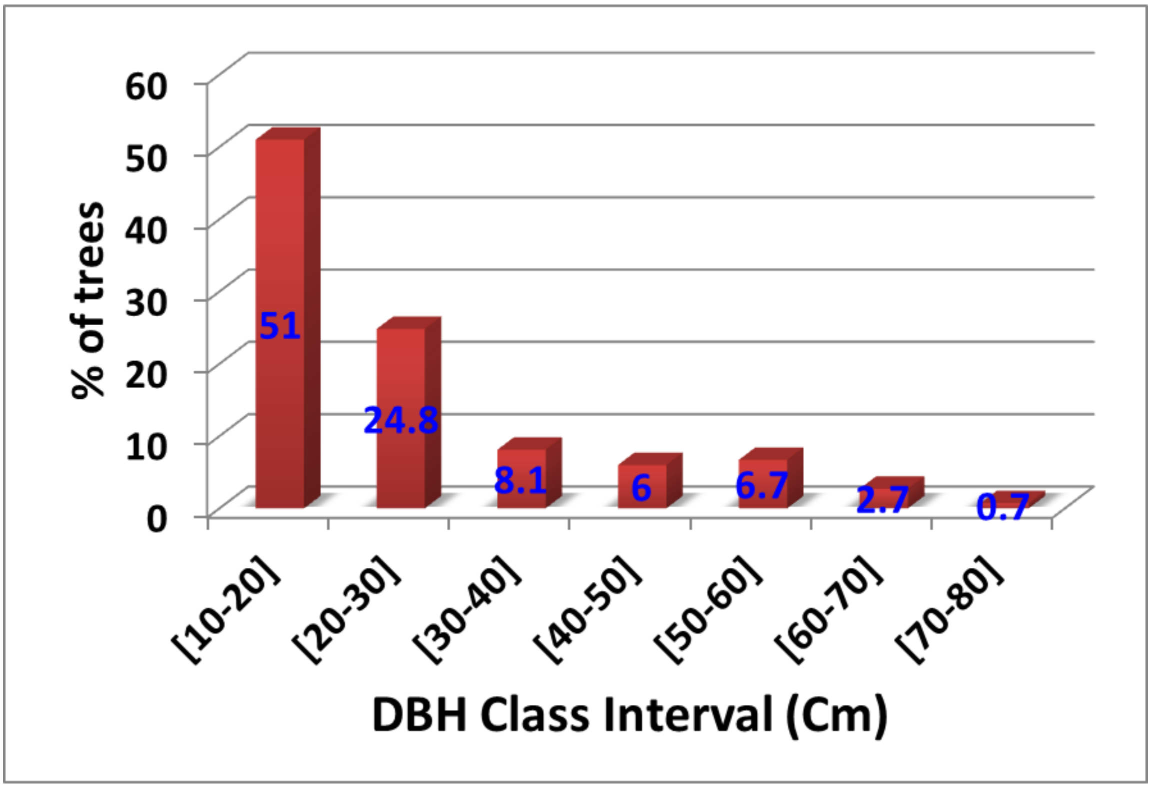

Figure 7. Karamba(1900m) spatial biomass distribution

Uwagashihe site (2500m) has high rate of biomass distribution (Figure 7) of young trees [10-20] cm of DBH measurement than other DBH class intervals and more than two other site Karamba and Bigugu. However other DBH class intervals are having low percentage comparing to other sites. The results show that, we have 62% of trees species are between 10cm and 20cm of DBH, 53% of trees species are between 20cm to 30cm followed by 8% of trees species from 30cm to 40cm and then 3% which is the lowest percentage from trees species between 50-60cm DBH class interval measurements.

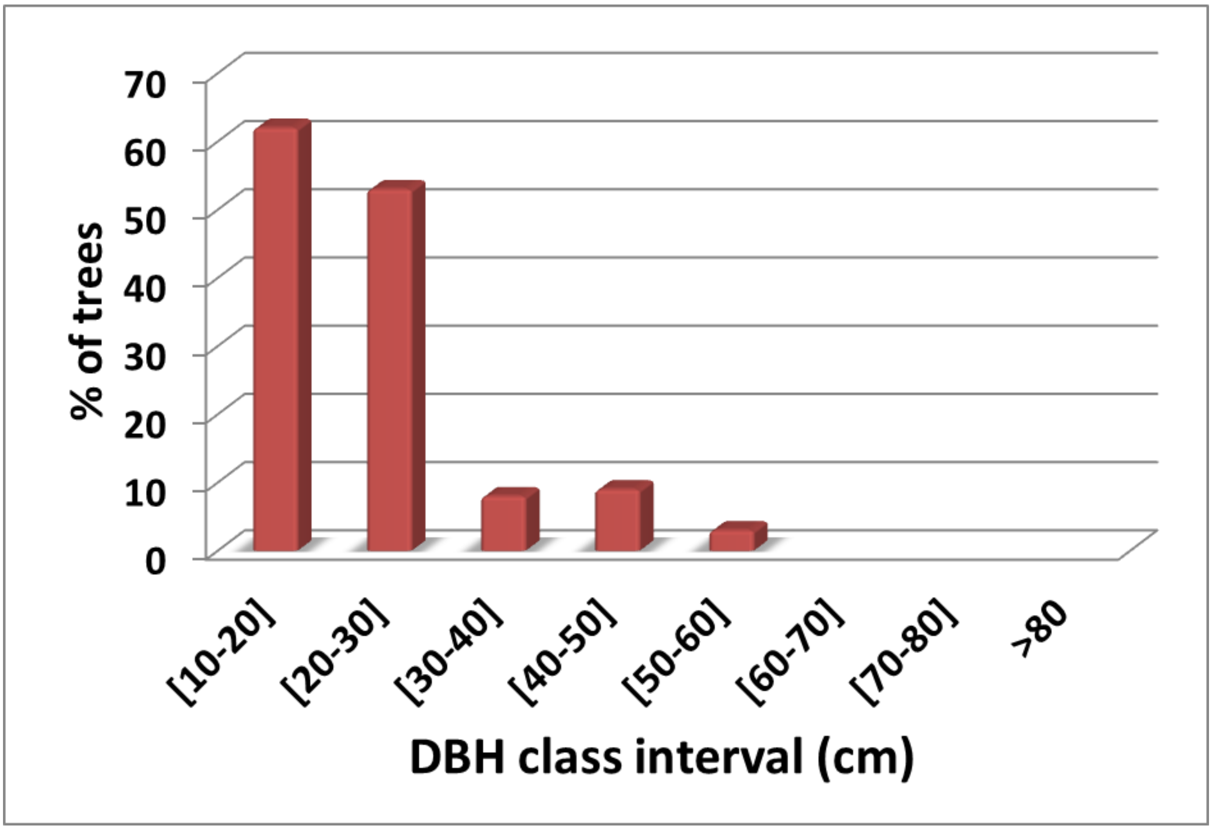

Figure 8. Uwagashihe (2500m) spatial biomass distribution

Bigugu site (2700m) was found to have a low rate of spatial distribution of biomass than two other sites. However, Bigugu has old trees even tree species of more than 80cm of DBH measurement the unique criteria which differentiate Bigugu from Karamba and Uwagashihe.

Figure 9 is showing how Bigugu with 2700m of altitude has middle and big trees species. We may assume that at this site the regeneration is taking place because the high value of biomass distribution is for trees species between 10cm and 20cm of DBH which represent 39%. The next are 26% and 22% for respective DBH measurement of between 20cm-30cm and 30cm to 40cm. Tree species with more than 80cm are represented by 2% of biomass distribution.

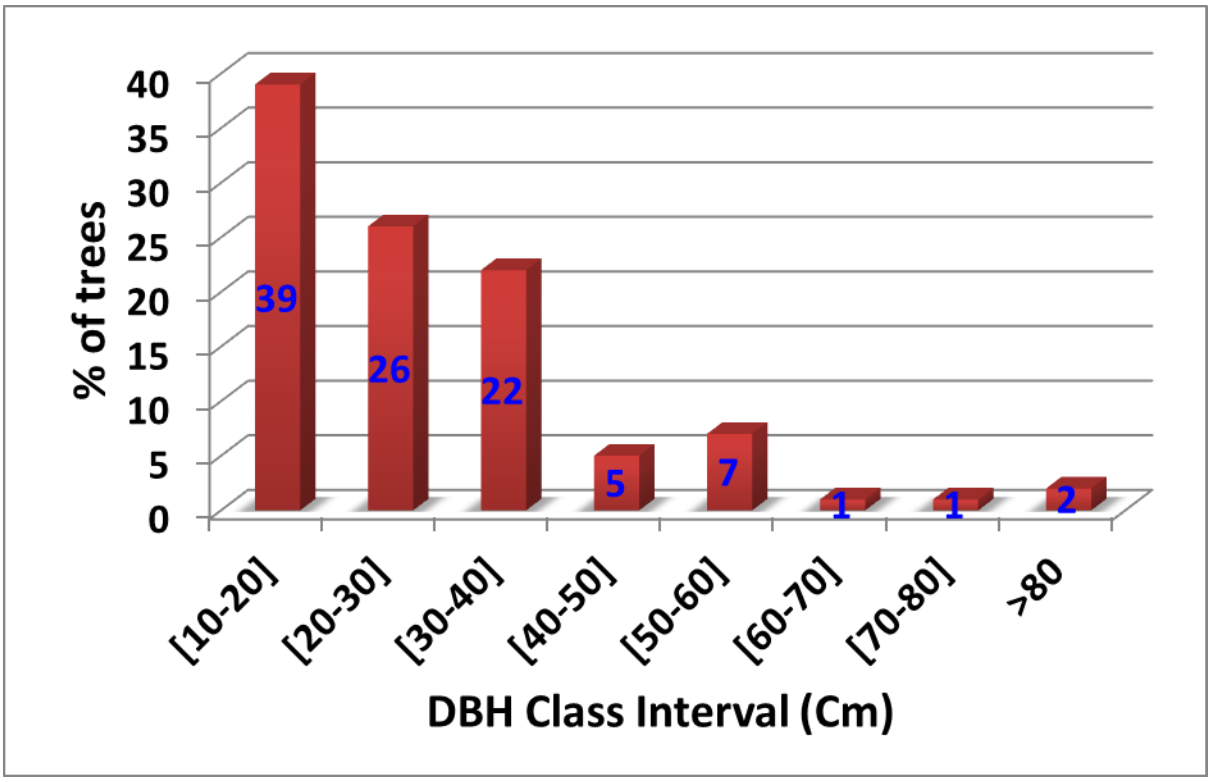

Figure 9. Bigugu (2700m) spatial biomass distribution

Addition to spatial distribution of biomass in Nyungwe forest, here below are figures which represent all altitudinal gradients by their respective tree species with total DBH(cm) measurement. Here, we are able to see which tree species has a high rate number of total DBH at every altitude site.

Cleistanthus polystachyus is a dominant tree species with a high total DBH of 1148 cm at Karamba site with 1900m of altitude as shown in figure 10.

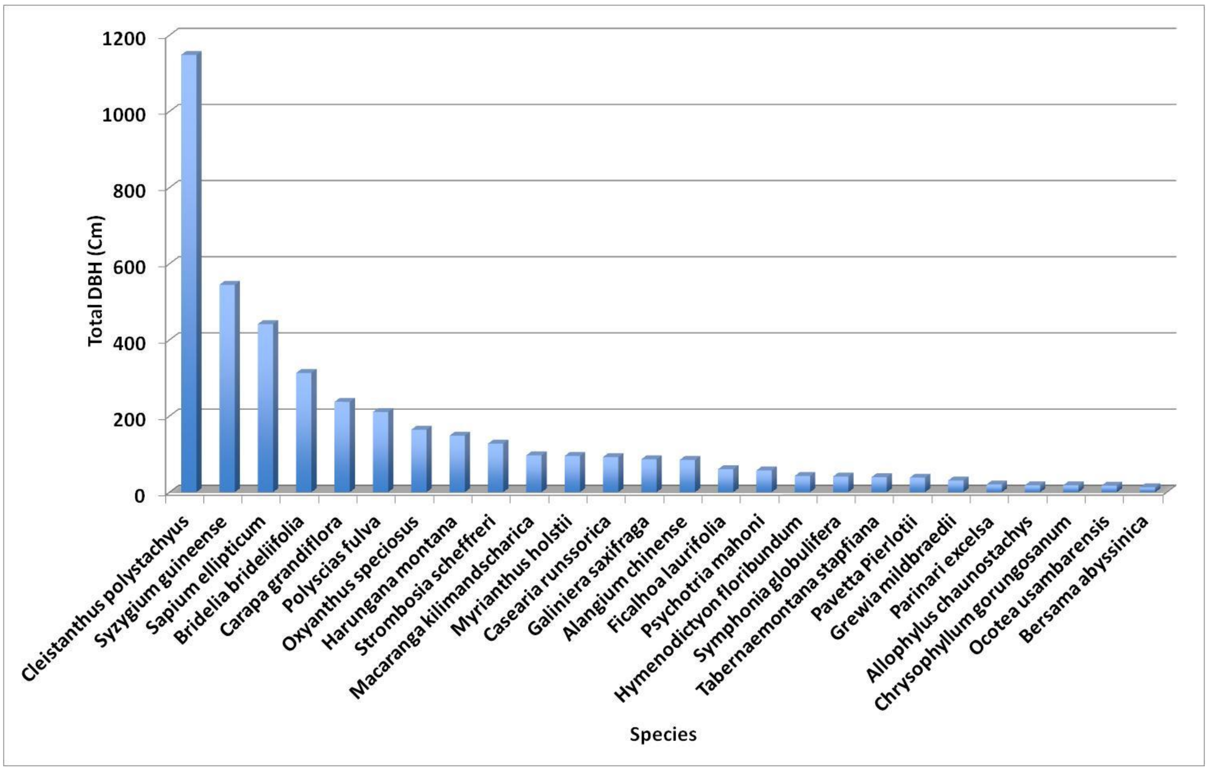

Figure 10. Karamba (1900m) dominant tree species with high rate of total DBH (cm)

Macaranga kilimandscharica is a dominant tree species with high rate of total DBH measurement of 1693 cm at Uwagashihe site as shown in figure 11.

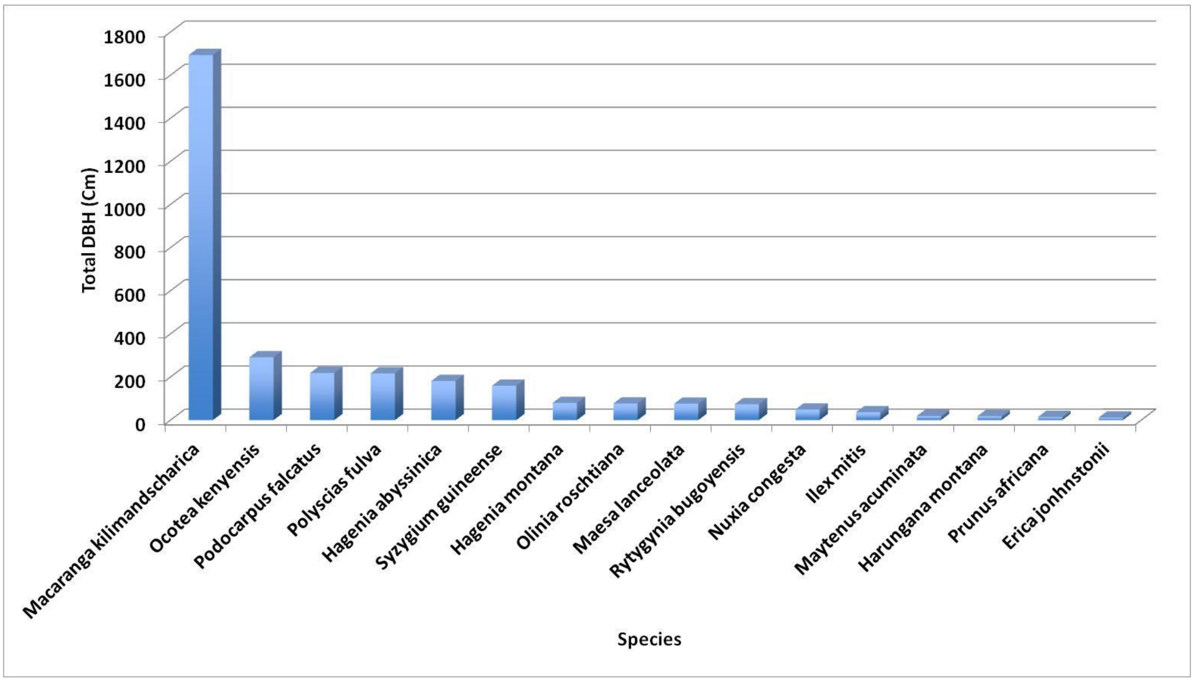

Figure 11. Uwagashihe (2500m) dominant tree species with high rate of total DBH (cm**)**

Podocarpus latifolius is a dominant tree species with a high rate total DBH measurement of 1372 at Bigugu site.

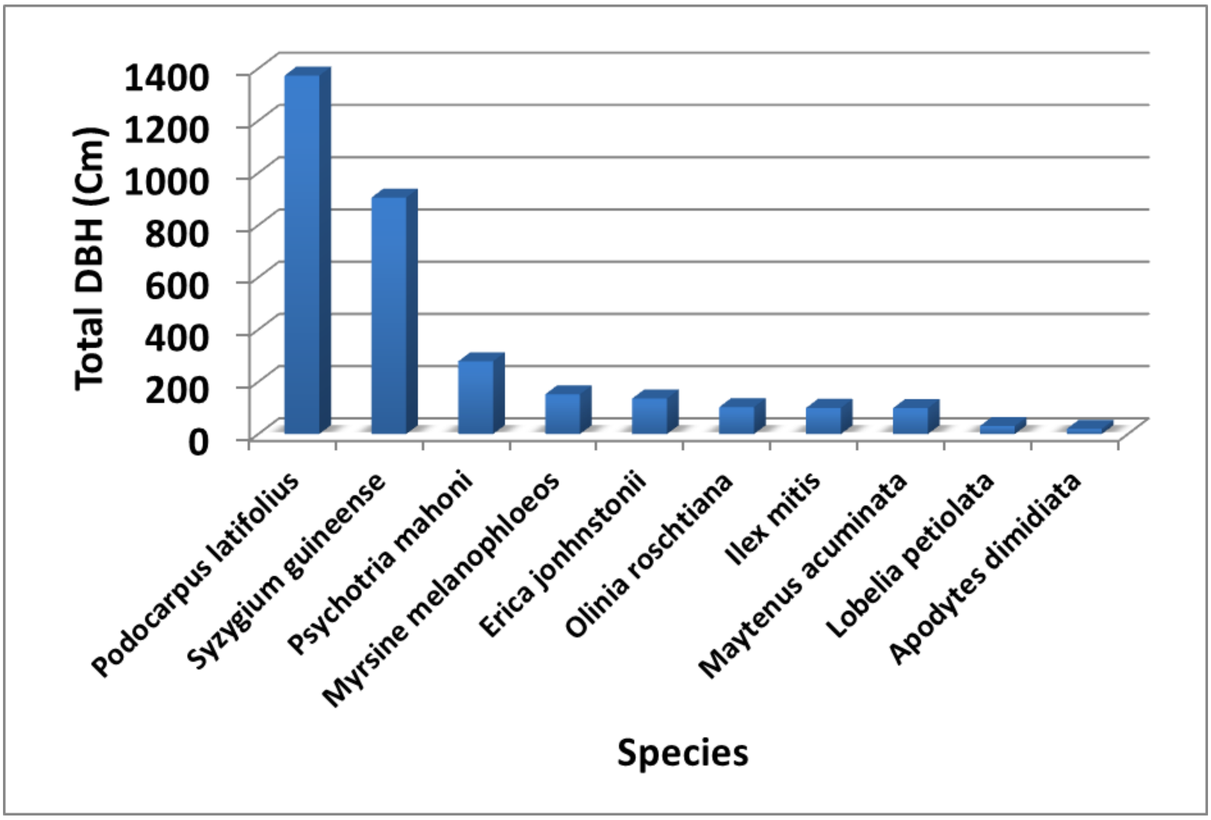

Figure 12. Bigugu (2700m) dominant tree species with high rate of total DBH (cm).

4.3 Vegetation variation along altitudinal gradient

4.3.1 Identification of Vegetation communities

First community is (U2, U3, U4) second community (K1, K2, K3, K4) and the third community is B1, B2, B3, B4) and explain how they look like on the field as shown in figure 11.The communities encircled are very close and similar the same as seen on the field. Uwagashihe site represented by U2, U3 and U4 is having the vegetation of middle trees, neither big nor small in DBH rate. U1 is very close to the third community of Bigugu , the reason behind may be the closeness of U1 and Bigugu at the field. U1 may be the result of seed pollination from Bigugu as U1 was located under Bigugu site see GPS point results
(ANNEX)

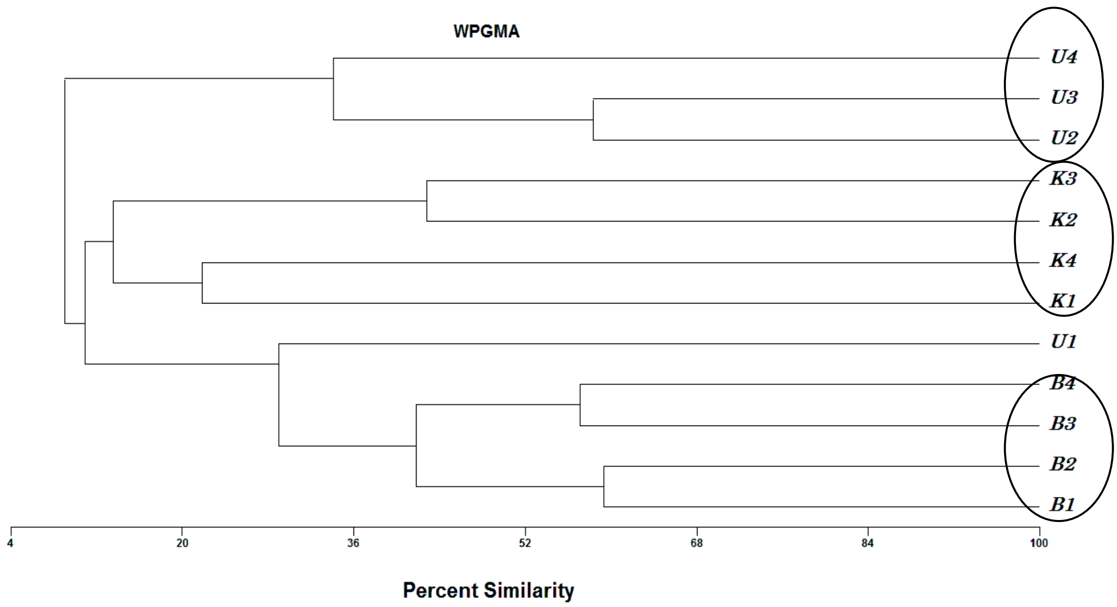

Figure 13. Plant communities at different altitudinal gradient in Nyungwe forest.

Species abundance

The species abundance helps to know how many species we have at all sites. Here below (Table 4.) is showing the species abundance at Karamba site which is decreasing by increasing the altitude.

434 trees number divided into 43 tree species was identified along three hectares of total studied sites (Karamba site, Uwagashihe site, Bigugu site).

Table 4. Species abundance

Plot	Index	Evenness	Num.Spec.
B1	1.595	0.726	9.000
B2	1.251	0.777	5.000
B3	1.209	0.751	5.000
B4	1.034	0.746	4.000
K1	1.653	0.665	**12.000**
K2	**2.195**	0.884	**12.000**
K3	**1.830**	0.795	10.000
K4	**2.038**	0.753	**15.000**
U1	1.332	0.961	4.000
U2	1.299	0.625	8.000
U3	1.170	0.727	5.000
U4	1.694	0.815	8.000

Community diversity along altitudinal gradient

The evaluation of vegetation variation along altitudinal gradient helped us to analyse plant community diversity to see which community is occupying or representing the sampling site and at which altitude we can find such plant community. Find below the tables (Table 5, 6 and 7) with respective plant community.

Frequency (Fq) % $= \frac{\text{Total number of plots in which the species occurred}}{\text{Total number of plots studied}} * 100$

Karamba site is represented by two dominant species which are *Syzygium guineense* and *Bridelia bridelifolia* community with cover (%) of 16.69 *Syzygium guineense* with the frequency of 100% the second community representing Karamba is *Bridelia bridelifolia* with 15.96% of cover and 75% of frequency. As shown in table 5. Other species with high frequency at Karamba site are *Sapium ellipticum, Carapa grandiflora, Polyscias fulva* and *Harungana Montana* with 75% of frequency.

***Syzygium guineense* and *Bridelia bridelifolia* community**

Table 5. Karamba site plant community diversity

Plant species	K1	K2	K3	K4	Cover (%)	Fq(%)
Syzygium guineense	**2**	**2**	**1**	**5**	**16.69**	**100**
Bridelia brideliifolia	**1**	**2**	**5**	**0**	**15.96**	**75**
Sapium ellipticum	1	3	4	0	12.82	75
Carapa grandiflora	1	4	0	2	9.92	75
Polyscias fulva	1	1	3	0	3.87	75
Harungana Montana	1	0	1	1	0.36	75
Cleistanthus polystachyus	5	0	0	4	24.18	50
Oxyanthus speciosus	3	0	0	2	4.35	50
Galiniera saxifrage	0	2	1	0	0.85	50
Macaranga kirimandscharica	2	1	0	0	0.85	50
Grewia mildbraedii	0	1	0	1	0.24	50
Macaranga kilimandscharica	0	0	1	1	0.24	50
Tabernaemontana stapfiana	0	1	1	0	0.24	50
Myrianthus holstii	0	3	0	0	3.63	25
Strombosia scheffreli	3	0	0	0	3.63	25
Symphonia globulifera	2	0	0	0	0.73	25
Alangium chinense	0	0	1	0	0.12	25
Allophylus chaunostachys	0	1	0	0	0.12	25
Bersama abyssinica	0	0	1	0	0.12	25
Casearia runssorica	1	0	0	0	0.12	25
Chrysophyllum gorungosanum	0	1	0	0	0.12	25
Ficalhoa laurifolia	0	0	0	1	0.12	25
Hymenodictyon floribundum	0	0	0	1	0.12	25
Ocotea usambarensis	0	0	0	1	0.12	25
Parinari excels	0	0	0	1	0.12	25
Pavetta Pierlotii	0	0	0	1	0.12	25
Psychotria mahoni	0	0	0	1	0.12	25
Strombosia scheffleri	0	0	0	1	0.12	25

Uwagashihe site is represented by *Macaranga kilimandscharica* and *Ocotea kenyensis* community (Table 6). *Macaranga kilimandscharica* is very dominant with 262.5% of plant cover and 100% of frequency. *Ocotea kenyensis* has 6% of plant cover and 66.67 % of frequency, followed by *Syzygium guineense* and *Nuxia congesta* community with 66.67% of frequency. Other layer species are following (table 6).

***Macaranga kilimandscharica* and *Ocotea kenyensis* community**

Table 6. Uwagashihe site plant community diversity

Plant species	U2	U3	U4	Cover (%)	FQ (%)
Macaranga kilimandscharica	**6**	**6**	**6**	**262.5**	**100**
Ocotea kenyensis	**2**	**0**	**2**	**6**	**66.67**
Syzygium guineense	2	0	1	3.5	66.67
Nuxia congesta	1	1	0	1	66.67
Hagenia abyssinica	0	3	0	15	33.33
Polyscias fulva	0	0	3	15	33.33
Hagenia Montana	0	0	2	3	33.33
Maesa lanceolata	0	2	0	3	33.33
Podocarpus falcatus	0	2	0	3	33.33
Urinia rocheina	0	0	2	3	33.33
Erica johnstonii	1	0	0	0.5	33.33
Harungana Montana	1	0	0	0.5	33.33
Ilex mitis	1	0	0	0.5	33.33
Maytenus acuminate	0	0	1	0.5	33.33
Prunus Africana	0	0	1	0.5	33.33
Rytygynia bugoyensis	1	0	0	0.5	33.33

Bigugu site is represented by *Podocarpus latifolius* and *Syzygium guineense* community. *Podocarpus latifolius* has 44.19% of plant cover and 100% of frequency. *Syzygium guineense* has 43.39% cover and 75% of frequency, followed by *Maytenus acuminata* and Rapanea melanophloeos which have 50% of frequency and 4.14% of plant cover.

***Podocarpus latifolius* and *Syzygium guineense* community**

Table 7. Bigugu site plant community diversity

Plant species	B1	B2	B3	B4	Cover (%)	FQ (%)
Podocarpus latifolius	**5**	**5**	**4**	**2**	**44.19**	**100**
Syzygium guineense	**4**	**0**	**5**	**5**	**43.39**	**75**
Maytenus acuminata	3	0	1	0	4.14	50
Rapanea melanophloeos	3	1	0	0	4.14	50
Psychotria mahoni	1	2	2	1	1.87	100
Orinia roschtiana	0	0	1	2	0.93	50
Erica jonhnstonii	2	0	0	0	0.8	25
Ilex mitis	1	1	0	0	0.27	50
Apodytes dimidiate	1	0	0	0	0.13	25
Lobelia petiolata	1	0	0	0	0.13	25

The increase in altitude may affect the plant variation status and spatial distribution of biomass by varying the soil nutrient disposal and the ability of plants for nutrient acquisition (Chapin, F.S. III, 1991). The variation of vegetation along altitudinal gradient was approved by the results obtained in this study. The dominant tree species *Bridelia bridelifolia* at Karamba site it may be caused by the disturbance where the species is known to grow in a tropical disturbed area and probably due to pollination made by chimpanzees as the seeds of that species are known to be found in the fecal samples of gorillas and chimpanzees.

5. CONCLUSION AND RECOMMANDATION

5.1 Conclusion

The nutrients availability in the soil helps the growth of plants as the trees absorb the nutrient available in the soil and combine it with different pattern, since much quantity of minerals in the soil came from the organic matter on the ground. The results of this study are showing how Soil nutrients (N, P and K) vary with altitudinal gradient in Nyungwe forest but with low significance. The results showed that with increasing the altitude total TN increased. Regarding spatial distribution of biomass, the more altitude increase, biomass is decreasing and the large trees increase with altitude. This shows that Karamba is a young forest and Bigugu is a mature old growth forest. Hence, The Plant communities change with respective altitude: *Syzygium guineense* and *Bridelia bridelifolia* at 1900m, *Macaranga kilimandscharica* and *Ocotea kenyensis* at 2500m, and *Podocarpus latifolius* and *Syzygium guineense* at 2700m,

5.2 Recommendations

Additional research is needed to clarify how the nutrient status of key ecosystem components responds to altitude gradients, because such studies can help us understand how changes in climate may alter nutrient cycling and ultimately plant growth. Next studies may also evaluate soil micronutrient along elevation gradient. Before applying fertilizers in the soil, Total nitrogen content has to be taken into account.

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ANNEX

No	**Plant Species**	**DBH(cm)**	**Canopy Cover (%)**
Karamba Site Plot:1 GPS_Point: 197 Elevation (m): 1900 X 401238 Y 9725408			
1	*Bridelia brideliifolia*	13	0.5
2	*Carapa grandiflora*	17	0.5
3	*Casearia runssorica*	34.1	0.5
4	***Cleistanthus polystachus***	55	70
5	*Cleistanthus polystachus*	25	
6	*Cleistanthus polystachus*	29	
7	*Cleistanthus polystachus*	36	
8	*Cleistanthus polystachus*	32	
9	*Cleistanthus polystachus*	53	
10	*Cleistanthus polystachus*	32	
11	*Cleistanthus polystachus*	50	
12	*Cleistanthus polystachus*	61	
13	*Cleistanthus polystachus*	70	
14	*Cleistanthus polystachus*	58	
15	*Cleistanthus polystachus*	56	
16	*Harungana Montana*	40	0.5

17	***Macaranga kirimandscharica***	16	1
18	*Macaranga kirimandscharica*	14	
19	***Oxyanthus speciosus***	14	10
20	*Oxyanthus speciosus*	11	
21	*Oxyanthus speciosus*	30	
22	*Polyscias fulva*	13	0.5
23	*Sapium ellipticum*	21	0.5
24	***Strombosia scheffreli***	36.2	10
25	*Strombosia scheffreli*	60	
26	*Symphonia globulifera*	41	1
27	***Syzygium guineense***	35	5
28	*Syzygium guineense*	16	
29	*Syzygium guineense*	23	

Karamba Site
Plot:2
GPS_Point: 198
Elevation(m) 1936
X 400992
Y 9725470

No	**Plant Species**	**DBH(cm)**	**Canopy Cover (%)**
1	*Allophylus chaunostachys*	18	0.1
2	***Bridelia brideliifolia***	15	1
3	*Bridelia brideliifolia*	22	
4	*Bridelia brideliifolia*	24	
5	***Carapa grandiflora***	58	25
6	*Carapa grandiflora*	14	
7	*Carapa grandiflora*	22	
8	*Carapa grandiflora*	28	
9	*Carapa grandiflora*	27	
10	*Chrysophyllum gorungosanum*	18	0.1
11	***Galiniera saxifraga***	16	5
12	*Galiniera saxifraga*	18	
13	*Galiniera saxifraga*	18	
14	*Grewia mildbraedii*	10	0.1
15	*Macaranga kirimandscharica*	14	0.5
16	*Myrianthus horstii*	20	20
17	*Myrianthus horstii*	75	

18	*Polyscias fulva*	60	0.5
19	***Sapium ellipticum***	21	15
20	*Sapium ellipticum*	20	
21	*Sapium ellipticum*	19	
22	*Sapium ellipticum*	57	
23	***Syzygium guineense***	65	3
24	*Tabernaemontana stapfiana*	17	0.5

Karamba site			
Plot: 3			
GPS point:	212		
Elevetion(m):	1935		
X	734897		
Y	9725668		
No	**Plant species**	**DBH(cm)**	**Canopy Cover(%)**
1	***Macaranga kilimandscharica***	17	0.1
2	***Polyscias fulva***	13.3	20
3	*Polyscias fulva*	27	
4	*Polyscias fulva*	24.6	
5	*Polyscias fulva*	24	
6	*Polyscias fulva*	21.5	
7	*Polyscias fulva*	27.1	
8	***Sapium ellipticum***	12	35
9	*Sapium ellipticum*	17	
10	*Sapium ellipticum*	21.5	
11	*Sapium ellipticum*	15.5	
12	*Sapium ellipticum*	15.5	
13	*Sapium ellipticum*	16.4	
14	*Sapium ellipticum*	12.2	
15	*Sapium ellipticum*	21.1	

16	*Sapium ellipticum*	21.6	
17	*Sapium ellipticum*	16	
18	*Sapium ellipticum*	13.9	
19	*Sapium ellipticum*	10.4	
20	*Sapium ellipticum*	12.5	
21	*Sapium ellipticum*	23.5	
22	*Sapium ellipticum*	13	
23	*Sapium ellipticum*	19	
24	*Sapium ellipticum*	12.3	
25	*Sapium ellipticum*	17.3	
26	*Sapium ellipticum*	12.5	
27	***Bridelia brideliifolia***	13	60
28	*Bridelia brideliifolia*	22	
29	*Bridelia brideliifolia*	16	
30	*Bridelia brideliifolia*	17	
31	*Bridelia brideliifolia*	11	
32	*Bridelia brideliifolia*	12.2	
33	*Bridelia brideliifolia*	18	
34	*Bridelia brideliifolia*	23	
35	*Bridelia brideliifolia*	28.2	
36	*Bridelia brideliifolia*	15	
37	*Bridelia brideliifolia*	12.6	
38	*Bridelia brideliifolia*	33.5	
39	*Bridelia brideliifolia*	17.5	
40	***Alangium chinense***	29.5	0.5
41	*Alangium chinense*	16	
42	*Alangium chinense*	39	
43	***Galiniera saxifraga***	11.3	0.5
44	*Galiniera saxifraga*	11	
45	*Galiniera saxifraga*	12	
46	***Bersama abyssinica***	12.6	0.1
47	***Harungana montana***	20.8	0.1
48	*Harungana montana*	20.1	
49	***Syzygium guineense***	11.3	0.1
50	*Syzygium guineense*	18.1	
51	*Syzygium guineense*	11.4	
52	***Tabernaemontana stapfiana***	11	0.1
53	*Tabernaemontana stapfiana*	11.2	

Karamba site Plot: 4 GPS point: 213 Elevetion(m): 1932 X 7348392 Y 9725876			
No	**Plant species**	**DBH (cm)**	**Canopy Cover (%)**
1	***Harungana montana***	23.3	0.5
2	*Harungana montana*	44	
3	***Syzygium guineense***	15.6	60
4	*Syzygium guineense*	15.8	
5	*Syzygium guineense*	18	
6	*Syzygium guineense*	16.2	
7	*Syzygium guineense*	13.2	
8	*Syzygium guineense*	29	
9	*Syzygium guineense*	19	
10	*Syzygium guineense*	49	
11	*Syzygium guineense*	30	
12	*Syzygium guineense*	52	
13	*Syzygium guineense*	41	
14	*Syzygium guineense*	13	
15	*Syzygium guineense*	53	

16	***Carapa grandiflora***	15.7	5
17	*Carapa grandiflora*	13.5	
18	*Carapa grandiflora*	16.1	
19	*Carapa grandiflora*	11.8	
20	*Carapa grandiflora*	14	
21	***Cleistanthus polystachysus***	34	35
22	*Cleistanthus polystachysus*	11	
23	*Cleistanthus polystachysus*	41	
24	*Cleistanthus polystachysus*	49	
25	*Cleistanthus polystachysus*	40.6	
26	*Cleistanthus polystachysus*	17	
27	*Cleistanthus polystachysus*	11.3	
28	*Cleistanthus polystachysus*	11.7	
29	*Cleistanthus polystachysus*	29	
30	*Cleistanthus polystachysus*	41	
31	*Cleistanthus polystachysus*	24	
32	*Cleistanthus polystachysus*	63	
33	*Cleistanthus polystachysus*	55	
34	*Cleistanthus polystachysus*	36	
35	*Cleistanthus polystachysus*	38	
36	*Cleistanthus polystachysus*	22.5	
37	*Cleistanthus polystachysus*	67	
38	***Oxyanthus speciosus***	15.2	5
39	*Oxyanthus speciosus*	21	
40	*Oxyanthus speciosus*	28	
41	*Oxyanthus speciosus*	21.1	
42	*Oxyanthus speciosus*	23.5	
43	***Hymenodictyon floribundum***	42.5	0.1
44	***Pavetta Pierlotii***	15	0.1
45	*Pavetta Pierlotii*	23	
46	*Psychotria mahoni*	30	0.1
47	*Psychotria mahoni*	12.4	
48	*Psychotria mahoni*	14.5	
49	***Casearia runssorica***	58	
50	***Macaranga kilimandscharica***	22	0.1
51	*Macaranga kilimandscharica*	13.5	
52	***Ocotea usambarensis***	17	0.1
53	***Ficalhoa laurifolia***	60	0.1
54	***Parinari excelsa***	20	0.1
55	***Grewia mildbraedii***	20.5	0.1
56	***Strombosia scheffleri***	31	0.1

Uwagashihe Site			
Plot: 1			
GPS_Point:	203		
Elevation (m)	2572		
X	431092		
Y	9720732		
No	**Plant Species**	**DBH(cm)**	**Canopy Cover (%)**
1	***Macaranga kirimandscharica***	11	60
2	*Macaranga kirimandscharica*	13	
3	*Macaranga kirimandscharica*	22	
4	*Macaranga kirimandscharica*	16	
5	*Macaranga kirimandscharica*	11	
6	*Macaranga kirimandscharica*	32	
7	*Macaranga kirimandscharica*	19.1	
8	***Maytenus acuminata***	27	5
9	*Maytenus acuminata*	24.8	

10	*Maytenus acuminata*	12	
11	*Myrsine melanophloeos*	15.1	0.5
12	*Myrsine melanophloeos*	17	
13	***Orinia roschtiana***	18	5
14	*Orinia roschtiana*	13	
15	*Orinia roschtiana*	19.5	
16	***Syzygium guineense***	18	20
17	*Syzygium guineense*	19	
18	*Syzygium guineense*	31.3	
19	*Syzygium guineense*	15	

Uwagashihe site			
Plot: 2			
GPS point:	214		
Elevetion(m):	2304		
X	764404		
Y	9720740		
No	**Plant species**	**DBH (cm)**	**Canopy Cover (%)**
1	***Macaranga kilimandscharica***	16.4	85
2	*Macaranga kilimandscharica*	17.4	
3	*Macaranga kilimandscharica*	19	
4	*Macaranga kilimandscharica*	13.1	
5	*Macaranga kilimandscharica*	21	
6	*Macaranga kilimandscharica*	14.7	
7	*Macaranga kilimandscharica*	10.4	
8	*Macaranga kilimandscharica*	28.5	
9	*Macaranga kilimandscharica*	31	
10	*Macaranga kilimandscharica*	26	
11	*Macaranga kilimandscharica*	38	
12	*Macaranga kilimandscharica*	18	
13	*Macaranga kilimandscharica*	19	
14	*Macaranga kilimandscharica*	20	
15	*Macaranga kilimandscharica*	19	

16	*Macaranga kilimandscharica*	11	
17	*Macaranga kilimandscharica*	26	
18	*Macaranga kilimandscharica*	21	
19	*Macaranga kilimandscharica*	27	
20	*Macaranga kilimandscharica*	23	
21	*Macaranga kilimandscharica*	27	
22	*Macaranga kilimandscharica*	17	
23	*Macaranga kilimandscharica*	18.3	
24	*Macaranga kilimandscharica*	22	
25	*Macaranga kilimandscharica*	23	
26	*Macaranga kilimandscharica*	17	
27	*Macaranga kilimandscharica*	22.5	
28	*Macaranga kilimandscharica*	21.5	
29	*Macaranga kilimandscharica*	14.4	
30	*Macaranga kilimandscharica*	22	
31	*Macaranga kilimandscharica*	19.5	
32	*Macaranga kilimandscharica*	19.6	
33	*Macaranga kilimandscharica*	25	
34	*Macaranga kilimandscharica*	22	
35	*Macaranga kilimandscharica*	12.4	
36	*Macaranga kilimandscharica*	15.3	
37	***Ilex mitis***	14.5	0.1
38	*Ilex mitis*	22	
39	***Rytygynia bugoyensis***	19	1
40	*Rytygynia bugoyensis*	16	
41	*Rytygynia bugoyensis*	23.5	
42	*Rytygynia bugoyensis*	15	
43	***Syzygium guineense***	34.2	5
44	*Syzygium guineense*	25	
45	*Syzygium guineense*	17	
46	*Syzygium guineense*	27	
47	*Syzygium guineense*	35.4	
48	***Ocotea kenyensis***	59	5
49	*Ocotea kenyensis*	43	
50	*Ocotea kenyensis*	30	
51	*Ocotea kenyensis*	46.5	
52	***Harungana montana***	18	0.1
53	***Erica johnstonii***	12	0.1
54	***Nuxia congesta***	13.7	0.1
55	*Nuxia congesta*	13.6	

Uwagashihe site			
Plot: 3			
GPS point:	215		
Elevetion(m):	2598		
X	764609		
Y	9720382		
No	**Plant species**	**DBH**	**Canopy Cover (%)**
1	***Macaranga kilimandscharica***	22.4	80
2	*Macaranga kilimandscharica*	12	
3	*Macaranga kilimandscharica*	12	
4	*Macaranga kilimandscharica*	18	
5	*Macaranga kilimandscharica*	12	
6	*Macaranga kilimandscharica*	19	
7	*Macaranga kilimandscharica*	20.9	
8	*Macaranga kilimandscharica*	14	
9	*Macaranga kilimandscharica*	23.4	
10	*Macaranga kilimandscharica*	19	
11	*Macaranga kilimandscharica*	25.4	
12	*Macaranga kilimandscharica*	23.6	
13	*Macaranga kilimandscharica*	25.3	
14	*Macaranga kilimandscharica*	23	

15	*Macaranga kilimandscharica*	22.5	
16	*Macaranga kilimandscharica*	11	
17	*Macaranga kilimandscharica*	11.8	
18	*Macaranga kilimandscharica*	10	
19	*Macaranga kilimandscharica*	16	
20	*Macaranga kilimandscharica*	16.5	
21	*Macaranga kilimandscharica*	13.9	
22	*Macaranga kilimandscharica*	12	
23	*Macaranga kilimandscharica*	10	
24	*Macaranga kilimandscharica*	13	
25	*Macaranga kilimandscharica*	19.3	
26	*Macaranga kilimandscharica*	16.4	
27	*Macaranga kilimandscharica*	11.5	
28	*Macaranga kilimandscharica*	23	
29	*Macaranga kilimandscharica*	24.7	
30	*Macaranga kilimandscharica*	20.8	
31	*Macaranga kilimandscharica*	15.6	
32	*Macaranga kilimandscharica*	28.5	
33	*Macaranga kilimandscharica*	20	
34	*Macaranga kilimandscharica*	12.5	
35	*Macaranga kilimandscharica*	14.5	
36	*Macaranga kilimandscharica*	28.2	
37	*Macaranga kilimandscharica*	15.4	
38	*Macaranga kilimandscharica*	20.2	
39	***Hagenia abyssinica***	25.7	10
40	*Hagenia abyssinica*	21	
41	*Hagenia abyssinica*	29	
42	*Hagenia abyssinica*	37	
43	*Hagenia abyssinica*	27	
44	*Hagenia abyssinica*	23	
45	*Hagenia abyssinica*	18.9	
46	***Maesa lanceolata***	12.3	1
47	*Maesa lanceolata*	15	
48	*Maesa lanceolata*	23.8	
49	*Maesa lanceolata*	11.7	
50	*Maesa lanceolata*	13	
51	***Podocarpus falcatus***	46	5
52	*Podocarpus falcatus*	46.5	
53	*Podocarpus falcatus*	41.5	
54	*Podocarpus falcatus*	25.2	
55	*Podocarpus falcatus*	40	
56	*Podocarpus falcatus*	19	
57	***Nuxia congesta***	21.9	0.1

Uwagashihe site			
Plot: 4			
GPS point:	216		
Elevetion(m):	2498		
X	765122		
Y	9720080		
No	**Plant species**	**DBH(cm)**	**Canopy Cover (%)**
1	***Hagenia montana***	34	1
2	*Hagenia montana*	46	
3	***Polyscias fulva***	55.2	20
4	*Polyscias fulva*	20	
5	*Polyscias fulva*	26	
6	*Polyscias fulva*	17.5	
7	*Polyscias fulva*	42	
8	*Polyscias fulva*	56.3	
9	***Macaranga kilimandscharica***	16	75
10	*Macaranga kilimandscharica*	22.6	
11	*Macaranga kilimandscharica*	26	
12	*Macaranga kilimandscharica*	12.3	
13	*Macaranga kilimandscharica*	21	
14	*Macaranga kilimandscharica*	24	

15	*Macaranga kilimandscharica*	24.2	
16	*Macaranga kilimandscharica*	33.3	
17	*Macaranga kilimandscharica*	35.5	
18	*Macaranga kilimandscharica*	41	
19	*Macaranga kilimandscharica*	22	
20	***Prunus africana***	14.6	0.1
21	***Syzygium guineense***	21	0.1
22	***Maytenus acuminata***	19	0.1
23	***Ocotea kenyensis***	26	1
24	*Ocotea kenyensis*	44.8	
25	*Ocotea kenyensis*	42	
26	***Urinia rocheina***	40	5
27	*Urinia rocheina*	17	
28	*Urinia rocheina*	20	

Bigugu site			
Plot: 1			
GPS Point:	199		
Elevation (m)	2783		
X	416477		
Y	9728862		
No	**Plant Species**	**DBH(cm)**	**Canopy Cover (%)**
1	***Apodytes dimidiata***	20.1	0.1
2	***Erica jonhnstonii***	35	5
3	*Erica jonhnstonii*	18	
4	*Erica jonhnstonii*	18	
5	*Erica jonhnstonii*	27	
6	*Erica jonhnstonii*	20	
7	*Erica jonhnstonii*	18	
8	***Ilex mitis***	23.1	0.1
9	***Lobelia petiolata***	14	0.5
10	*Lobelia petiolata*	17	
11	***Maytenus acuminata***	16	15
12	*Maytenus acuminata*	14	
13	*Maytenus acuminata*	11	
14	*Maytenus acuminata*	12	

15	*Maytenus acuminata*	11.1	
16	*Maytenus acuminata*	14	
17	***Myrsine melanophloeos***	11.1	10
18	*Myrsine melanophloeos*	12	
19	*Myrsine melanophloeos*	13	
20	*Myrsine melanophloeos*	19	
21	*Myrsine melanophloeos*	26	
22	*Myrsine melanophloeos*	20	
23	*Podocarpus latifolius*	11	70
24	*Podocarpus latifolius*	19	
25	*Podocarpus latifolius*	16	
26	*Podocarpus latifolius*	11	
27	*Podocarpus latifolius*	17	
28	*Podocarpus latifolius*	12	
29	*Podocarpus latifolius*	13	
30	*Podocarpus latifolius*	19	
31	*Podocarpus latifolius*	12.1	
32	*Podocarpus latifolius*	12	
33	*Podocarpus latifolius*	36	
34	*Podocarpus latifolius*	18	
35	*Podocarpus latifolius*	37	
36	*Podocarpus latifolius*	12	
37	*Podocarpus latifolius*	36	
38	*Podocarpus latifolius*	30	
39	*Podocarpus latifolius*	15	
40	*Podocarpus latifolius*	31	
41	*Podocarpus latifolius*	37.1	
42	*Podocarpus latifolius*	26	
43	*Podocarpus latifolius*	28	
44	*Podocarpus latifolius*	29	
45	*Podocarpus latifolius*	54	
46	*Podocarpus latifolius*	48	
47	*Podocarpus latifolius*	40	
48	*Psychotria mahoni*	10	0.1
49	*Psychotria mahoni*	22	
50	*Syzygium guineense*	19	25
51	*Syzygium guineense*	22	
52	*Syzygium guineense*	22	
53	*Syzygium guineense*	32	
54	*Syzygium guineense*	28	
55	*Syzygium guineense*	37	
56	*Syzygium guineense*	18.1	
57	*Syzygium guineense*	20	
58	*Syzygium guineense*	29	

59	*Syzygium guineense*	30	

Bigugu Site			
Plot: 2			
GPS_Point:	200		
Elevation (m)	2795		
X	416502		
Y	9728974		
No	**Plant Species**	**DBH(cm)**	**Canopy Cover (%)**
1	***Ilex mitis***	39	0.5
2	*Ilex mitis*	38	
3	***Myrsine melanophloeos***	23.1	0.1
4	*Myrsine melanophloeos*	28	
5	***Podocarpus latifolius***	34	70
6	*Podocarpus latifolius*	33	
7	*Podocarpus latifolius*	61	
8	*Podocarpus latifolius*	22	
9	*Podocarpus latifolius*	43	
10	*Podocarpus latifolius*	52	
11	*Podocarpus latifolius*	90.2	

12	*Podocarpus latifolius*	55	
13	*Podocarpus latifolius*	52	
14	***Psychotria mahoni***	12.1	5
15	*Psychotria mahoni*	24	
16	*Psychotria mahoni*	19	
17	*Psychotria mahoni*	32	
18	*Psychotria mahoni*	28.1	
19	*Psychotria mahoni*	26.1	
20	***Syzygium guineense***	30	
21	*Syzygium guineense*	38	

Bigugu Site			
Plot: 3			
GPS_Point:	201		
Elevation (m)	2756		
X	416468		
Y	972869		
No	**Plant Species**	**DBH(cm)**	**Canopy Cover (%)**
1	***Syzygium guineense***	25	65
2	*Syzygium guineense*	31	
3	*Syzygium guineense*	39.1	
4	*Syzygium guineense*	51	
5	*Syzygium guineense*	40	
6	*Syzygium guineense*	28	
7	*Syzygium guineense*	23	
8	*Syzygium guineense*	44	
9	*Syzygium guineense*	27	
10	*Syzygium guineense*	20	

11	*Syzygium guineense*	36	
12	*Psychotria mahoni*	13.1	5
13	*Psychotria mahoni*	19	
14	*Psychotria mahoni*	21.1	
15	*Psychotria mahoni*	41	
16	***Podocarpus latifolius***	31	30
17	*Podocarpus latifolius*	18	
18	*Podocarpus latifolius*	111	
19	*Podocarpus latifolius*	58	
20	*Podocarpus latifolius*	32	
21	***Orinia roschtiana***	32	0.5
22	***Maytenus acuminata***	21	0.1

Bigugu Site			
Plot: 4			
GPS_Point:	202		
Elevation (m)	2715		
X	416384		
Y	9728554		
No	**Plant Species**	**DBH(cm)**	**Canopy Cover (%)**
1	***Syzygium guineense***	38	65
2	*Syzygium guineense*	57	
3	*Syzygium guineense*	43	
4	*Syzygium guineense*	27	
5	*Syzygium guineense*	18	
6	*Syzygium guineense*	33.1	
7	***Psychotria mahoni***	11	0.5
8	***Podocarpus latifolius***	26	10
9	*Podocarpus latifolius*	17	

10	*Podocarpus latifolius*	18	
11	***Orinia roschtiana***	71	1

APPENDIX

Table 8. Concentration of total Nitrogen

Sites&Plots		Absorbance	TN (mg/kg)	Altitude (m)
Karamba	1	0.30385	3.27	1900
	2	0.21066	2.65	1900
	3	0.31876	3.37	1900
	4	0.28596	3.15	1900
Uwagashihe	1	7.84356	53.57	2500
	2	6	47.08	2500
	3	7.40821	50.66	2500
	4	8.403	57.30	2500
Bigugu	1	7.23506	49.51	2700
	2	7.63725	52.19	2700
	3	6.99996	47.94385	2700
	4	7.41101	50.6858	2700

Table 9. Concentration of total Phosphorus in the soil

Sites&Plots	Absorbance	TP (mg/Kg)	Altitude (m)
Karamba 1	0.44646	11.80	1900
2	0.90102	25.17	1900
3	0.66239	18.15	1900
4	0.68275	18.75	1900
Uwagashihe 1	0.76532	21.18	2500
2	0.54217	14.62	2500
3	0.68574	18.84	2500
4	0.80367	22.31	2500
Bigugu 1	0.67073	18.40	2700
2	0.58962	16.01	2700
3	0.8491	23.64	2700
4	0.564	15.26	2700

Table 10. Potassium concentration results

Sites&Plots	Absorbance	Potassium (mg/Kg)	altitude(m)
Karamba 1	0.016	8.5	1900
2	0.022	11.5	1900
3	0.016	8.5	1900
4	0.022	11.5	1900
Uwagashihe 1	0.026	13.5	2500
2	0.042	21.5	2500
3	0.043	22	2500
4	0.035	18	2500
Bigugu 1	0.069	35	2700
2	0.061	31	2700
3	0.056	28.5	2700
4	0.07	35.5	2700