ASSESSMENT OF MANGROVE BLUE CARBON STOCKS IN NYEKE MANGROVE FOREST IN UNGUJA - ZANZIBAR

BY

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DECLARATION

Candidate

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

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We as supervisors confirm that the work reported in this dissertation was carried out by the candidate under our supervision.

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DEDICATION

To my lovely parents, wife and children for giving me the spirit of not giving up for long move up to the success of this study.

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LIST OF ABBREVIATION AND ACRONYMS

AGB	Above ground biomass
ANOVA	Analysis of Variance
A.m	*Avicenia marina*
BGB	Below ground biomass
B.g	*Bruguiera gymnorrhiza*
C	Carbon
CO_2	Carbon dioxide
CDM	Clean Development Mechanism
CFM	Community Forest Management
DBH	Diameter at Breast Height (measured 1.3m above the ground)
FAO	Food Agricultural Organization
GIS	Geographical Information System
HT	Height
H_0	Null hypothesis
IPCC	Intergovernmental Panel on Climate Change
JUMIJAZA	Jumuiya ya Uhifadhi wa Misitu Asili Zanzibar
LSD	Least Significant Difference
IUCN	International Union of Conservation of Nature
Max.	Maximum
Mg	Mega gram
NAMAs	National Appropriate Mitigation Actions
PES	Payment for Ecosystem Services
REDD+	Reduced Emission from Deforestation and Degradation
R.m	*Rhizophora mucronata*
SPSS	Statistical Package for Social Sciences
TC	Total Carbon
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nation Environmental Programme
WWF	World Wildlife Fund

ABSTRACTS

Blue carbon refers to carbon stored or sequestered in vegetated marinesincluding mangroves, sea grass, salt marsh and coral reef.Despite their benefits and services, blue carbon mangrove ecosystems are some of the most threatened ecosystems on the earth, they are disappearing three to five times faster than overall global forest losses, with serious ecological and socio-economic impacts. It is estimated that every year about 0.15 - 1.02 billion tons of carbon dioxide are being released from deforestation and degradation of blue carbon ecosystems, which account up to 19% of carbon emissions from global tropical deforestation. This field study was carried out to quantify the above ground and below ground blue carbon stocks of the three dominant mangroves: *Avicenia marina* (Mchu), *Bruguiera gymnorrhiza* (Msisi/Msinzi) *and Rhizophora mucronata* (Mkoko magondi). This study was conducted in March 2020, at Nyeke-Uzi mangrove forests in Zanzibar and employed field survey and explorative study design. It used an allometric method for biomass determination where diameter at breast height (DBH) and tree height (TH) were measured as dependent variables. Biomass were then used to calculate the carbon contents both above ground and below ground tree parties through zones. *R. mucronata* contributed higher value of carbon contents of 8323Mg C ha^{-1} (41.66%) followed by *A. marina*of 5952 Mg C /ha (29.79%) and *B. gymnorrhiza*of 5705 Mg C /ha (28.55%). AGC was higher 12300 Mg C /ha (61.56%) than BGC 7681 Mg C /ha (38.44%). This is because carbon content is affected by size of DBH found in the upper zone contributed by *Avicenia marina* having greater mean value of DBH 36.2cm, max. DBH 250cm followed by 17cm (max.DBH 60cm) and 15cm (max. DBH 5cm) of R.m and B.g respectively.Lower zone contributed higher carbon content 7345 Mg C /ha (36.76%) followed by upper zone 6735 Mg C /ha (33.71%) and mid zone 5901 Mg C /ha (29.53%). This result is due to high distribution of *R. mucronata* with prop roots in the lower zone and lack of *A. marina* species. Trees with higher DBH and height had We conclude that for rising carbon stock capacity in mangrove ecosystem of Zanzibar, more conservation efforts are needed by the community including shifting to non-destructive forest demands such as bee keeping, eco-tourism, seaweed and fish farming confirmed having higher carbon contents than the rest lacking such characteristics. We conclude that for rising carbon stock capacity in mangrove ecosystem of Zanzibar, more conservation efforts are needed by the community including shifting to non-destructive forest demands such as bee keeping, eco-tourism, seaweed and fish farming so as to provide important chance for carbon stocking as well as improving blue economy[1].

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[1] Blue Economy means sustainable use of ocean resources for economic growth, improved livelihoods and jobs while preserving the health of ocean ecosystems.

CHAPTER ONE

1. Introduction

1.1 Background information

Blue carbon refers to carbon stored or sequestered in vegetated marine including mangrove forests, salt tidal marshes and sea grass meadows, as well as coral reefs and oceanic carbon sinks in the form of marine algae (Thomas 2014; Mcleod *et al*. 2011; Mitra and Zaman 2015). Blue carbon now offers the possibility of collecting extra funds and revenue by combining best-practices in coastal management with climate change mitigation goals and needs. To intelligibly dealing with blue carbon ecosystems in climate change mitigation through policy, regulatory, economics, or other performance; the carbon stocks in marine ecosystems need to be recognized and quantified (Howard et al. 2014).

Globally, there are a number of 70 known mangrove species within some 19 families based on criteria of "anatomical and physiological adaptations to saline and hypoxic soil" without including hybrids (Polidoro et al. 2010; Webber et al. 2014). The total area of mangroves in the year 2000 was 137,760 km^2 in 118 countries and territories and 152,000 km^2 in 123 countries and territories in the tropical and subtropical regions of the world (Giri et al. 2010; FAO 2007). Although, they are found in 123 countries, mangrove forests are globally rare and represent less than 1% of all tropical forests worldwide, and less than 0.4% of the total global forest estate (FAO, 2007; Spalding et al. 2010).

Mangroves as a blue carbon sink provides numerous benefits and services that are essential for climate change mitigation along the coasts worldwide, including protection from storms and sea level rise, prevention of shoreline erosion, regulation of coastal water quality, provision of habitat for commercially important fisheries and endangered marine species, and food security for many coastal communities (Mchenga and Ali 2014; Laffoley &Grimsditch 2009).

Despite their benefits and services, blue carbon mangrove ecosystems are some of the most threatened ecosystems on the earth, they are disappearing three to five times faster than overall global forest losses, with serious ecological and socio-economic impacts. It is estimated that every year about 0.15 - 1.02 billion tons of carbon dioxide are being released from deforestation and degradation of blue carbon ecosystems, which account up to 19% of carbon emissions from global tropical deforestation (Pendleton*et al.* 2011).The loss of blue carbon ecosystems is caused by land-use change, over exploitation (for salt production, fuel wood supply and building materials) and pollution which reduce their carbon sink capacity and other ecosystem services offered by the blue carbon ecosystems. This is likely to exacerbate the effect of climate change and sea-level rise on blue carbon ecosystem (Lovelock et al. 2019).

Like many other parts of the world, the mangroves of Zanzibar are threatened by destruction intimately linked with both climate change (Watkiss et. al., 2012) and human activities such as harvesting for timber and fuel-wood (Hussein, 1995; Semesi, 1998), land reclamation for aquaculture and salt-pond construction (Terchunian et al.1986; Primavera 1995; SONARECO 2008). Due to the preceded consequences, this study aimed to quantitatively estimate the blue carbon stocks among the dominant mangrove species of *Avicenia marina, Bruguiera gymnorrhiza and Rhizophora mucronata*,while considering friendly and less expensive ways in climate change mitigation.

1.2 Statement of the problem

The vital of blue carbon has long been recognized globally as effective carbon sink and considered as a 'proxy'[2] for a collection of outcomes: including mitigating climate change effects, support of food security and the building of social-ecological coastal resilience. However, clearance of these forests reduces their sequestration and mitigation power; in turn make them a significant source of atmospheric CO_2 which contribute further to global warming. To date, there are few information concerning to blue carbon stocks of mangrove forests in Zanzibar, this restricts meaningfully participation on global carbon market. Also, inhibits productivity and effective conservation of mangrove forest against climatic events. In response to these problems, this study quantified the blue carbon stocks in mangrove forests while considering friendly and less expensive ways in climate change mitigation.

1.3 General objective

To assess the mangrove blue carbon stocks in Zanzibar.

1.4 Specific objectives

- To compare carbon contents among the dominant mangrove species.
- To quantitatively estimate the AGC and BGC among the dominant mangrove species.
- To compare carbon contents in sampled mangroves through different mangrove zones.

1.5 Research hypotheses

- **Ho**: There is no significant difference in carbon stocks between the three dominant mangrove species in Nyeke mangrove forest.

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[2] Proxy in this study means physical characteristics of possessing different roles.

- **Ho**: There is no significant difference in carbon accumulation between above ground and below ground parties among the dominant mangrove species.
- **Ho:** There is no significant relationship between mangrove species and zonation factors in carbon accumulation in Nyeke mangrove forest.

1.6 Significance of the study

- To constitute onsustainable blue economy for social and environmental benefits as blue carbon mangrove ecosystem plays an important role in recycling nutrients, regulating climate and temperature.
- Also, to have a meaningful participation on global carbon market based on the idea that quantified blue carbon stored in natural mangrove ecosystem can be sold as credits by the community.
- Understanding the blue carbon stocks helps in the proper conservation of mangrove forests with positive implication to, tourism, seaweed farming and fisheries in Zanzibar Island.

CHAPTER TWO

LITERATURE REVIEW

2.1 Mangrove blue carbon

According to McLeod et al. (2011), blue carbon refers to carbon stored or sequestered in vegetated marine including mangrove forests, salt tidal marshes and seagrass meadows. Mangrove blue carbon ecosystemsare found along protected coastlines in the tropics and subtropics where they satisfy significant functions in term ofstoring organic carbon over millennium, providing wood and non-wood forest products such as coastal protection, conservation of biological diversity and provision of habitat, spawning grounds and nutrients for a variety of fish and shellfish (FAO 2007; Taillardat et al. 2018). They are also characterized to survive in harsh environment with high salinity, high temperature, high tides, high sedimentation and in anoxic mudflat where other vascular plants are unable to survive (Giri et al., 2010; Lupembe, 2014).

2.2 Values of mangrove ecosystem services to the local communities

The mangrove ecosystems offer the significant benefits to the coastal communities that include: providing protection from climate change events such as storms, shoreline erosion and sea-level rise, such value of mangrove in coastal protection has been observed following the 2004 Indian Oceanic Tsunami (Barbier, 2007); regulate coastal water quality and climate (Herr et al., 2011); functioning as a supporting materials or habitat, mangroves can provide variety of foods such as fish, crabs, birds and marine animals (Mchenga and ali, 2015); also, provide natural herbs for local treatment and building materials (timber and wood) Pendleton, et al., 2011; offers education opportunities and recreation of tourists in cultural value (Herr and Laffoley, 2011).Thus, based on Payment for Ecosystem Services (PES) schemes, quantification of the blue carbon stocks had made them attractive for protection and restoration of mangroves (Donato et al., 2011).

FAO (2007) revealed that, mangroves protect the coast against erosion due to wind, waves and water currents and protect coral reefs, seagrass beds and shipping lanes against siltation. Also, they host a number of different animal species including endangered mammals, reptiles, amphibians and birds; offer nutrients to the marine food web and provide spawning grounds to a variety of fish and shellfish, including several commercial species. Thus, mangrove deforestation threatens the survival of these species and contributes to land erosion and salinization of coastal soils.

According to Laffoley & Grimsditch (2009), it is cost effective to invest in the conservation and restoration of mangrove blue carbon ecosystem as a means of decreasing atmospheric carbon meanwhile the income that can be generated through conservation of their blue carbon sequestration potential may be comparable to the income of many of the common causes of conversion or degradation for fish ponds, livestock or farming. Where such carbon financing may be derived from a carbon market or other regulatory mechanism like the REDD+, NAMAs or CDMs. (Caplow et al. 2014) noted that the nonprofit international organization: CARE International worked with JUMIJAZA; a federation for community forestry in Zanzibar which served as carbon aggregator by managing the sale of carbon credits through voluntary carbon markets putting emphasize on pro-poor and gender equitable. Thus, restoration of mangrove forests is not only to be encouraged based on ecological or socio-economic considerations, but also have the potential of providing an efficient long-term sinks as they bind carbon for millennial time scales (Bryan, et al., 2015).

2.3 Mangrove extinction

Global mangrove forests cover has declined to < 1% of the earth's continental surface (Girr et al. 2010). While, in Africa the decline is estimated to fall in average of 25 % (FAO 2007). In Tanzania mangrove loss is about 1,455 ha from the year 1990 to 2000 (Njana et al. 2015). These losses are largely due to over-harvesting for timber and fuel-wood production, reclamation for aquaculture and salt pond construction and pollution that alter water salinity levels (Laffoley & Grimsditch 2009). Mangrove extinction may also be caused naturally by strong wind

(hurricanes and cyclones) as they stand as natural barrier against sea surges, the lack

of this precious ecosystem in coastal habitat tend to increase its vulnerability to climatic stressors resulting to serious inundation and erosion of the coastal habitat (Mangor 2021). Extensive disturbance of mangrove carbon stocks may results to very high emission of green house gases like carbon dioxide and methane which currently contributed to respiratory diseases from air pollution and food demand interruption due to extreme weather conditions (Alongi2014).

Zanzibar as small Islands in Tanzania, its mangroves cover an area of about 16,488 ha as reported by the inventory of 2012 using rapid eye images. However, its loss is about 542 ha in a period of 20 years between year 1992 to 2012 (Mchenga and Ali 2014). (Mchenga and Ali 2015) argued that mangroves are threatened by both anthropogenic and natural factors; the natural factors mainly included the global climate change, which has associated effects on rising of temperature, increasing level of carbon dioxide, change in precipitation pattern, storminess and sea-level rise. However, gradual sea level rise in recent years poses significant threat to the mangroves of Zanzibar, where the rising trend exceeded the limit of which mangroves can cope.

IPCC, (2007) observed that the loss of mangroves is more significant for small islands as being more vulnerable to sea level rise and shoreline erosion caused by climate change and climate variability. Studies have shown that mangrove forests in some small islands will be lost as a result of elevated sea levels. For example, it is projected that with a 1-m sea-level rise in Cuba, more than 300 ha of mangroves, representing approximately 3% of that country's forests, would be at risk. Barbier (2007)reported the same cases, where in Andaman and Nicobar Islands in India there have been a loss of 20 km^2 of mangroves, due to the effects of Tsunami in December 2004. Also, the declining territorial division of mangroves and the resulting impacts on ecosystem services has led to negative impacts on social welfare at the local level, on the costal communities of Zanzibar that rely on mangrove resources for their livelihoods such as availability of food and tourism recreation (Quinn, et al., 2017).Thus, conservation of mangrove forests as a blue carbon sinks will help to mitigate climate change impacts in a low cost and friendly environment, especially in small Islands as being characterized by having insufficient financial, technical and institutional capacity to adapt to climatic events (IPCC, 2007; Metra and Zamani, 2015).

2.4 Biomass estimation and uncertainty

The blue carbon sequestered within mangroves are stored above ground (tree trunks, stems and leaves), below ground (roots and rhizomes) in term of plant biomass and in carbon rich organic soil (Laffoley & Grimsditch, 2009). The largest proportion of above ground biomass was stored in height class 5 (18m - 28.9m) and height class 6 (29m - 35m) Fatoyimbo et al., (2018).

Biomass in mangrove forest can be estimated by using two main methods as follows;

2.4.1 The direct (harvest) methods includes:

The harvest method**:** involves uproot or destructive harvest of all trees to obtain some of the required tree variables including wood density or dry weight of the samples (Komiyama, 2005).This method is undesirable to be used in mature forests to most researchers and it is non reproductive as all trees must be destroyed which is beyond the goal of conservation. Thus, an alternative is to develop non-destructive methods of measuring tree biomasses (Jachowsk et al., 2013).

The mean tree method**:** is used only in forest with a homogenous tree size distribution like in estate forests or plantation. Few trees are cut down for measurement and results are generalized due to uniformity of the forest structure (Komiyama, 2005).

2.4.2 An indirect (no harvest) methods include:

The allometric method: a non-destructive method that estimates the whole or partial weight of a tree from measurable tree dimension such as trunk dbh and height using general or species specific allometric equations. It is more reasonable to be used in the reserved forests as it does not involve any cut of trees (Komiyama, 2008; Njana, 2015).

Remote sensing method: is used to quantify mangrove biomass of greater forest by using a machine learning model.It is very expensive to operate and its data are difficult to interpret. For example, evaluation of remote sensing model may over estimate biomass at low observed values or under estimate at high values (Jachowsk et al., 2013).

Adame et al., 2011 observed that, in mangrove forest with low salinity and truncated tree density, biomass values derived from allometric equations that were not locally developed are likely to be highly uncertain, to reduce error in biomass estimation species-specific allometric equation should be used where possible. Also, coring or narrow trenching in the field largely underestimate root biomass and this should include depth of at least 45 cm deep. Mangrove biomass is likely to be higher in dense forest, with tree of small DBH, where salinity is high and tidal flooding is infrequent (Adame et al., 2011). Mangroves store much of their biomass into their root system because environmental conditions are more extremes at the root level than at the above ground parties (Komiyama et al., 2008; Nurruhwati, 2018).

2.5 Blue carbon estimation

According to Lubembe (2014), *Rhizophora mucronata* stored the highest amount of carbon per unit area (39.87%) followed by *Avicenia marina* (28.06%) and *Bruguiera gymnorrhiza* (15.61%) to the total carbon stocks by using destructive samples. Nurruhwati, (2018) on the same case examined that the carbon content of *Rhizophora mucronata*was of higher value than the *Avicennia marina* type. The total carbon content of *Avicennia marina* was 67.5 % while it was 93.42% in *Rhizophora mucronata*by using the harvest method.

2.6 Blue carbon implications to climate change

Climate change has presented greater efforts on quantification of carbon sequestration capacity of mangrove forests as they play role in global carbon budgets (Herr and Landis, 2016). Mangrove blue carbon ecosystems are highly productive and have been sites for fulfillment of human needs through provision of their services and thus, many small Island states will be focused on "keeping the green economy blue" for effective mangrove ecosystem management for its benefits for coastal communities (Lovelock, et al., 2019; Herr at al., 2017). Based on the same scenario, the Revolutional Government of Zanzibar through its national development agenda observed to address the the challenges facing oceanic resources such as climate change and unsustainable human activities so as to build a sustainable blue economy for social, environmental and economic benefits (UONGOZI Institute, 2021)The IPCC introduced the guidelines on the blue carbon within the NAMAs and REDD+ as win-win financial instrument for promoting climate change mitigation and preserving the blue ecosystems while improving local livelihoods. (UNFCCC, 2011; Herr et al., 2017). Thus, blue carbon has received international attention as a climate change mitigation tool due to its high carbon sequestration and storage capacity (Taillard et al., 2018).

CHAPTER THREE

MATERIAL AND METHODS

3.1 Study site

Zanzibar is composed of two major islands: Unguja and Pemba located in the Indian Ocean about 25–50 km off the east coast of the Tanzania mainland. This study was conducted in Nyeke-Uzi Mangrove Forest in the Uzi Island which lie between 619“ and 624` S and 39 25` E on southwest coast of main Island of Zanzibar (figure 1) The area is characterized by a tropical climate with a long rainy season (Masika) occurs from March to May and the short rainy season (Vuli) occurs from October to November. The annual average rainfall varies between 1000 mm to 2500 mm. The hot season occurs during the NE monsoon period (Kaskazi) between December and February and a relatively cool, dry season (Kipupwe) occurs between June and September. The temperatures range between 17° and 40°C.

The mangrove forest is found both in sandy and rocky shore in northern tip and southern part of the Island within the Menai Bay Conservation Area close to Jozani Chwaka Bay National Park. The site has eight mangrove species being reported: *R. mucronata, B. gymnorrhiza, C. tagal, A. marina, X. granatum, L. racemosa, S. alba and P. acidula* (Mchenga and Rashid 2011; Mchenga and Ali 2014).

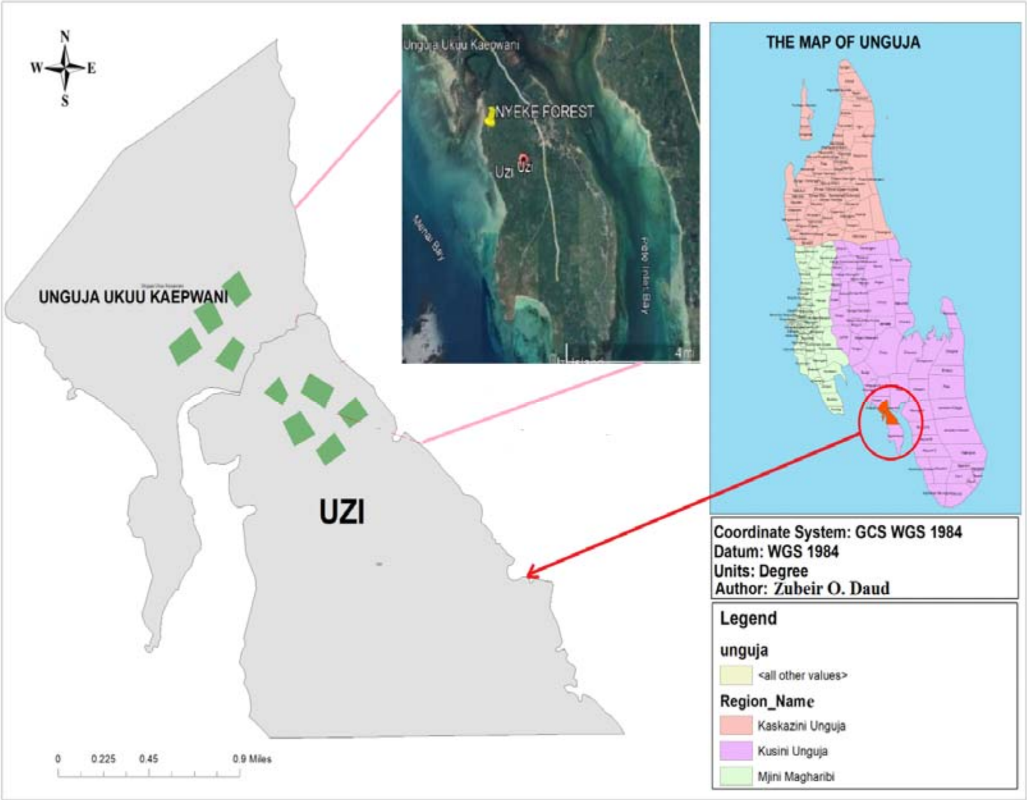

Figure 1: Map of Unguja-Zanzibar showing the study site and sampled field plots

3.2 Study design

Field survey method was used to describe information concerning the current status of the forest. This helped to get rich data for detailed analysis and recommendation. Also, **explorative design**was used to examine and reveals something from the field as findings that helped to generate new ideas, and techniques for future research (Nurruhwati et al., 2018).

3.3 Sampling methods

Random stratification was used where 3 strata (zones) were established based on tree species dominance, where the upper forest zone was dominated by *Avicenia marina*, middle zone dominated by *Brugueira gymnorrhiza* and lower zone dominated by *Rhizophora mucronata*.(Mchenga and Ali, 2015). GPS was used for tracking the plot area for developing the aerial photos and Map of vegetation. Nine (9) squered-temporary plots were settled along a randomly established 100 m transects where the largest plots measured 100 m^2.

3.4 Data collection methods

Random stratification method was used where 3 strata (zones) were established based on mangrove species dominance of *A. marina*, *B. gymnorrhiza* and *R. mucronata* at the upper, middle and lower zones respectively. 9 squared-temporary plots were established along a randomly 100 m transects where the plots were measured 100 m^2.

All mangrove components necessary to determine carbon stocks by allometric method were collected in each of the 9 established temporary plots. These includes the main stem diameters and height of all tree rooted within each plot (Howard *et al*. 2014). The diameter of *R. mucronata* trees was measured above the highest prop root while other mangrove species such as *A. marina* and *B. gymnorrhiza* were measured at 1.3 m above the soil surface (DBH). Trees > 3 cm in diameter were measured in a plot of 100 m^2 (Kauffman and Donato 2012). Basic data were recorded in individual mangrove tree in a plot including; species name, main stem diameter at breast height (DBH), tree height and location (Howard *et al*. 2014). Simple tools were employed for measurement such as the diameter tape for measuring DBH and field tape for measuring tree height supported by a very long pole.

a) b)

Image 1: measuring tree diameter: (a) at breast height (DBH), (b) measured above the highest prop root for *Rhizophora mucronata* at Nyeke forest-Zanzibar (picture: Zubeir 2020)

3.5 Data analysis

A two-tailed paired Student's t-test was used to compare difference in total carbon contents contribution between the above and below ground biomass. Variation in carbon content between dominant mangrove species in the upper, middle and lower mangrove zones were tested using a one-way analysis of variance (ANOVA). Post-hoc Tukey (HSD) and Fisher’s (LSD) tests were used to detect differences between treatments when significant differences were found. Results were considered significant if $p < 0.05$.

Allometric equations were used for biomass and carbon content estimation where tree diameter (DBH) and tree height were used as dependent variables, with exception of

B. gymnorriza that used the addition of wood density in its general equation. The equations were used to calculate both the above and below ground tree biomass for the three dominant mangrove species. Species- specific allometric formulas developed by Njana *et al*. 2015 for the mangrove of Tanzania were applied for the *R. mucronata* and *A. marina* biomass estimation, while the biomass of *B. gymnorrhiza* was estimated using the general mangrove equation by Njana *et al*. 2015 due to lack of its species-specific allometric equation (table 1). This equation represents average characteristics of mangrove species that were not covered in species-specific equation in the country.

Table 1: Selected allometric equations used in this study to estimate AGB and BGB of sampled mangrove species.

Species	**AGB allometric eq. (kg)**	**BGB allometric eq. (kg)**	**Equation type**
Rm	$0.19633*dbh^{2.10853}*ht^{0.29654}$	$1.4204*dbh^{1.68979}$	**species-specific**
A. m	$0.19633*dbh^{2.08791}*ht^{0.29654}$	$1.4204*dbh^{1.44260}$	**species-specific**
B. g	$0.353*p^{1.13}*dbh^{2.08}*ht^{0.29}$	$1.4204*dbh^{1.59666}$	**General equation**

Where, AGB = above ground biomass (kg), BGB = below ground biomass (kg), p = wood density (gcm^{-3}), DBH = diameter at breast height (cm), and HT = total tree height (Chave et al. 2005).

Table 2:Global wood density database for three mangrove species.

Mangrove species	**Wood density (kg m^{-3})**		
	Low	**Mid**	**High**
Avicennia marina	0.79	0.81	0.85
Bruguiera gymnorrhiza	0.63	0.84	1.05
Rhizophora mucronata	0.94	1.02	1.12

This study applied allometric method in biomass estimation because it was locally available in the same region where the study was carried out to reduce uncertainty (Adame et al., 2017). Also, it was less expensive in term of time and resource availability and also, it was friendly to be conducted in a protected mangrove forests as it was a non-destructive method (Haward et al,. 2015; Honorio and Baker, 2010).

3.5.1 Determination of Carbon stocks

Tree carbon was calculated by multiplying biomass by the carbon conversion factor of **0.48** for above ground biomass and **0.39** for below ground biomass as suggested by Howard *et al*. 2014. And carbon content per plot was calculated as:-

- AGC content of each tree (kg C) = above ground tree biomass (kg C) *carbon conversion factor (0.48).
- BGC content of each tree (kg C) = Below ground tree biomass (kg C) *carbon conversion factor (0.39).
- Carbon content of AGC per plot (kg C/m^2) = (AGC content of tree #1 + carbon content of tree #2 + carbon content of tree #n) / plot area (m^2).

- Carbon content of BGC per plot (kg C/m^2) = (BGC content of tree #1 + carbon content of tree #2 + carbon content of tree #n) / plot area (m^2) Kauffman and Donato (2012).

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Total blue carbon contents of mangrove dominant species

The results showed that *R. mucronata* contributed higher value of blue carbon contents of 8,323Mg C ha^{-1} (41.66%) followed by *A. marina* of 5,952 Mg C /ha (29.79%) and *B. gymnorrhiza* of 5,707 Mg C /ha (28.55%) (Figure 2). However, there is no significant difference in total blue carbon contents between reported mangrove species The observation showed that *R. mucronata* contributed higher amount of carbon contents as they have interconnected prop roots and large leaves that are highly distributed in large area becoming the dominant species among the rest. This results agreed with the previous works in Gazi bay, Kenya where total carbon content of *R. mucronata* was 62% of followed by *A. marina* and *B. gymnorhiza* 25% and 12.8% respectively (Githaiga 2013). Meanwhile, Lupembe (2014) reported that *R. mucronata* stored the highest amount of carbon per unit area (39.87%) followed by *A. marina* (28.06%) and *B. gymnorrhiza* (15.61%) at Rufiji Delta, Tanzania.

Image 2: the interconnected prop roots of *R. mucronata* at Nyeke forest-Zanzibar (picture: Zubeir, 2020).

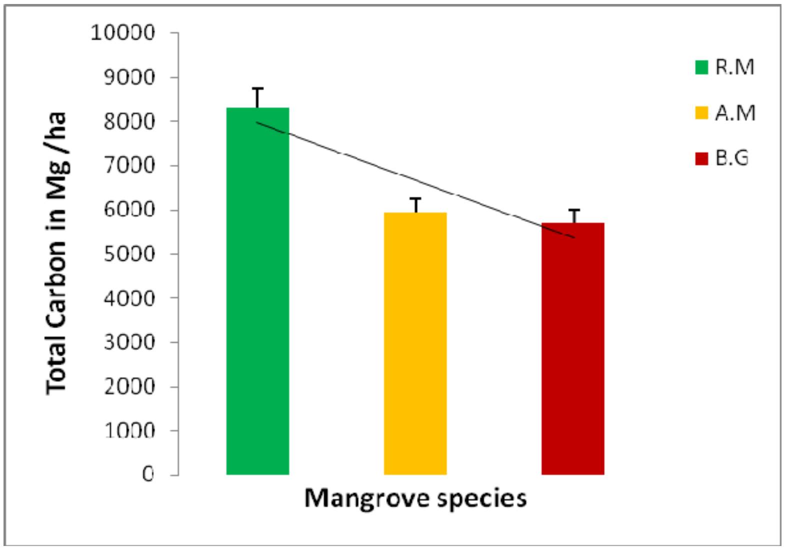

Figure 2. Comparison of total contribution of carbon contents in relation to mangrove dominant Species.

4.2 Contribution of AGC and BGC carbon content regardless of mangrove speciesand zonation

Regardless of mangrove species and zonation, contribution of above ground carbon content (AGC) to total carbon stock accounted significant higher 12,300 Mg C /ha (61.56%) than below ground carbon content (BGC) 7, 681 Mg C /ha (38.44%) (Figure 3, Paired *t-test*, *p*=<0.05). This resultsagreed with other studies at Mtimbwani-Tanga, the AGC measured 70% and BGC measured 21.93% (Alavaisha and Mangora 2016) and in Kerala-India, the AGC contributed 68.49% and BGC contributed 31.51% to the total mangrove carbon stocks (Harishma, Sandeep & Sreekumar 2020). In contrast, Kathiresam and Bingham (2001) adopted that BGC was the dominant component in mangrove ecosystem building a sedimentary carbon stock as it fixed carbon from different sources like through root transportation, dead wood and litter decomposition. However, Faridah-Hanum *et al*. (2012) showed that 50% of the total AGC was contributed by *R. mucronata* due to its enormous interconnected prop roots.

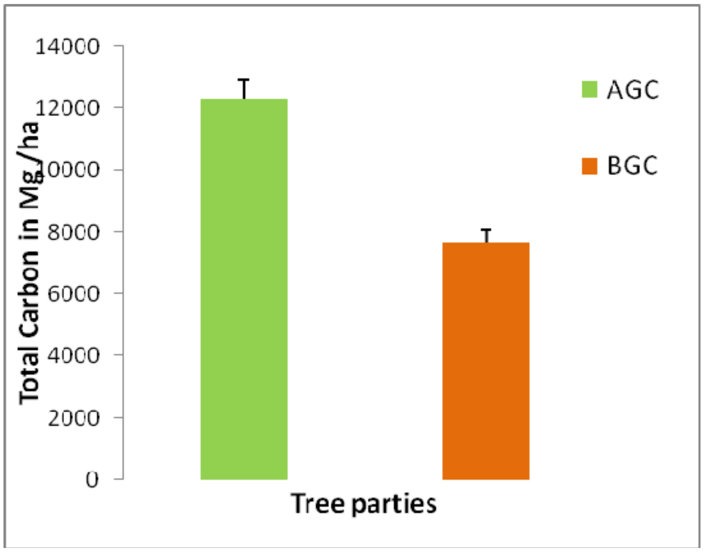

Figure 3. Comparison of total contribution of carbon contents in relation to mangrove tree parties (AGC & BGC).

4.3 Contribution of blue carbon contents by mangrove dominant species in relation to mangrove zonation.

Results of carbon contents among species varied in the upper zone where*A. marina* was significantly higher 4,941Mg C /ha (73.36%) than *B. gymnorrhiza* 1367 Mg C /ha (20.30%) and *R. mucronata* 427 Mg C /ha (6.34%) (ANOVA, *F*=6.7, df=2, $p < 0.05$). This is due to the fact that *A. marina* measured higher DBH value of 36.2 cm and maximum DBH of 128 - 250 cm than other two species. The value of DBH was observed to influence the amount of carbon content per individual tree. Whereas a tree with higher value of DBH, also showed to have higher amount of carbon contents.In the middle mangrove zone, *R. mucronata* contributed higher carbon contents of about 2,636 Mg C /ha (44.67%) followed by *B. gymnorrhiza* 2,253 Mg C /ha (38.18%) and *A. marina* 1,012 Mg C /ha (17.15%). However, there is no significant different in carbon content between *R. mucronata* and *A. marina* (ANOVA, *F*=2.9, df=2, $p > 0.05$). Similarly,*R. mucronata* recorded significantly higher in the lower mangrove zone 5,260 Mg C /ha (71.61%) when compared to *B. gymnorrhiza* 2,085 Mg C /ha (28,39%), (ANOVA, *F*=8.4, df=2, $p > 0.05$), meanwhile *A. marina* measured zero contribution because was not found in this zone (Table 2).

Table 3: Variation of the carbon contents (Mg C/ha) in sampled mangrove dominant species both above and below ground carbon. Values are mean (±SE), n= 6. Same letter at the top indicates no significant difference at $p < 0.05$; ANOVA followed by post hoc Turkey (HSD) and Fisher's (LSD) test.

	RM	AM	BG
Upper zone	427±134.11^{a}	4,940±999.90^{b}	1,367±347.40^{a}
Middle zone	2,635±525.29^{a}	1,011±303.69^{a}	2,254±127.39^{b}
Lower zone	5,260±1213.16^{a}	0.0±0.0^{b}	2086±181.41^{c}
Above ground	648.23±13.56^{a}	3,337.69±507.36^{b}	734.95±35.48^{a}
Below ground	839.72±22.23^{a}	557.26±62.40^{a}	671.84±22.11^{b}

There is significant higher contribution of the above ground carbon contents at the upper mangrove zone 5,120 Mg C /ha than the lower and middle mangrove zone 3,640 Kg C /ha and 3,540 Mg C /ha respectively (ANOVA, F=21.1, df=2, $p < 0.001$). However, there is no significant difference between the middle and lower mangrove zone. Meanwhile, below ground carbon contents were significantly higher at the lower mangrove zone 3,705 Kg C /ha than the middle 2,361 Mg C /ha and the upper mangrove zone 1,615 Mg C /ha (ANOVA, F=14.3, df=2, $p < 0.001$). Total blue carbon contents were higher in the order of lower zone > upper zone > middle zone (Figure 3).

Based on zonation, the above ground carbon contents of the upper mangrove zone 5,120 Mg C /ha (76.02%) was significantly higher than the below ground carbon 1,615 Mg C /ha (23.98) (ANOVA, $F = 6.7$, df = 2, $p < 0.001$).This is due to the fact that *A. marina* was dominant species having higher average DBH (36.2 cm) and higher average maximum DBH (128 cm) (Image: 3) than other sampled mangrove species. Similarly, above ground contents at the middle mangrove was significantly higher 3540 Mg C /ha (59.99%) when compared with below ground 2,361 Mg C /ha (40.01%) (ANOVA, $F = 2.91$, df = 2, $p < 0.05$). In contrary, there is no significant difference between below ground carbon contents 3,705 Mg C /ha (50.44%) and above ground 3,640 Mg C /ha (49.56%) at the lower mangrove zone (ANOVA, $F = 2.1$, df = 2, $p > 0.05$).

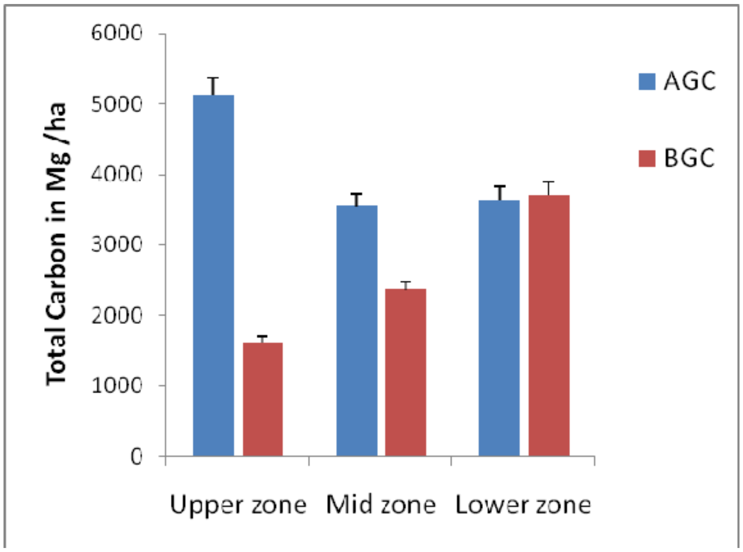

Figure 4. Comparison of total contribution of carbon contents by tree parties in relation to mangrove zonation.

Image 3: *Avicenia marina* with highest value of DBH among the sampled species (picture: Zubeir 2020)

4.4 Contribution of blue carbon contents by mangrove dominant species inrelation to above and below ground carbon.

The results of the average above ground (AGC) blue carbon among dominated mangrove showed that*A. marina* contributed the highest average carbon content of 3,338 Mg C ha^{-1} (70.70%) compared to *B. gymnorrhiza* 735 Mg C ha^{-1} (15.57%) and *R. mucronata* 648 Mg C ha^{-1} (13.73%). According toHarishma et al. (2020), the AGC value tend to be relatively low in the mangrove ecosystem close to the sea. In this study site, *A. marina* and *B. gymnorrhiza* occupied 47.4% and 19.2% of the upper mangrove zone nearby the land, while *R. mucronata* accounted for 66 % of mangrove species distribution in the middle zone (Mchenga & Rashid (2011). In contrast, the average carbon content of below ground (BGC) had been highly contributed by *R. mucronata* 840 Mg C ha^{-1} (39.35%) preceded by *B. gymnorhiza* 672 Mg C ha^{-1} (29.34%) and *A. marina* 557 Mg C ha^{-1} (31.34%). (Table 2). *R. mucronata* contributed the highest BGC due to the presence of massive interconnected prop roots that provide adaptive support against sea surges as they occupied the flooded zone. These results agreed with the previous works whose study revealed the average carbon content of 62% of *R. mucronata* followed by 25% of *A. marina* and 12.8% *B. gymnorhiza* inGazi bay in Kenya (Githaiga 2013).

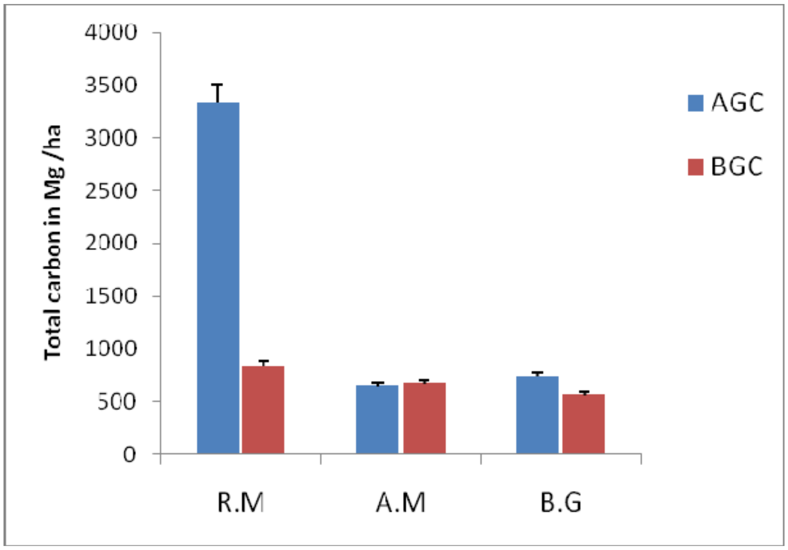

Figure 5. Comparison of total contribution of carbon contents by mangrove dominant species in relation to above and below ground carbon**.**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

Image 5: wet road dividing the Nyeke mangrove forest directing to Uzi Island of Zanzibar (picture: Zubeir, 2020)

5.1 Conclusion

This research aimed to assess the mangrove blue carbon by the use of allometric equations (non destructive method) to determine the biomass by using both DBH and tree height as dependent variables. The biomass obtained was then used to estimate the AGC and BGC contents among the sampled mangrove species. The results of this study indicated that the carbon contents of mangroves differed due to variations in DBH and tree height. Trees with higher DBH and height contributed high amount of carbon contents than trees with low DBH and height.*R. mucronata* contributed higher value of carbon contents (41.66%) followed by *A. marina*of (29.79%) and *B. gymnorrhiza*of (28.55%). Also, the carbon contents contributed by tree partiesindicated that AGC was higher (61.56%) than BGC (38.44%) and variation in zones based on carbon contribution revealed that the lower zone contributed higher (36.76%) followed by upper zone (33.71%) and mid zone (29.53%).

5.2 Recommendation

The international organizations such as WWF, IUCN, UNEP, UNDP and other organizations in concern, should provide substantial financial support to small Islands in developing countries for the trust of improving blue economy as the best action for valuing and conserving mangrove ecosystems for the long-term equitable benefit of their local people.

The ministry of blue economy as stack holder, should find external support for investing on carbon offset in this Island for the sake of reducing carbon emission to compensate emission made in higher income countries.

Also, other national level organizations concerning to blue ecosystem conservation such as NAMAs, CFM and JUMIJAZA should be on front line in emphasizing the use of electricity and gases as source of energy for cooking this could reduce over exploitation of mangroves for firewood and charcoal and in turn rises its carbon storage capacitythat can be sold as carboncredits.

To better understanding of the implications of these results, the coming studiescould address the relationship between sediment ratio and carbon contents in Nyeke mangrove forest for widening information along this scenario.

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APPENDICES

Appendix 1: ANOVA test results of AGC and BGC

Carbon parties		Std. error	df	F	Sig.
UPPER ZONE	AGC	162.12	2	6.738	.002
	BGC	17.83	2	8.145	.000
	Total C	178	2	6.761	.001
MID. ZONE	AGC	28.67	2	2.96	.055
	BGC	9.00	2	21.04	.000
	Total C	36.65	2	2.91	.057
LOWER ZONE	AGC	16.30	2	8.477	.000
	BGC	11.46	2	14.370	.000
	Total C	27.32	2	11.064	.000

APPENDEX 2:

RAW DATA FROM THE FIELD

RAW DATA FROM THE FIELD RECORDED FROM ONE PLOT IN UPPER ZONE

N/S	*R. mucronata*		*A. marina*		*B. gymnorhiza*	
	DBH (cm)	**TH (m)**	**DBH (cm)**	**TH (m)**	**DBH (cm)**	**TH (m)**
1	25.00	7.00	33.00	7.00	10.00	2.00
2	18.00	6.50	30.00	7.00	4.00	1.50
3	19.00	6.00	21.00	5.50	11.50	2.00
4	17.00	4.00	35.00	5.50	10.00	3.50
5	30.00	7.00	34.00	5.50	14.00	3.50
6	10.00	4.00	6.00	2.00	10.00	5.00
7	16.00	7.00	5.50	3.00	8.00	3.00
8	16.00	6.00	50.00	14.00	8.50	3.00
9	23.00	6.00	31.00	7.00	5.00	1.50
10	20.00	6.00	28.50	5.00	2.00	0.50
11	26.00	6.00	26.00	5.50	26.00	4.00
12	23.00	7.00	70.00	14.00	25.00	4.00
13	12.00	4.00	95.00	14.00	14.00	3.00

14	11.00	3.00	160.00	16.00	6.00	3.00
15	19.00	6.00	83.00	14.00	20.00	4.00
16	24.00	5.00	150.00	14.00	13.00	4.50
17	26.00	4.00	22.00	7.00	23.00	4.50
18	24.00	3.00	32.00	7.00	16.00	3.50
19	19.00	4.00	33.00	7.00	4.00	0.50
20	20.00	4.00	19.00	7.00	10.00	2.50
21	3.00	1.50	27.00	7.00	13.00	2.00
22	4.00	1.50	27.00	5.50	14.00	4.50
23	3.00	1.50	24.00	5.00	12.00	3.50
24	6.00	1.50	26.00	7.00	11.00	3.50
25	2.00	1.00	32.00	6.00	15.00	4.50
26	12.00	4.00	9.00	5.50	7.00	2.50
27	8.00	4.00	15.00	1.50	12.00	4.50
28	9.00	5.00	54.00	5.00	9.00	4.00
29	20.00	4.00	16.00	2.00	6.00	4.00
30	8.00	3.00	67.00	13.00	10.00	2.50
31	3.00	1.00	21.00	4.00	6.00	2.00

32	6.00	4.00	60.00	6.00	9.00	4.00
33	10.00	3.00	19.00	7.00	5.00	3.50
34	19.00	3.00	58.00	14.00	8.50	3.00
35	3.00	1.00	11.00	3.00	11.00	3.50
36	12.00	2.00	30.00	8.00	15.00	6.00
37	12.00	3.00	17.00	10.00	13.00	5.00
38	11.00	3.50	45.00	13.00	13.00	5.00
39	10.00	3.00	44.00	15.00	12.00	4.00
40	7.00	1.50	90.00	6.00	10.00	3.00
41	5.00	1.00	59.00	6.00	10.00	4.00
42	13.00	4.00	26.00	5.00	8.00	3.00
43	11.00	3.00	270.00	9.00	12.00	7.00
44	7.00	2.00	260.00	9.00	11.00	6.00
45	19.00	3.00	270.00	8.00	6.00	2.50
46	17.00	5.00	23.00	5.00	10.00	4.00
47	22.00	5.00	220.00	9.00	8.00	2.00
48	12.00	2.00	14.00	3.00	21.00	4.00
49	30.00	6.00	29.00	5.00	8.00	2.50

50	32.00	5.00	16.00	3.00	14.00	7.00
51	19.00	4.00	87.00	6.00	13.00	4.50