EVALUATION OF THE ROLE OF AGROFORESTRY SYSTEMS AND PRACTICES ON THE CLIMATE CHANGE ADAPTATION AND MITIGATION IN THE KILOMBERO CLUSTER OF SAGCOTS. KILOMBERO TANZANIA

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

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EXTENDED ABSTRACT

Agroforestry systems and practices comprise of a long list of land management practices. Well-managed agroforestry can play a crucial role in improving resilience to climate change. Climate change adaptation involves actions to reduce or eliminate the negative effects of climate change or taking actions for the positive effects. Mitigation involves any activities related to the reduction of greenhouse gas emissions in the ecosystem. Agroforestry has been practiced for a long time in Kilombero and various government and non-governmental organizations have been facilitating their implementation to overcome the impact of climate change and enhance resilience. This seems an important aspect in implementing the Kilombero SACGOT cluster framework as it's likely to contribute to multiple value chains being addressed by the cluster. Despite agroforestry being considered as the best option for climate change adaptation and mitigation in Kilombero, there is a little information on the agroforestry systems and agroforestry practices that are more potential for climate change adaptation and mitigation since they are difference in practical. Therefore, a study was conducted in the Kilombero cluster of Sagcot in Kilombero District aiming to evaluate the role of agroforestry systems and practices in climate change adaptation and mitigation. The specific objectives of the study were to identify the agroforestry systems and practices, to determine the role of agroforestry systems and practices in climate change adaptation, to determine the socio-economic factors influencing the adoption of agroforestry systems and practices, and to quantify the role of systems and practices in carbon capture and emission mitigation. Household surveys were conducted in a community with agroforestry farmland. Key informant interviews were carried out with government officials, and focus group discussions involved people who had stayed in the study area for a long time and who had the best history of climate change trends. A biophysical survey was conducted on the farmland where the diameter and height of trees were measured. The collected data were analyzed through descriptive analysis, one-way ANOVA and multinomial logistic regression. Data from biophysical survey were subjected to allometric model for biomass and then carbon stock computation. Data were analyzed using descriptive statistics to identify different agroforestry systems and practices in Kilombero, one-way ANOVA to show the influence of different agroforestry systems and practices on increasing the adaptive capacity through contribution of household income, multinomial logistic regression was used to determine the determinants factor influencing the adoption of agroforestry, and quantitative data from biophysical survey were subjected to an allometric model for carbon stock computation.

The results revealed that the major agroforestry systems in Kilombero District are agrosilvopasture, agrosilviculture and silvopasture, while the agroforestry practices are home garden, boundary planting, mixed intercropping and parkland. The diversification of the systems and practices through agroforestry ensures multiple and diverse products from the land such as fruits, timber, fodder, and wood fuel. These were significant in sustaining production all the seasons thus enhancing resilience to climate change variability. Agroforestry practices had no statistically significant differences in increasing adaptive capacity through contribution of household's income. On the other hand, agroforestry systems showed to be statistically significant differences in increasing the adaptive capacity through their contribution to household income, $P<0.05$. The most significance systems in income generation were agrosilvopasture and agrosilviculture. The results on determinant factors influencing the adoption of agroforestry, using Multinomial logistic regression showed that time for staying in the village, residence type, extension services, and sex had statistically significant differences in determining the adoption of agroforestry practices while sex and residence status had statistically significant differences in determining the adoption of agroforestry systems ($P<0.05$).According to the findings of an ecological survey, *Mangifera indica* sequestered higher carbon 70.57 Mg C ha^{-1} than other species encountered in the agroforestry systems and practices. Home gardens, mixed intercropping, parkland, and boundaries planting sequestered 185.79 MgCha^{-1}, 17.79 MgCha^{-1}, 26.75 MgCha^{-1}, and 23.22 MgCha^{-1}, respectively. With respect to agroforestry systems agrosilvopasture sequestered the highest amount of carbon (115.3MgCha^{-1}) followed by silvopasture (81.5 MgCha^{-1}). and agrosilviculture (55.7 Mg C ha^{-1}). The study concluded that agroforestry contributes significantly in increasing the resilience to climate change mitigation through carbon sequestration as well as climate change adaptation through the use of different agroforestry products. Therefore, agroforestry should be taken into consideration in the agriculture value chain of Kilombero cluster.

DISSERTATION ORGANIZATION

This dissertation is organized into six chapters, being preceded by an extended abstract which summarizes the study by providing the objectives, materials and methods, principal research findings and conclusion. Chapter one presents the general introduction covering the background information, literature review, problem statement, justification of the study, objectives and research questions. Chapters two, three, four, and five present results obtained from the specific objectives which are synthesized in the manuscript. The synthesized manuscript will be submitted for publication in a peer reviewed scientific journal. Chapter six presents the general conclusions and recommendations.

DECLARATION

I, LAZARO ELIBARIKI NNKO, hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has not been or is currently being submitted for a degree award at any other institution.

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LIST OF ABREVIATIONS AND ACRONYMS

AF	Agroforestry
AFPs	Agroforestry practices
AFS	Agroforestry systems
AGB	Above ground biomass

BGB	Below ground biomass
C	Carbon
Dbh	Diameter at breast height
H	Height
Ha	Hectare
ICRAF	International center for research on agriculture and forestry
IPCC	Intergovernmental panel on climate change
Mg	Megagram
SAGCOT	Southern Agricultural Growth Corridor of Tanzania
SPSS	Statistical Package for Social Sciences
URT	United Republic of Tanzania

CHAPTER ONE

1.1 INTRODUCTION

1.2 Background information

Agroforestry (AF) has been defined in several ways (Nair 1989). Currently, International center for research on agriculture and forestry defines AF as a collective name for land-use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land-management unit, either in some form of spatial arrangement or temporal sequence in which there are both ecological and economic interactions between different components (Kang, 1992; Sanchez, 1995; Leakey, 1996; Leakey, 2017).

Also (AF) is referred to as a new name for an ancient land use practice and is just a compromise between agriculture and forestry (Raj *et al*., 2014; Raj *et al*., 2016). Therefore, AF can be defined as an efficient and integrated land use management system by raising a certain agricultural crop, forest tree species, and/or animals simultaneously or sequentially on the same unit of land with appropriate management practices, which results in an overall increase in production under a particular set of climatic and edaphic conditions and the social economic status of the local people (Raj *et al*., 2016). As a form of land use, AF offers a more viable opportunity as it appears to be more environmentally friendly in maintaining and enlightening soil fertility status, particularly in developing countries where low capital farmers exist (Oyebade *et al*., 2010).

AF is categorized into Agroforestry systems (AFS) and Agroforestry practices (AFPs) (Ajayi, 2006). AFS and AFPs have been referred to as the best options due to their potential for addressing various on-farm adaptations and fulfilling many roles in agriculture, forest and other land uses. Moreover, AF provides ecosystem services while mitigating climate change impacts by capturing carbon from the atmosphere through photosynthesis and storing it in biomass and soil (Albrecht and Kandji, 2003; Mbow *et al*., 2014). Practices such as intercropping short and long-term trees with crops can lead to higher crop production in many parts of the tropics (Hall *et al*., 2005) and increase well-being (Thorlakson and Neufeldt, 2012; Dinesh *et al.*, 2017).

In Tanzania like in other countries in Sub-Saharan Africa, AF has been practiced for many years. AFS and AFPs have been used to keep trees, agricultural crops, and animals productive while also increasing adaptive capacity and mitigating climate change variability (Simmons *et al*., 2002). It is for this reason that the government of the United Republic of Tanzania introduced the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), with the aim of improving agriculture production, while maintaining and conserving biodiversity (Kangalawe, 2012).

Kilombero is one of the clusters in the SAGCOT, and AF has been practiced by the local community (Milder *at al*., 2012) over the years. Local communities have been using AF to diversify income, increase farmers' resilience to climate variability, buffer crop failure, and increase carbon sequestration, hence climate change adaptation and mitigation. Following the

AF potential, this study evaluated the agroforestry systems and practices that affect climate change adaptation and mitigation.

1.3 Literature Review

1.3.1 Overview on Agroforestry

In the last three-decades, AF has been widely promoted in the tropics as a natural resource management strategy that attempts to balance not only agriculture development, but also conservation of soil, water, local regional climate, and more recently, biodiversity (Schroth *et al*., 2004). On-farm trees have promoted biodiversity and agricultural production for the local community in Africa. This has proved the past notion that the conservation of biodiversity can only be promoted through the management of protected areas and natural forests (Acharya, 2006).

1.3.2 Agroforestry systems

Agroforestry system is a specific local example of a practice, characterized by environment, plant species and their arrangement, management, and socioeconomic functioning (Nair 1993). According to Nair *et al.* (1989), based on the nature of the components, AF can be grouped into three systems, agrosilviculture (trees and crops), silvopasture (animals and trees) and agrosilvopasture (trees, crops and animals). Local communities in many parts of Africa have shown a great response in developing farming practices to meet their needs and minimize risk. However, this system can be grouped into temporal or spatial arrangements.

In spatial arrangement, the components are arranged in respect to space in the management unit. This can result to mixed and dense stand of plant species while, in temporal arrangement, the growing periods for food and tree crops on the same plot of land are separated by time (Kang and Akinnifesi, 2000).

1.3.3 Agroforestry practices

Agroforestry practices describe the distinctive arrangement of components of AFS in space and time (Nair 1993). Generally, AFPs offer practical ways of applying various focused knowledge and skills to the development of sustainable rural production systems. In AFPs, the grown trees do not have the usual silvicultural recommendations in terms of spacing (Owonubi, 2002), and the trees grown on different farms in the same locality when combined can bring about-better wooded situations, thereby enhancing environmental protection (Otegbeye, 2002). A home garden, boundary, live fence, alley farming, parkland, and mixed intercropping are examples of common AFPs (Repping *et al.*,2020). Another term that is also frequently used is agroforestry technology which refers to an innovation or improvement, usually through scientific intervention, to either modify an existing system or practice, or develop a new one. Technologies are often distinctly different from the systems and practice (Nair 1993).

1.3.3.1 Parkland

Parkland practices are also referred to as tiered practice. It is described as a practice where the farmer plants scattered trees of a wide variety on the cropland. Generally, parkland incorporates several agroforestry tree species for fire wood, medicine, food and nutrition (Faye *et al*., 2010; Faye *et al*., 2011). Parkland agroforestry practice further provides four broad ecosystem services, which are; provision services, regulation services, supporting services, and cultural services.

1.3.3.2 Live fence

This practice is frequently used as a life fence post in the tropics, especially in cattle farms (Somarriba *et al*., 1998). They are regarded as important by farmers as they protect homes from strong wind and protect the field crops from livestock and theft (Maroyi, 2009).

1.3.3.3 Alley farming

In alley farming, food crops are grown in an alley formed by a hedgerow of trees and shrubs, preferably nitrogen fixing species (Somarriba *et al*., 1998). Some of the principles of alley cropping have already been practiced for sustaining crop production with upland farming, particularly on sloping land, by traditional farmers in various regions of tropical Africa (Kang, 1991).

1.3.3.4 Home garden

A wide range of useful woody perennial and annual crops as well as animals are managed close to the household in a way that resembles the natural forest and provides food for the family throughout the year (Somarriba *et al*., 1998). Continued cultivation and use of the home garden over the past millennium have played a key role in the successful achievement of sustainable livelihood (Mayori, 2009). In Tanzania, the home garden has been the dominant agroforestry practice due to its integration of livestock keeping and food crops such as bananas, maize, beans, cassava, sweet potatoes, cocoa, and coffee (Rugalema *et al*., 1994)

1.3.3.5 Mixed intercropping

This refers to the practice in which crops are grown in strips between rows of the growing trees. In this practice, trees are periodically pruned to reduce shade, control erosion and to promote mulch for associated crops (Somarriba *et al*., 1998). Combining trees and crops in a systematic arrangement in the same field protects the arable land against wind erosion, and it can improve the soil nutrient balance (Yin and Hyde, 2000). For example, in northern China, Paulownia (*Paulownia elongata*) is intercropped with wheat and beans to enhance the suitability of the microclimate for wheat and beans. On the other hand, Poplar (*Populus tumentosa*) is intercropped with cereals and cotton (Hong *et al*., 2017). As long as the trees are young and their resource capture is small, such agroforestry practice is a type of cropping beneath trees (Wang *et al.,* 2016). However, mixed intercropping is more complicated to manage than single crops, and mechanization is often not available, so mixed intercropping becomes labour intensive (Feike *et al*., 2012).

1.3.3.6 Boundary Planting

In boundary planting practice, wood perennials (trees and shrubs) are planted along the boundary to obtain various wood products and for demarcation to reduce boundary conflicts, which are among the major causes of land conflicts (Maduka, 2007). Usually, the common boundary planting in agroforestry is observed as a single line of woody perennials trees or shrubs (Mbwiga, 2016).

1.3.4 Climate change mitigation through agroforestry

1.3.4.1 Climate change mitigation

According to IPCC (2007), climate change mitigation is described as an intervention to reduce emissions sources or enhance the greenhouse gas sink. As one of the sustainable resources management, AF can help to reduce agricultural greenhouse gas emissions through energy conservation, promote levels of carbon-based input processes example photosynthesis, lower use of synthetic fertilizer, and other features that minimize greenhouse gas emissions and sequester carbon in the soil. AF has been recognized as afforestation and reforestation activities for promoting greenhouse gas (GHG) mitigation under the Kyoto protocol (Nair *et al.*, 2009). Compared with other resource uses such as pastures and agriculture, AF can sequester a high amount of carbon in the soil because of the increased rate of organic matter addition and retention (Kirby and Potvin, 2007; Sharrow and Ismail, 2004). But AF requires proper management to influence the amount of carbon to be sequestered (Paudel *et al.*, 2017; Tefera *et al.*, 2019). Most of the research in Africa shows that all the agricultural land management activities suggest greenhouse gas mitigation, but AF can be worth affective if UV has been most widely applied (Brown *et al.*, 2018).

1.3.4.2 Carbon sequestration in agroforestry

Carbon sequestration can be defined as the uptake of carbon containing substances, in particular carbon dioxide, into another reservoir with a longer residence time (IPCC, 2007). On the other hand, carbon sequestration is fixing atmospheric carbon dioxide in physical, chemical, or biological processes into long lived carbon pools such as oceans, vegetation, or geologic information in a manner that it is not re-emitted back into the atmosphere in the near future (Kumar *et al*., 2019). AFPs and AFS have a higher potential to sequester atmospheric CO_2 than crop land, pastures, or natural grasslands since they have the potential to store carbon in the soil and wood biomass. Carbon assessment in the Philippines by Matthias (2006) indicates that carbon accumulation is higher in AFPs and AFS than in other land use systems such as grazing management, forestry management, and crop land management. Soil organic carbon in AF is generally high (> 150Mg/ha) due to continuous deposition of plant litter into the soil and relatively little removal of carbon from the Ppactices through the harvested product (Oelbermann *et al.,* 2006).

The atmospheric concentration of carbon dioxide and other greenhouse gases increased by 70% between the years 1970 and 2004 (Smiley and Kroschel, 2008) due to fossil fuel consumption, conversion of the forest into land for agriculture, pasture, industry, and the energy sector. Among the incentives to emit less and capture more greenhouse gases, agroforestry is credited with stocking a significant amount of carbon and has the potential to mitigate climate change (Montagnini and Nair, 2004; Nair *et al*., 2009).

1.3.5 Agroforestry as an adaptation strategy towards climate change

1.3.5.1 Adaptation and Adaptive capacity

Adaptation refers to the adjustments in a natural or human system in response to actual or expected climatic change or its effects to reduce harm or exploit beneficial opportunities (Singh *et al*., 2017). Adaptive capacity refers to the ability of an individual or groups of individuals to adjust to climate variability and change (Gupta *et al*., 2010) and accommodate shock and stress to the system. Adaptive capacity also includes a community's capacity to take advantage of the benefits and opportunities associated with climate change (Jones *et al*., 2010).

1.3.5.2 Agroforestry and adaptation to climate change

AF may provide a means for diversifying the production system and increasing the sustainability for smallholder farming systems. The most worrisome components of climate change from the point of view of smallholder farmers are the increased inter-annual rainfall and temperature (Matocha *et al*., 2012). A tree-based system provides multiple benefits, including economic and environmental values, which increase farmers' adaptive capacity. Trees with sprout characteristics have been mostly used due to high return and low cost of management (Charles *et al*., 2013). Also, agroforestry improves income due to its diversification with other crops, including bananas, timber, firewood, poles, fruits, and non-wood products. AF practices are known to be ecologically sustainable and diversify the livelihoods of local communities.

High diversity in AF has wide social, economic, and agroecological roles, including the production of food and a wide range of other products such as firewood, fodder, medicinal plants, and ornamentals (Unofia *et al*., 2012; Fernandes and Nair, 1990). The diversity of plants, in association with other organisms, contributes to the improvement of soil structure, retention of moisture, and nutrient levels. In addition, it promotes the recycling of nutrients, which reduces ecosystem vulnerability to climate change (Verchot *et al*., 2007). During drought, farmers maintain the AF as a coping strategy against climate variability and avoid long-term vulnerability by integrating trees with crops as insurance of food security (Pandey, 2007). AF has been observed as a guarantee in terms of sustainable adaptation as it becomes useful when one wants to secure basic needs during climate change (Eriksen and O'brien, 2007).

1.3.6 Socio-economic factors and agroforestry

Social-economic factors have been attributed to influencing the adoption of agroforestry (Kofi *et al*., 2003; Magugu *et al*., 2018). In the landscape, AF leads to the generation of enhancement of the desired ecological process, essential for sustainable land use (Alemu, 2012). However, high population pressure, land fragmentation, and poor market infrastructure are the key factors making AF a subject of study in Africa (Magugu *et al*., 2018). A study conducted in Ghana indicated that farming experience, access to extension information, proximity of a forest area and farmers, willingness to plant trees may influence the adoption of AF positively (Obeng and Weber, 2014). On the other hand, in Pakistan, communities with high education levels, large family sizes, high monthly incomes showed positive responses to the adoption of AF due to their ability to afford different resources and inputs necessary for AF (Irshad *et al*., 2011). Nevertheless, AF adoption has been limited by a number of factors. Mwase *et al*. (2015) reported that the barrier to adoption of AF is the high initial cost, including labour and herbicides, low extension capacity, seed availability, and poor tree management. Other factors include limited available land, stakeholders providing conflicting extension education, and the absence of a guiding policy on agroforestry. In some communities, trees are accorded second, or third, or even lower priority in developing countries compared to annual crops (Obeng and Weber, 2014).

1.4 Problem statement

Crop cultivation has been considered as a driver for deforestation and general land-use changes as crops are grown in cleared forest areas, replacing the forest ecosystems thus contributing to climate change in Kilombero district of Sagcot cluster (Labata *et al*., 2012). This has contributed to critical sustainability challenges due to its undesirable effects on the climate system, water resources, biodiversity, and human welfare (Turner *et al*., 2007; Lambin and Meyfroidt, 2011). The Kilombero district being one of the clusters in Southern Agricultural Growth Corridor of Tanzania a lot have been done to ensure environmental stability and conservation agriculture (Milder *et al*., 2012).

Despite the efforts by the government, Kilombero ecosystems and biodiversity have been highly affected by land-use change driven by human activities, mainly the opening up of large-scale commercial agriculture, small-scale farming activities and livestock keeping

(Msofe *et al*., 2019). Therefore, AF has been viewed as a land-use practice that complements food production while at the same time influencing the conservation of biodiversity (Rice and Greenberg, 2000). Previous studies by Kilawe *et al*. (2001), Msofe *et al*. (2019) and Abdi and Johansson (2019) conducted in Kilombero mainly based on land-use change and biodiversity recommended trees and crop integration to improve biodiversity conservation while improving agriculture production. Despite the acknowledgment of tree-crop integration in different literature, none of them described the types of systems and practices that should be implemented to enhance climate change adaptation and mitigation. Therefore, this study was designed to evaluate the impact of agroforestry systems and practices on climate change adaptation and mitigation.

1.5 Justification of the study

Information obtained from the study will be used as a reference by policy makers and various stakeholders to implement agroforestry project, especially in SAGCOT clusters. The study will justify the agroforestry systems and practices to be implemented with a high response to climate change mitigation and adaptation while improving agriculture production. The results will also assist climate change stakeholders to identify the contributions of different agroforestry systems and practices to climate change adaptation and mitigation. Moreover, these results will be a road map towards carbon trading in agroforestry farming.

1.6 Objectives of the study

1.6.1 General objective

The overall objective of this study was to determine the way agroforestry systems and practices contribute to climate change adaptation and mitigation in the Kilombero District.

1.6.2 Specific objectives

The specific objectives of the study were to;

i. To identify the agroforestry systems and practices practiced in Kilombero
ii. Determine the role of agroforestry systems and practices on climate change adaptation in Kilombero District
iii. Determine the socio-economic factors influencing the adoption of agroforestry in Kilombero District.
iv. Quantify the carbon stock in different agroforestry systems and practices in Kilombero District.

1.6.3 Research questions

This study was guided by the following research questions:

i. What are the agroforestry systems and practices practiced in Kilombero district?
ii. What are the available quantities of carbon stock in different agroforestry systems and practices?
iii. What role does different agroforestry systems and practices play in climate change adaptation in Kilombero?

iv. How socio-economic factors influence the adoption of agroforestry in Kilombero?

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CHAPTER TWO

2 Status of Agroforestry systems and practices in Kilombero District

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Abstract

Traditionally, agroforestry systems and practices are widely established to ensure that products produced are for household consumption and income generation. To improve understanding of agroforestry a study was conducted to identify the agroforestry systems and practices in Kilombero District. Three villages, namely Mbingu, Ngajengwa, and Igima, were purposely selected for the study. A questionnaire was administered to households to get the information on the AFS and AFPs they are practicing while a checklist was used for key informants' interview and focus group discussion. Descriptive statistics were applied for the data analysis to get the frequencies and percentages on different agroforestry systems and practices. The results showed that there is mainly three agroforestry systems and four agroforestry practices in Kilombero District. Home garden were most prevalent in Igima and Ngajengwa villages as revealed by 63.3% and 66.7% of the respondents respectively while Mbingu village was dominated by mixed intercropping practices (56.67%). On the other hand, agrosilvopasture was the most dominant system practiced in Igima and Ngajengwa villages by 56.7% and 66.7% respectively while in Mbingu village, the most dominant system was agrosilviculture with (66.7%). Alongside, several constraints to agroforestry practices were presented; the major identified challenge agroforestry were shortage of land. The study concludes that both agroforestry systems and practices have potential for the community as well as the environment. Therefore, agroforestry farmers should develop proper management in order to increase the number of agroforestry products to meet domestic as well as market demand. On the other hand, the study recommends that extension education should also be taken into consideration in order to assist farmers in implementing agroforestry systems and practices in an area with limited land resources.

Keywords: Agroforestry, Agroforestry systems, Agroforestry practices and Kilombero District.

2.1 INTRODUCTION

Agroforestry systems and practices have been used interchangeably in various articles. However, Nair (1989) pointed out that agroforestry systems are described based on the components (animals, crops, and trees) present in the agroforestry and agroforestry practices as an arrangement of the components present in the agroforestry system. Agroforestry systems and practices sustain production for increased socio-economic and environmental benefits for resources management uses at all levels (Icraf, 2006). Since agroforestry is now emerging as a promising resource use option, its productivity depends on the system that involves components available and their arrangements (Syampunan, 2010). In order to overcome the reduction of arable land, assure food security, and improve livelihoods, it is important to consider the systems and practices since their productivities and managements differ (Vincent and Mosango, 2012). Sanchez *et al*. (1997) pointed out that agroforestry systems and practices gave alternative solutions to poor smallholder farmers who would otherwise have a reduction in the crop products diversity and yield. However, unless farmers engage in agroforestry, the potential benefits for improved livelihoods and long-term environmental management will not be realized (Magugu *et al*., 2018). The purpose of this study was to identify the agroforestry systems and practices as well as identifying associated constraints.

2.1 Materials and methods

2.1.1 Description of the study area

The study was conducted in Kilombero District, which is located in Morogoro Region between 8°15'0" S and 36°25'0" E with elevation ranging from 262 m to 550 m above mean sea level. Administratively, Kilombero District has five divisions, 19 wards and 46 villages. The district is bordered by Kilosa District in the North, the South East by Ulanga District, the West by the Iringa Region and in the East by the Lindi Region (URT, 2007).

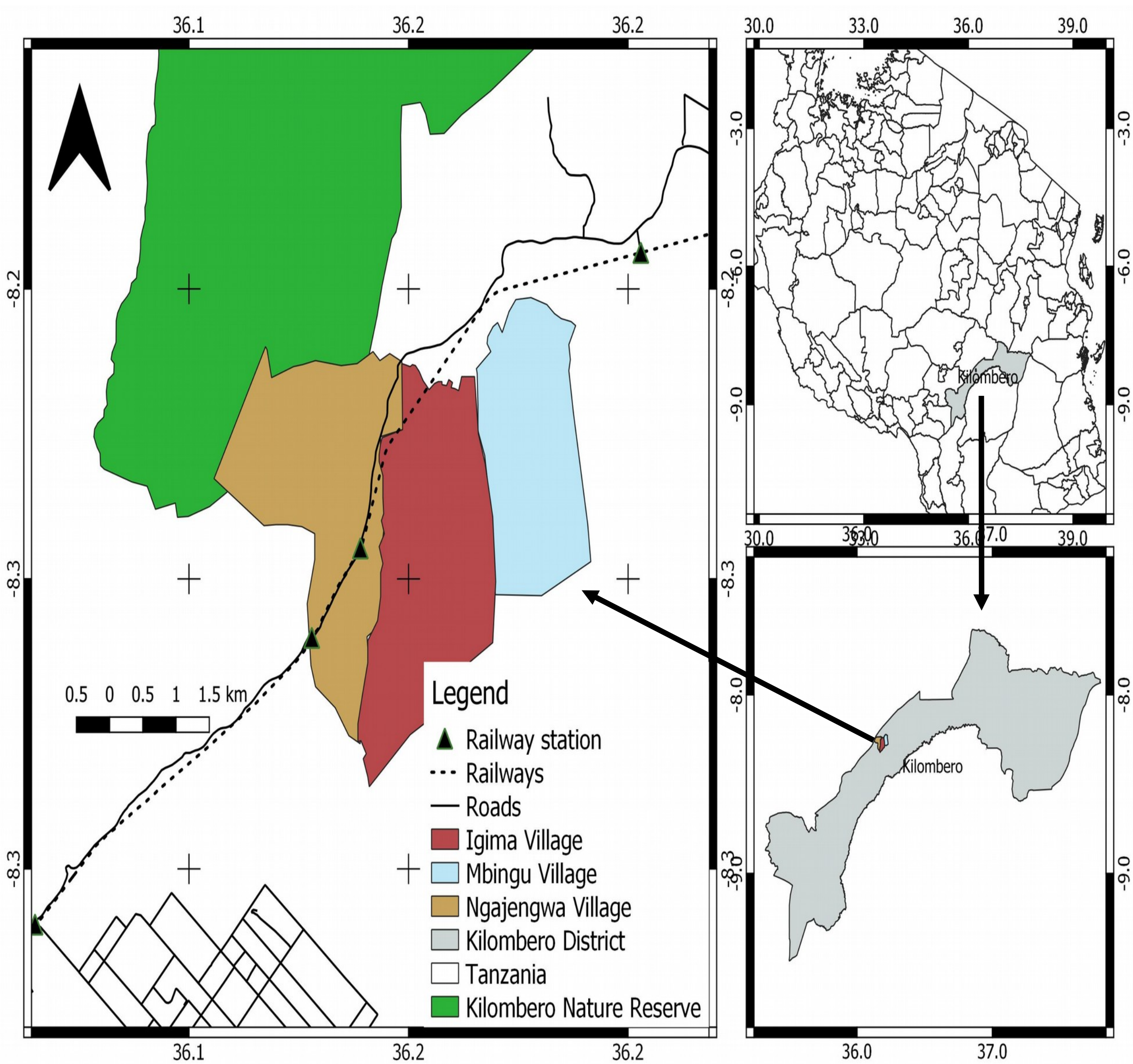

Figure 1 : Kilombero District map showing the study area

2.1.1.1 Climate

The climate in the study area is marked by wet and dry seasons, which are further categorized into four sub seasons, hot wet season from December to March, the cool wet season from April to June, the cool dry season from July to August, and the hot dry season from

September to November. The area receives between 1200 and 1800 mm of rainfall per year, and temperatures range from 26 to 32 °C (Balama *et al*., 2016).

2.1.1.2 Land use

Generally, the land use is categorized as village land, reserved land and general land as defined in the Village Land Act 1999 (URT, 2017). Meanwhile, Kilombero is considered as one of the fertile spots in Tanzania. The main economic activities in the area include cash crop cultivation, food crop cultivation, petty trading, and fishing in the Kilombero River (URT, 2007). Overall, cereals of the coast such as rice, millet and maize are widely grown. Also, vegetables such as sweet potatoes, yams, ground-nuts, melons, pumpkins, cucumbers and many other excellent food crops are grown. Tobacco is grown abundantly, sugar-cane, the castor oil plant, cocoa, and cotton are also cultivated (Bergius *et al*., 2020).

2.1.1.3 Population

According to the 2012 census, the population of Kilombero was 407 880, with 202 789 males and 205 091 females (URT, 2013). This area is currently experiencing a doubling of the human population over the years. It has been demonstrated that within Tanzania, population growth results in environmental degradation (Madulu, 2004). The large migration of farmers due to fertile land and livestock keepers due to the presence of animal fodder is the primary cause of population growth.

2.1.1.4 Soil

Geologically, the Kilombero is characterized by sedimentary basin infillings forming a seasonal alluvial floodplain dominated by Fluvisols (Beck, 1964 and Daniel *et al*., 2017).

Kilombero is covered by the flood plain. Since the area is characterized by wetland, the soil is mainly heavy black cotton (mbuga) soil that retains water over relatively long periods, with isolated patches of lighter sand soil. Annual flooding is a crucial factor in the maintenance of the fertility of the soil for vegetation. In other areas, soil originates from granites which are deeply weathered. Some parts of Kilombero soil are moderately acidic, poor, freely drained, and markedly compacted near the surface where there is often a very high coarse grained soil fraction. The soil is generally red loamy sand (latosol).

2.1.1.5 Vegetation

Natural vegetation in the Kilombero District depends on the gradients from the rivers. On the riverside, vegetation is often dominated by *Hyparrhenia spp.* and *Reed* (*Phragmites mauritianus Kunth*.), followed by the low-lying valley grassland with perennial grasses including Guinea grass (*Panicum maximum Jacq.*) marginal grasslands, *combretacoes* wooded grasslands, and last, miombo woodland and forests exist in the upper valley (Starkey *et al*., 2002). The natural forests and miombo woodlands occupy the large part of the district. Miombo is the Swahili word for the *Brachystegia* genus, which is the dominant tree in this natural environment together with *Julbernardia* and *Isoberlinia*, of the subfamily Caesalpinioideae. Artificial grassland and shrublands are also present due to human activities (Frost, 1996)

2.1.2 Methods

2.1.2.1 Reconnaissance survey

A pre-visit as well as pre-testing of questionnaires and checklists for clarity, comprehensiveness, redundancy, and meaningfulness were conducted. Also, this enabled the researcher to be familiar with the study area. During the survey, two households from each of the identified villages were randomly selected and interviewed to pre-test the questionnaire so as to check reliability and validity of the questions. Some corrections were made to meet the research objectives. The research design for this study was cross-sectional as data was collected at once in the study area without repetitions.

2.1.2.2 Sampling procedure

Three villages were purposely selected due to the presence of agroforestry farmers. Random sampling procedure was adopted for selecting households with agroforestry systems and practices, and village registers were used as a sampling frame. The sampling unit for this study was the individuals chosen from the population as respondents to represent others, and the information obtained can be used to describe the characteristics of the entire population (Bryman, 2004 and Nkonoki, 2015).

2.1.2.3 Sample size determination

Nachimias and Nachimias (1996) pointed out that sample size is the most important determinant of any survey estimates. The author continues to demonstrate that the greater the precision of the estimate and the confidence in the results, the larger the sample size is needed. These authors explain further that another factor equally important in determining the sample size is the amount of resources (time, money, and personnel) available for the study. Gay and Diehl (1992) describe that the number of respondents depends on the type of research involved, such as descriptive, correlational, or experimental. However, 30-unit subjects are good to establish the relationship in any research. This is similar to studies by Bailey (1998), Saunders *et al.* (2007), Mbeyale (2009) and Mtongani *et al*. (2014), who also indicated that a sample of 30 units is sufficient irrespectively of the population size and constitutes a representative sample size for data collection and analysis. On the other hand, investigations into socio-economic studies in Sub-Saharan Africa require a sample size of between 80 to 120 household respondents (Jew and Bonnington, 2011; McClanahan *et al*., 2005; Mtongani *et al.*, 2014). Therefore, a total of 90 respondents were sampled from the three villages (Igima, Mbingu and Ngajengwa) for interviews and this sample size was considered sufficient to generate statistical inferences required for making study conclusions.

2.1.2.4 Data collection

A variety of methods were used to collect primary data, including house hold interviews, key information interviews, and focus group discussions. The questionnaire was the main instrument for collecting the primary data from the agroforestry farmers and included both closed and open-ended questions. Focus group discussions enabled to get insights on status of agroforestry in the villages. Key informant interviews enabled to get more clarification on particular issues raised during the focus group discussion and interviews.

2.1.2.5 Data analysis

The qualitative information was analyzed using content analysis whereby raw data was broken down to generate meaningful units of information. The information obtained was then categorized and subjected according to study objectives and discussed to develop themes that answer the stated objectives. Information from the household survey was coded and assigned variables in SPSS and subjected to descriptive statistics. Outputs such as frequencies and percentages were obtained and discussed showing the status of agroforestry practices and agroforestry systems.

2.2 Results and discussion

2.2.1 Results

2.2.1.1 Socio-economic characteristics of the respondents

Table 1 presents the socioeconomic characteristics of the respondents. The results show that about 66.7 % of respondents had primary education, 16.7 % secondary education 12.2 % have no formal education and only 4 % have a college education. Almost 94.4 % of the respondents depend on farming as their main occupation, 3.3 % of the respondents are employed by the government and private organizations. The food industry and masonry had the same percentage, 1.1%.

About 83.3 % of the respondents were married, followed by 8.9 % of widowed, 6.7 % of single and 1.1 % of divorced. Most of the respondents (70.6%) had spent less than 35 years in the study area, indicating that most of the respondents were non-native residents.

Furthermore, the results show that respondents with 36 - 40 years were 12.2 %, 41 - 50 years were 9.9 %, 51-60 years were 5.5 % and those with above 60 years in the villages were 1.1%. The results also revealed that about 73.3% of the respondents migrated to Kilombero due to its potential in agriculture, and only 26.7% were native to the study area.

Table 1: Respondents and household socio-economic characteristics

Socio-economic	Characteristics	Frequency	Percentages (%)
Education level	Primary	60	66.7
	Secondary	15	16.7
	College/University	4	4.4
	Not attended	11	12.2
Marital status	Single	6	6.7
	Married	75	83.3
	Window	8	8.9
	Divorced	1	1.1
Occupation	Farming	85	94.4
	Employed	3	3.3
	Masonry	1	1.1
	Food business	1	1.1
Sex	Male	46	51.1
	Female	44	48.9
Residence	Native	24	26.7
	Non native	66	73.3
Length of stay	≤35 years	64	70.6
	36-40 years	11	12.2
	41-50 years	9	9.9
	51-60 years	5	5.5
	≥61 years	1	1.1

2.2.1.2 Agroforestry systems and practices in Kilombero

A total of three agroforestry systems were found in this study, and the agrosilvopastoral system was highly practiced in Igima and Ngajengwa villages. In Mbingu village, the most dominant system was the agrosilvicultural system (Figure 2).

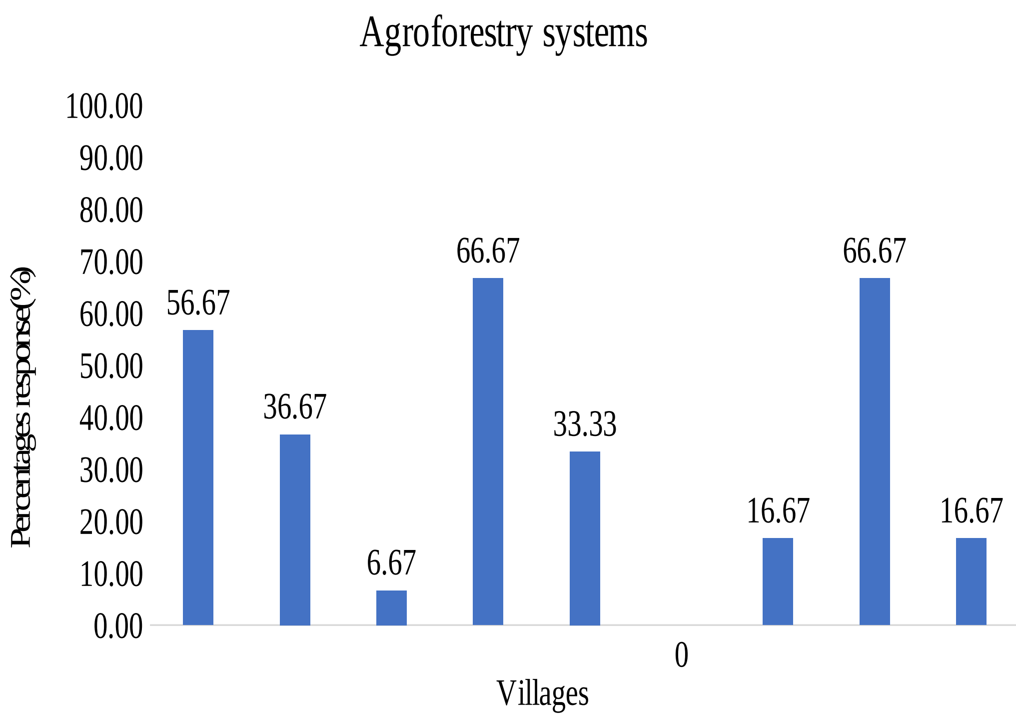

Figure 2: Major agroforestry systems in Kilombero District

Four agroforestry practices were identified in the study area. Agroforestry practices found were home garden, parkland, boundary and mixed intercropping. In all the three villages, agroforestry practices were identified at different levels. Home garden was highly practiced in Igima and Ngajengwa villages, while mixed intercropping was highly practiced in Mbingu village (Figure 3).

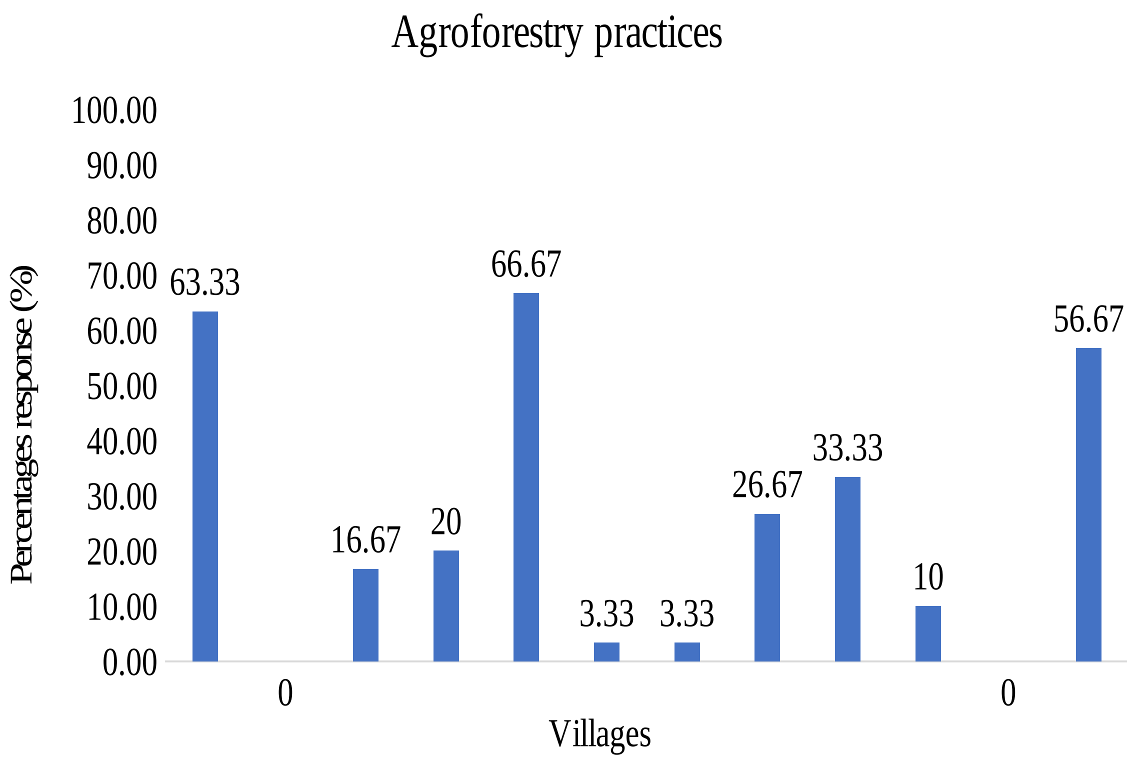

Figure 3: Major agroforestry practices in Kilombero

Trees are the major component of any agroforestry, and several tree species were associated with agroforestry practices as well as agroforestry systems. Each system and practice had a different tree species distribution. Table 2, 3, 4, 5, 6, 7, 8.

Table 2: Tree species associated with Agrosilvicultural system

Agrosilviculture	Frequency	Percentages
Theobroma cacao	901	70.34
Tectona grandis	98	7.65
Cocos nucifera	68	5.31
Mangifera indica	67	5.23
Percea americana	44	3.43
Ficus stuhlmannii	15	1.17
Cinnamomum zeilanicum	12	0.94
Citrus lemon	10	0.78
Citrus sinensis	9	0.70
Psidium guajava	6	0.47
Senna siamea	6	0.47
Anacardium occidentale	5	0.39
Annona murcata	5	0.39
Artocarpus heterophyllus	4	0.31
Canica papaya	4	0.31
Khaya anthotheca	4	0.31
Delonix regia	3	0.23
Sclerocarya birrea	3	0.23
Vitex doniana	3	0.23
Annona squamosa	2	0.16
Brachystegia boehmi	2	0.16
Olea europeana	2	0.16
Syzygium cordatum	2	0.16
Averrhoa bilimbi	1	0.08
Cedrella odorata	1	0.08
Citrus reticulata	1	0.08
Milicia excelsa	1	0.08
Syzygium cumini	1	0.08
Tamarindus indica	1	0.08

Table 3: Tree species associated with Agrosilvopastural system

Agrosilvopasture	Frequency	Percentages
Theobroma cacao	131	22.47
Cocos nucifera	105	18.01
Mangifera indica	96	16.47
Tectona grandis	57	9.78
Elaeis guineensis	27	4.63
Citrus sinensis	25	4.29
Percea americana	23	3.95
Citrus lemon	12	2.06
Annona murcata	11	1.89
Ficus stuhlmannii	11	1.89
Canica papaya	10	1.72
Khaya anthotheca	8	1.37
Senna siamea	8	1.37
Cedrella odorata	7	1.20
Citrus reticulata	7	1.20
Senna spectabilis	7	1.20
Azadirachta indica	5	0.86
Cinnamomum zeilanicum	5	0.86
Artocarpus heterophyllus	3	0.51
Averrhoa bilimbi	3	0.51
Bauhinia thonningii	3	0.51
Milicia excelsa	3	0.51
Psidium guajava	3	0.51
Anacardium occidentale	2	0.34
Annona squamosa	2	0.34
Saraca asoca	2	0.34
Syzygium cordatum	2	0.34
Citrus autatiifolia	1	0.17
Sclerocarya birrea	1	0.17
Syzygium cumini	1	0.17
Tamarindus indica	1	0.17
Terminalia aemula	1	0.17

Table 4: Tree species associated with Silvopastural system

Silvopasture	Frequency	Percentages
Theobroma cacao	70	42.94
Mangifera indica	24	14.72
Cocos nucifera	21	12.88
Percea americana	17	10.43
Tectona grandis	7	4.29
Ficus stuhlmannii	6	3.68
Citrus sinensis	3	1.84
Annona murcata	2	1.23
Citrus autatiifolia	2	1.23
Olea europeana	2	1.23
Psidium guajava	2	1.23
Sorindeia obtusifolia	2	1.23
Artocarpus heterophyllus	1	0.61
Averrhoa bilimbi	1	0.61
Citrus lemon	1	0.61
Citrus reticulata	1	0.61
Vitex doniana	1	0.61

Table 5: Tree species associated with Boundary agroforestry practice

Boundary	Frequency	Percentages
Tectona grandis	45	56.25
Mangifera indica	14	17.5
Ficus stuhlmannii	5	6.25
Cedrella odorata	3	3.75
Sclerocarya birrea	3	3.75
Delonix regia	2	2.5
Psidium guajava	2	2.5
Theobroma cacao	2	2.5
Vitex doniana	2	2.5

Khaya anthotheca	1	1.25
Tamarindus indica	1	1.25

Table 6: Tree species associated with Home garden practice

Home garden	**Frequency**	**Percentages**
Theobroma cacao	185	25.98
Cocos nucifera	119	16.71
Mangifera indica	114	16.01
Tectona grandis	62	8.71
Percea americana	41	5.76
Citrus sinensis	28	3.93
Elaeis guineensis	27	3.79
Ficus stuhlmannii	16	2.25
Annona murcata	14	1.97
Citrus lemon	14	1.97
Canica papaya	11	1.54
Khaya anthotheca	8	1.12
Senna siamea	8	1.12
Citrus reticulata	7	0.98
Senna spectabilis	7	0.98
Cinnamomum zeilanicum	5	0.70
Psidium guajava	5	0.70
Averrhoa bilimbi	4	0.56
Azadirachta indica	4	0.56
Cedrella odorata	4	0.56
Artocarpus heterophyllus	3	0.42
Bauhinia thonningii	3	0.42
Citrus autatiifolia	3	0.42
Milicia excelsa	3	0.42
Anacardium occidentale	2	0.28
Annona squamosa	2	0.28
Olea europeana	2	0.28
Saraca asoca	2	0.28
Sorindeia obtusifolia	2	0.28

Syzygium cordatum	2	0.28
Sclerocarya birrea	1	0.14
Syzygium cumini	1	0.14
Tamarindus indica	1	0.14
Terminalia aemula	1	0.14
Vitex doniana	1	0.14

Table 7: Tree species associated with Mixed intercropping practice

Mixed intercropping	Frequency	Percentages
Theobroma cacao	907	78.39
Cocos nucifera	54	4.67
Mangifera indica	42	3.63
Tectona grandis	42	3.63
Percea americana	37	3.20
Cinnamomum zeilanicum	12	1.04
Ficus stuhlmannii	10	0.86
Citrus lemon	8	0.69
Citrus sinensis	8	0.69
Senna siamea	6	0.52
Anacardium occidentale	4	0.35
Annona murcata	4	0.35
Psidium guajava	4	0.35
Artocarpus heterophyllus	3	0.26
Canica papaya	3	0.26
Khaya anthotheca	3	0.26
Annona squamosa	2	0.17
Olea europeana	2	0.17
Syzygium cordatum	2	0.17
Brachystegia boehmi	1	0.09
Delonix regia	1	0.09
Milicia excelsa	1	0.09
Syzygium cumini	1	0.09

Table 8: Tree species associated with Park land practice

Park land	Frequency	Percentages
Cocos nucifera	21	26.92
Mangifera indica	17	21.79
Tectona grandis	13	16.67
Theobroma cacao	8	10.26
Percea americana	6	7.69
Artocarpus heterophyllus	2	2.56
Citrus reticulata	2	2.56
Anacardium occidentale	1	1.28
Averrhoa bilimbi	1	1.28
Azadirachta indica	1	1.28
Brachystegia boehmi	1	1.28
Cedrella odorata	1	1.28
Citrus lemon	1	1.28
Citrus sinensis	1	1.28
Ficus stuhlmannii	1	1.28
Vitex doniana	1	1.28

2.2.1.3 Constraints for the development of agroforestry systems and practices

Figure 4 presents the identified constraints to development of the agroforestry systems and practices. These constraints include, land shortage as revealed by 41% of the respondents, pest and diseases 7.9 %, land conflict 21.9 %, agricultural input 12.9 % and extension services 16.3 %.

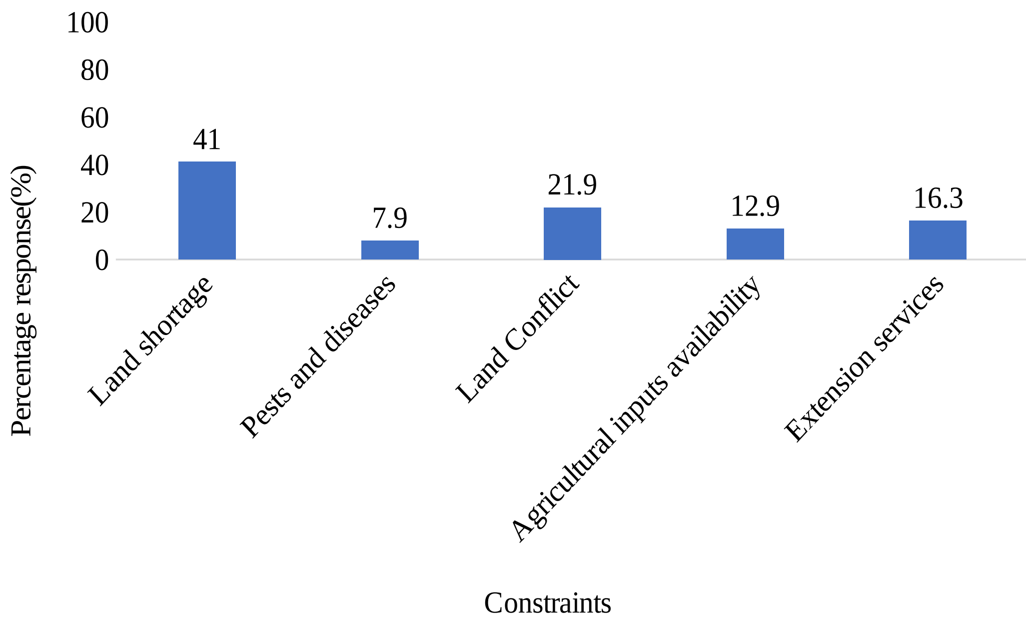

Figure 4: Constraints of agroforestry practices and systems in Kilombero

2.3 Discussion

2.3.1 Agroforestry systems and practices development in Kilombero

From a total of 90 respondents, 82.8% were respondents from communities that stayed in the study area for less than 40 years. This is justified by the fact that 73.3% of the respondents were non-native residents. They were immigrants from outside Kilombero who moved there purposely for cultivation and grazing. Those with more than 40 years in the village are categorized as non-productive and not much engaged in agroforestry practices and systems. A similar study conducted by Mwase *et al*., (2015) found that younger people are highly engaged in agroforestry because they are risk takers compared to older people. In addition, management of agroforestry systems and practices is labor-demanding in the initial stage, therefore not favoring the categories of old farmers. This study is different from the study conducted in Indonesia which shows that young people are not interested in farming (Saiyut *et al*., 2017). According to Dinis *et al*. (2019) education level is important for adoption of agroforestry systems or practices. In this study, the majority of the respondents had primary education, 66.7%. This implies that farmers do not have high education. Similarly, a study conducted in Indonesia indicates that many agroforestry farmers do not have a high education and about 53.96 % have just an elementary education (Anandita and Patria, 2016). Married people were mostly practicing agroforestry in this study. This is in agreement with the study conducted by Maroyi (2009) which indicated that married households engage in agroforestry systems and practices purposely as a strategy to provide an important measure of food security.

2.3.2 Agroforestry systems and practices in Kilombero

Two villages were discovered to be more practicing home garden and agrosilvopasture through observation and interviews, leading to the conclusion that the components involved were trees, herbaceous crops, and/or animals at a high percentage. During interviews, respondents said that the availability of animal fodder and small grazing areas has attracted many farmers to engage in home garden practice. Furthermore, home garden practice and agrosilvopasture are highly practiced because they produce supplementary staple crops and also serve as a source of income for many families. The home garden provides a diversity of crops and livestock, which enables year-round production of different products and reduces production risk. A study conducted by Maroyi (2009) shows that goods obtained from home garden practice are all consumed at home and cannot be sold to other relatives, so they are offered for free to strengthen the relationships in the village and can only be sold when the household has a surplus. Farmers also urge that agrosilvopastoral systems optimize the production per unit area while ensuring the sustained yield over time. Growing trees on farms while integrating with livestock also helps to increase income, produce more food, resulting in food security, and protect the environment, according to a key informant. A study by Saleh (2016) indicates that agrosilvopasture contributes significantly to soil improvement by the supply of the green manure to the soil. Sixty-six-point seven three percent (66.73%) of tree species used in the agrosilvopastoral system were *Theobroma cacao*, *Mangifera indica, and Tectona grandis,* which provide animal fodder, shade, fruits, timber, and are used as a source of food for households. On the other hand, 73.17% of the tree species encountered in home gardens were similar to tree species found in agrosilvopasture.

In Mbingu village, mixed intercropping was the most dominant agroforestry practice, and this was due to suitable land for cocoa growing as well as lack of reserved area for grazing compared to the other two villages. Also, in the focus group discussion, respondents revealed that mixed intercropping provides diversification of crops, especially cash crops like cocoa, which in turn provide income to households. Also, during focus group discussion, respondents in Mbingu village revealed that the presence of Cocoa Kamili Company in the village has influenced mixed intercropping and agrosilviculture of cocoa with trees and other crops. Since mixed intercropping dominates in Mbingu Village, the components included were trees and herbaceous crops, which are termed as agrosilviculture. A study conducted by Antriyandarti *et al*. (2013) indicated that agrosilviculture dominates the land suitable for vegetation. Most of the trees intercropped were *Theobroma cacao* and fruit trees such as

Cocos nucifera and *Mangifera indica*. Robiglio *et al*. (2013) pointed out that integration of cocoa trees, other trees, and food crops has been an easily manageable strategy because it is easier to manage cocoa and tree species. Another survey by Sonwa (2004) found that farmers in Southern Cameroon usually use fruit plants to diversify the cocoa plantations.

Silvopasture was observed among few farmers, and it is not commonly practiced by farmers in the study area. During focus group discussion, it was revealed that silvopasture is difficult to implement due to a shortage of grazing land and climate variability. Other respondents pointed out that operation costs are very high and there is a poor market structure for the livestock products. Caradona *et al.* (2014) pointed out that livestock production depends on climate factors; therefore, changes in the climate have an enormous impact on production.

2.3.3 Constrains of agroforestry systems and practices in Kilombero

For the development of agroforestry systems and practices, the improvement of social economic factors is very important. During interviews and focus group discussions, respondents claimed that there is a severe shortage of land and a large part of the village's land has been included in the Kilombero Nature Reserve. This has reduced a large proportion of the village land, which in turn affects the development of agroforestry. A similar condition has been observed in the area with a high population in Southern Malawi, which shows that small pieces of land become barriers towards the development of agroforestry systems and practices (Thangata *et al*., 2007). Extension education was noted to be very low, and the available working staff were not dedicated to farmers visiting. This is similar to a study conducted by Matata *et al*. (2010) who argued that extension education is a key factor in developing favorable attitudes towards the implementation of agroforestry systems and practices. In Kilombero, like other places in Tanzania, there is high land conflict and the major source is the immigration of pastoralists who are looking for grazing areas. This also affected the implementation of agroforestry, especially in the initial stages of tree growth. Some respondents during focus group discussion pointed out that most pastoralists are Maasai and Sukuma, and they do not care about crops, what they consider important is their livestock. This agrees with the findings from Kwesiga *et al*. (2003) who pointed out that farmers become more committed to free conflict land areas. Pest diseases and agricultural inputs are also the key factors which appear to be challenging in agroforestry systems and practices. Farmers require quality seedlings of cocoa, tree species, and chemicals for controlling pests and diseases. Nyoka *et al*. (2011) pointed out that the high cost of agricultural inputs may limit development as most local communities who practice agroforestry are not able to acquire such inputs.

2.4 Conclusion

From the study, it is clear that potential exists in agroforestry systems and practices in terms of product diversification and biodiversity conservation. Also, the results indicates that farmers have different preferences in establishing agroforestry systems and practices for different purposes, but the major purposes identified were for domestic use. In order to achieve the development of agroforestry systems and practices, smallholder farmers must develop intensive management to yield a quality product from priority components to meet market demand.

This study recommends that for the development of agroforestry systems and practices, various factors should be addressed by government and non-governmental stakeholders. Extension education is highly required in the study area from forest officers and agriculture officers. A land dispute between villagers and the Kilombero nature reserve should be settled to allow agroforestry systems and practices to be implemented in the area near the Kilombero Nature reserve.

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CHAPTER THREE

3 Role of agroforestry systems and practices on climate change adaptation in Kilombero District

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Abstract

Agroforestry systems and practices across sub-Saharan Africa have supported a number of farmers in adapting to climate change impacts through diversification of crops. With the services it provides, agroforestry has been used as a strategy for adapting to climate change impacts. Although this has already been acknowledged, there is limited understanding of the roles of agroforestry systems and practices in combating the impacts of climate change on agricultural landscapes. Therefore, this study was conducted in Kilombero District to assess the role of agroforestry systems and practices on climate change adaptation. The study employed various approaches to collect data, including household surveys, key informant interviews, and focus group discussion. Descriptive statistics and analysis of variance were employed. The results showed that crop diversification in different agroforestry systems and practices, with different tree uses, increases farmers' resilience in the event of climate variability and change. On the other hand, all the available agroforestry practices indicate that there is no statistically significant difference in increasing adaptive capacity through the contribution of household income. Agroforestry systems revealed a statistically significant difference in increasing adaptive capacity through household income. This study concludes that in crop diversification tree uses and income enable farmers to increase the adaptive capacity in Kilombero. The study recommends that all components of agroforestry which are wood perennials, herbaceous crops and animals should be integrated at once in assessing the climate change adaptation benefits through agroforestry systems and practices.

Keywords: Climate Change adaptation, Agroforestry systems, Agroforestry Practices.

3.1 INTRODUCTION

Agroforestry systems and practices use trees and shrubs in land management for crop and or animal production and it is estimated to be practiced by 30% of the global rural population (Zomer *et al.*, 2009). These systems and practices provide key ecosystem services such as water conservation, improved microclimate condition, enhanced soil productivity, nutrient cycling and conservation as well as control of pest and diseases (Kandji *et al*., 2006). These services are critical in improving the capacity of farmers to cope with the impacts of climate change. In adaptation to climate change, agroforestry provides economic resilience for rural population through trees in agriculture that provides farmers with alternative or addition sources of income. Tree products like timber, fodder, resins and fruits also buffer against income risk in case of crops failure (Schroth *et al*., 2000). Fuel wood have also become the second most cited benefit from agroforestry (Thorlakson and Neufeldt, 2012).

A study on intercropping of maize and *Leucaena leucocephala* shows significant increase in rainwater use, efficiency in increased soil moisture retention, additional biomass, nutrient cycling and space utilization while maintaining stable yields (Bates *et al*.,2008). The presence of trees in agroforestry systems and practices helps to buffer against extreme events by modifying temperature, providing shade and shelter and by acting as alternative food sources during period of floods and droughts. Furthermore, agroforestry can directly improve the adaptive capacity of a farmer through stabilizing the variability of microclimate (Lin, 2007) and more important maybe more resilient to extreme climatic condition than annual crops alone (Schwendenmann *et al.*, 2010). Agroforestry is a multiple production activity that are complementary in economic and ecological dimension involving crops, trees, livestock and post-harvest processing hence generating cash income (Rao *et al.*, 2007; Mendez, 2001). Despite the importance of agroforestry systems and practices in climate change adaptation there is little information on the systems and practices that need to be implemented in order to increase the adaptive capacity as well as resilience to climate variability in Kilombero valley. Therefore, this chapter presents findings of a study on the role of agroforestry systems and practices on climate change adaptation.

3.1 Materials and methods

3.1.1 Description of the study area

The study was conducted in Kilombero District, which is located in Morogoro Region between 8°15'0" S and 36°25'0" E with elevation ranging from 262 m to 550 m above mean sea level. Administratively, Kilombero District has five divisions, 19 wards and 46 villages. The district is bordered by Kilosa District in the North, the South East by Ulanga District, the West by the Iringa Region and in the East by the Lindi Region (URT, 2007).

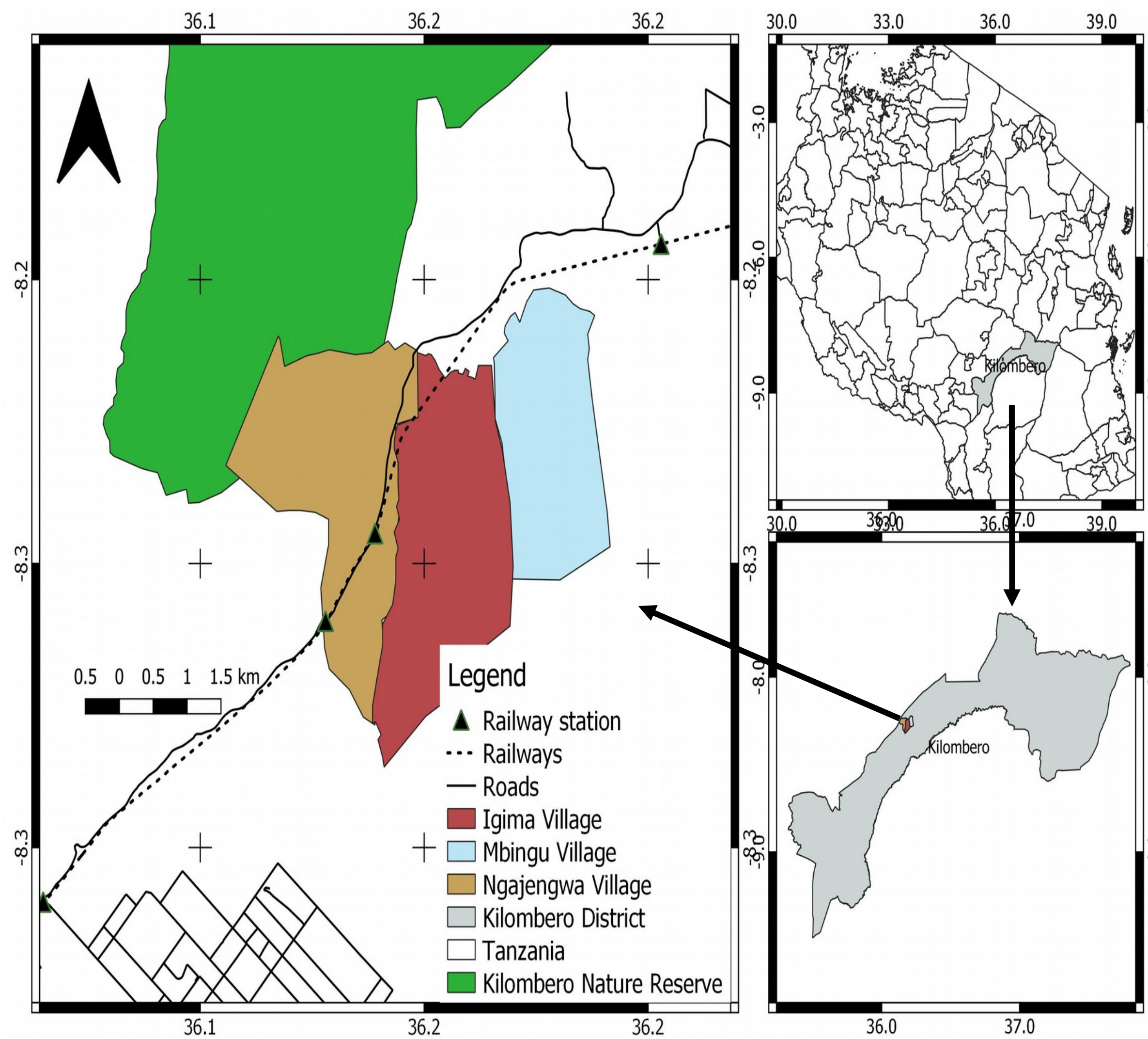


Figure 5 : Kilombero District map showing the study area

3.1.1.1 Climate

The climate in the study area is marked by wet and dry seasons, which are further categorized into four sub seasons, hot wet season from December to March, the cool wet season from April to June, the cool dry season from July to August, and the hot dry season from September to November. The area receives between 1200 and 1800 mm of rainfall per year, and temperatures range from 26 to 32 °C (Balama *et al*., 2016).

3.1.1.2 Land use

Generally, the land use is categorized as village land, reserved land and general land as defined in the Village Land Act 1999 (URT, 2017). Meanwhile, Kilombero is considered as one of the fertile spots in Tanzania. The main economic activities in the area include cash crop cultivation, food crop cultivation, petty trading, and fishing in the Kilombero River (URT, 2007). Overall, cereals of the coast such as rice, millet and maize are widely grown. Also, vegetables such as sweet potatoes, yams, ground-nuts, melons, pumpkins, cucumbers and many other excellent food crops are grown. Tobacco is grown abundantly, sugar-cane, the castor oil plant, cocoa, and cotton are also cultivated (Bergius *et al*., 2020).

3.1.1.3 Population

According to the 2012 census, the population of Kilombero was 407 880, with 202 789 males and 205 091 females (URT, 2013). This area is currently experiencing a doubling of the human population over the years. It has been demonstrated that within Tanzania, population growth results in environmental degradation (Madulu, 2004). The large migration of farmers due to fertile land and livestock keepers due to the presence of animal fodder is the primary cause of population growth.

3.1.1.4 Soil

Geologically, the Kilombero is characterized by sedimentary basin infillings forming a seasonal alluvial floodplain dominated by Fluvisols (Beck,1964 and Daniel *et al*, 2017). Kilombero is covered by the flood plain. Since the area is characterized by wetland, the soil is mainly heavy black cotton (mbuga) soil that retains water over relatively long periods, with isolated patches of lighter sand soil. Annual flooding is a crucial factor in the maintenance of the fertility of the soil for vegetation. In other areas, soil originates from granites which are deeply weathered. Some parts of Kilombero soil are moderately acidic, poor, freely drained, and markedly compacted near the surface where there is often a very high coarse grained soil fraction. The soil is generally red loamy sand (latosol).

3.1.1.5 Vegetation

Natural vegetation in the Kilombero District depends on the gradients from the rivers. On the riverside, vegetation is often dominated by *Hyparrhenia spp.* and *Reed* (*Phragmites mauritianus Kunth*.), followed by the low-lying valley grassland with perennial grasses including Guinea grass (*Panicum maximum Jacq.*) marginal grasslands, *combretacoes* wooded grasslands, and last, miombo woodland and forests exist in the upper valley (Starkey *et al*., 2002). The natural forests and Miombo woodlands occupy the large part of the district. Miombo is the Swahili word for the *Brachystegia* genus, which is the dominant tree in this natural environment together with *Julbernardia* and *Isoberlinia*, of the subfamily *Caesalpinioideae*. Artificial grassland and shrublands are also present due to human activities (Frost, 1996)

3.1.2 Methods

3.1.2.1 Reconnaissance survey

A pre-visit as well as pre-testing of questionnaires and checklists for clarity, comprehensiveness, redundancy, and meaningfulness were conducted. Also, this enabled the researcher to be familiar with the study area. During the survey, two households from each of the identified villages were randomly selected and interviewed to pre-test the questionnaire so as to check reliability and validity of the questions. Some corrections were made to meet the research objectives. The research design for this study was cross-sectional as data was collected at once in the study area without repetitions.

3.1.2.2 Sampling procedure

Three villages were purposely selected due to the presence of agroforestry farmers. Random sampling procedure was adopted for selecting households with agroforestry systems and practices, and village registers were used as a sampling frame. The sampling unit for this study was the individuals chosen from the population as respondents to represent others, and the information obtained can be used to describe the characteristics of the entire population (Bryman, 2004 and Nkonoki, 2015).

3.1.2.3 Sample size determination

Nachimias and Nachimias (1996) pointed out that sample size is the most important determinant of any survey estimates. The author continues to demonstrate that the greater the precision of the estimate and the confidence in the results, the larger the sample size is needed. These authors explain further that another factor equally important in determining the sample size is the amount of resources (time, money, and personnel) available for the study. Gay and Diehl (1992) described that the number of respondents depends on the type of research involved, such as descriptive, correlational, or experimental. However, 30-unit subjects are good to establish the relationship in any research. This is similar to studies by Bailey (1998), Saunders *et al.* (2007), Mbeyale (2009) and Mtongani *et al*. (2014), who also indicated that a sample of 30 units is sufficient irrespectively of the population size and constitutes a representative sample size for data collection and analysis. On the other hand, investigations into socio-economic studies in Sub-Saharan Africa require a sample size of between 80 to 120 household respondents (Jew and Bonnington, 2011; McClanahan *et al*., 2005; Mtongani *et al.*, 2014). Therefore, a total of 90 respondents were sampled from the three villages (Igima, Mbingu and Ngajengwa) for interviews and this sample size was considered sufficient to generate statistical inferences required for making study conclusions.

3.1.2.4 Data collection

Primary data was collected using a combination of methods. The Households interviews, key informant interviews, and focus group discussions. The questionnaire was the main instrument for collecting the primary data from the agroforestry farmers and included both closed and open-ended questions. Focus group discussions enabled to get insights into the status of agroforestry in the villages. Key informant interviews enabled to get more clarification on particular issues raised during the focus group discussion and interviews.

3.1.2.5 Data analysis

The qualitative information was analyzed using content analysis whereby raw data was broken down to generate meaningful units of information. Quantitative data were subjected to descriptive statistics to obtain information in terms of frequency and percentage, which were then presented in the form of a histogram. In addition, cross tabulation was used to compare the observed variable under investigation. One-way ANOVA was conducted to determine if the average income of households was significantly different between the agroforestry practices and agroforestry systems (Ahmad *et al*., 2021 and Quandt, 2021). In addition, in order to determine where the differences exist in each group, a post hoc test was used to complement the analysis.

3.2 Results and Discussion

3.3 Results

3.3.1 Diversification in agroforestry systems and practices in increasing farmers resilience against climate variability

Generally, components diversification in agroforestry systems and practices increases farmers' resilience against climate change variability. From the study area, crops intercropped in different agroforestry systems and practices were purposely intended to promote food security in the society and increase income. Such components include maize, groundnuts, sweet potatoes, pineapples, cocoa products, cassava, and bananas (Figure 6 and 7). Moreover, Figure 8 presents the animals that were found in the study areas during the survey. Major animals were poultry (26.78%), cows (24.8%), pigs (19.7%), goats (15.9%), and sheep (12.7%).

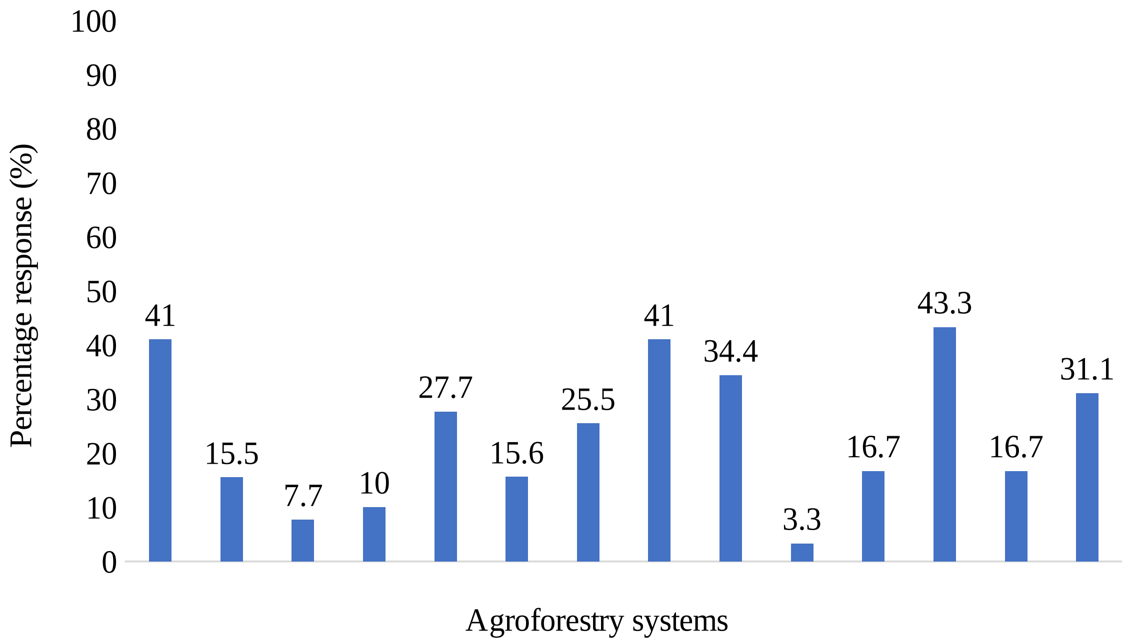
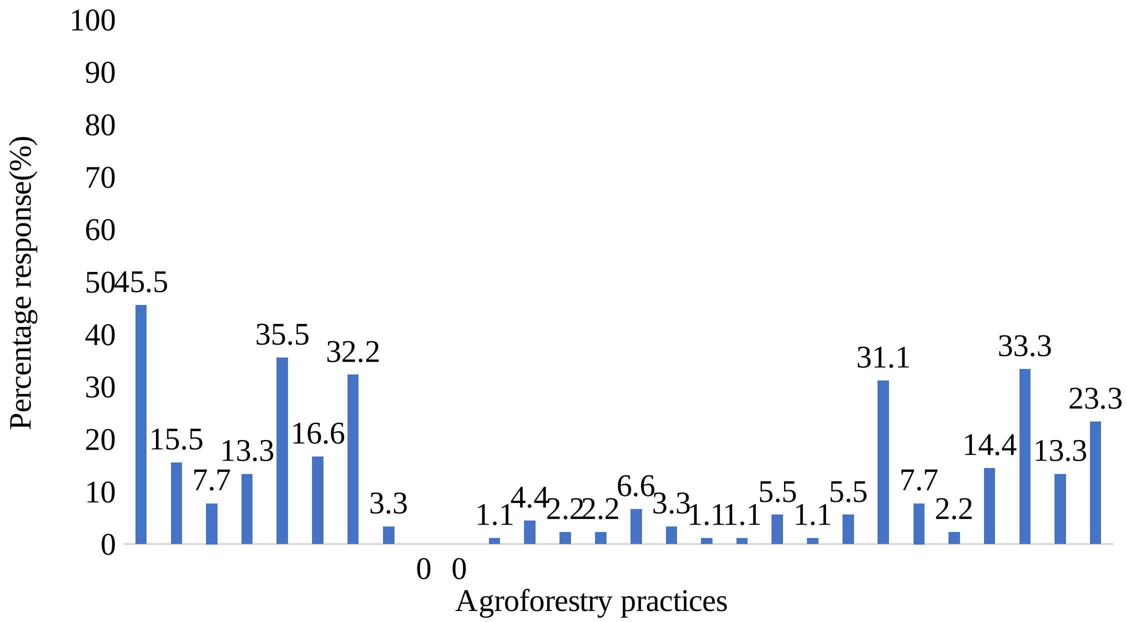


Figure 6: Agricultural crops intercropped in different agroforestry systems

NAOMBA IWE LAND SCAPE SHANGAZI



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igure 7: Agriculture crops intercropped in different agroforestry practices

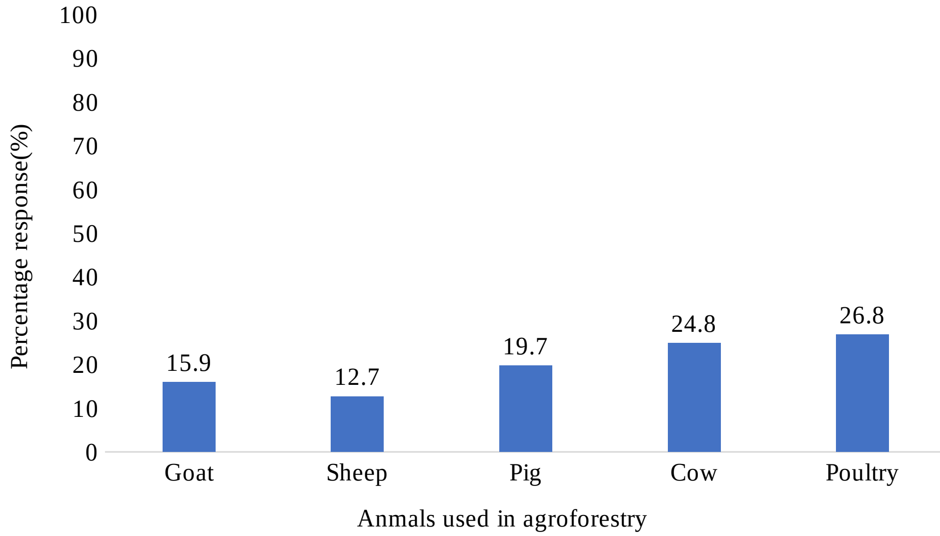

Figure 8: Group of animals included by the agroforestry farmers in Kilombero

3.3.2 The role of agroforestry trees in increasing the adaptive capacity in Kilombero

Trees are a major component in all agroforestry systems and practices, and it has been observed that the presence of trees in farmland has largely influenced income, shade, food availability, biodiversity conservation, soil erosion control, and wind break as different trees play different roles in the farmland (Figure 9). Table 9 lists the major trees used in agroforestry systems and practices.

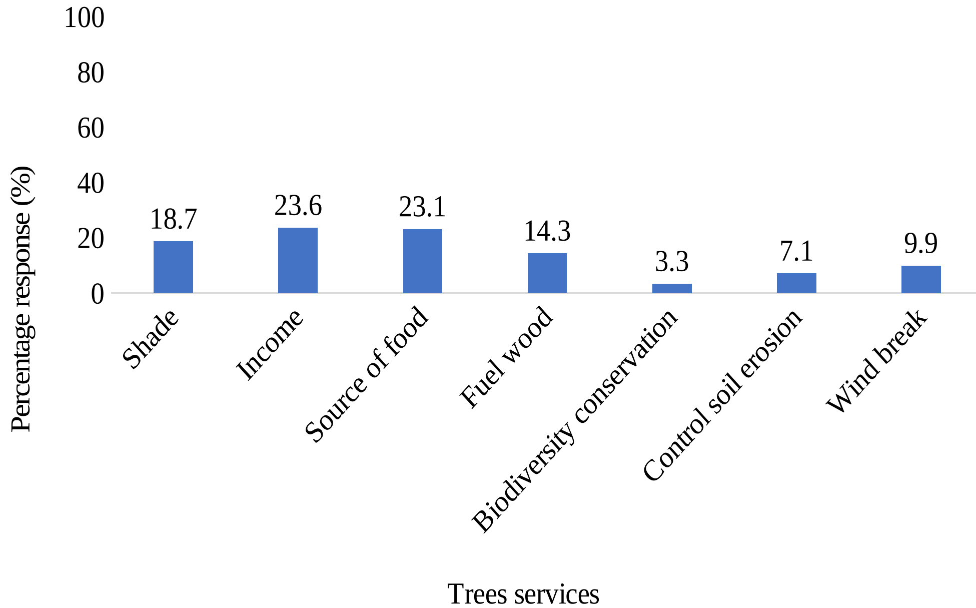

Figure 9: Trees components use in increasing the adaptive capacity of agroforestry.

Table 9: Agroforestry trees species and their uses in Kilombero.

Botanical name	Local name	Family	Tree uses
Averrhoa bilimbi	Mbilimbi	Oxalidaceae	Fruits, Shade, Wind break
Citrus reticulata	Mchenza	Rutaceae	Fruits
Elaeis guineensis	Mchikichi	Aracaceae	Oil, Shade
Citrus sinensis	Mchungwa	Rutaceae	Fruits
Cinnamomu zeilanicum	Mdalasini	Lauraceae	Agricultural spice
Artocarpus heterophyllus	Mfenesi	Moraceae	Fruits, Shade, Wind break
Vitex doniana	Mfuru	Verbenaceae	Edible fruits, Timber
Senna Spectabilis	Mjohoro	Fabaceae	Ornamental, fuel
Senna siamea	Mjohoropori	Fabaceae	Ornamental, fuel
Khaya anthotheca	Mkangazi	Meliaceae	Timber
Delonix regia	Mkirismasi	Fabaceae	Shade, ornamental
Theobroma cacao	Mkokoa	Malvaceae	Cocoa beans
Anacardium occidentale	Mkorosho	Anacardiaceae	Agricultural crop
Terminalia aemula	Mkulungu	Combretaceae	Timber, Wood fuel
Ficus stuhlmannii	Mkuyu	Moraceae	Shade, fruits, Windbreak
Tamarindus indica	Mkwaju	Fabaceae	Fruits
Citrus lemon	Mlimao	Rutaceae	Fruits
Cocos nucifera	Mnazi	Aracaceae	Timber, Food
Citrus autatiifolia	Mndimu	Rutaceae	Fruits
Sclerocarya birrea	Mng'ong'o	Anacardiaceae	Edible fruits, Timber
Syzygium cordatum	Mnyonyo	Myrtaceae	Fruits
Canica papaya	Mpapai	Caricaceae	Fruits
Percea americana	Mparachichi	Lauraceae	Fruits, Shade
Psidium guajava	Mpera	Myrtaceae	Fruits
Sorindeia obtusifolia	Mpilipili	Anacardiaceae	Edible fruits, medicinal
Cedrella odorata	Msedrela	Meliaceae	Timber
Bauhinia thonningii	Msegese	Fabaceae	Medicinal, ornamental
Annona murcata	Mstafeli	Annonaceae	Fruits, Shade, Wind break
Tectona grandis	Mtiki	Lamiaceae	Timber
Annona squamosa	Mtopetope	Annonaceae	Fruits, Shade, Wind break
Mangifera indica	Muembe	Anacardiaceae	Fruits, Shade
Milicia excelsa	Mvule	Moraceae	Timber
Azadirachta indica	Mwarobaini	Meliaceae	Shade, medicinal

Saraca asoca	Mwashoki	Myrtaceae	Ornamental
Brachystegia boehmi	Myombo	Fabaceae	Timber
Olea europeana	Mzaituni	Oleaceae	Timber
Syzygium cumini	Mzambarau	Myrtaceae	Fruits

In adapting to climate change impacts, various strategies other than agroforestry systems and practices were obtained during the survey (Figure10).

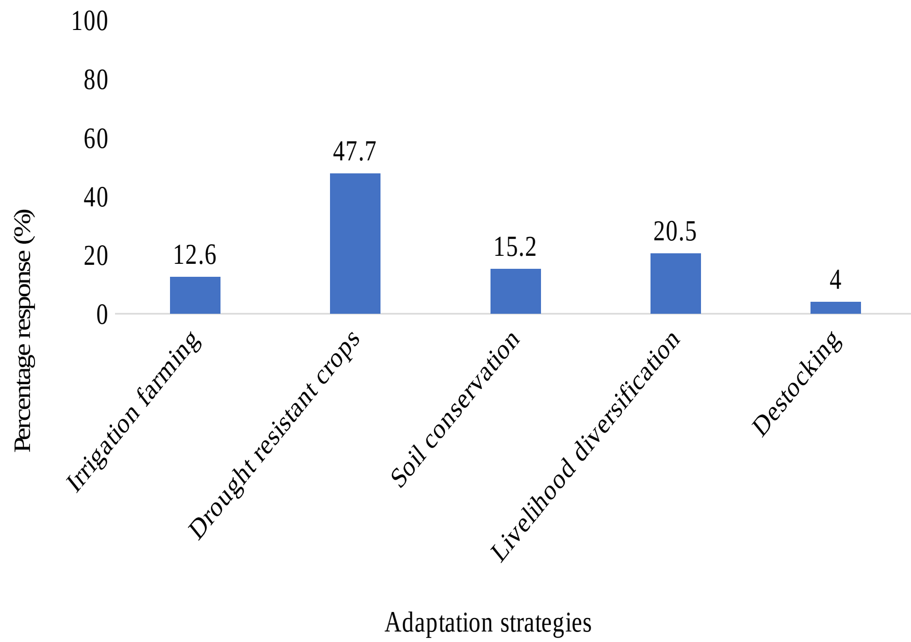

Figure 10: Other adaptation strategies to climate change variability in Kilombero

3.3.3 Income from agroforestry systems and practices in increasing the adaptive capacity

Table 10 shows the results from the analysis of variance of agroforestry systems. The results suggest that the extent of the role of various agroforestry systems (Agrosilvopasture, Agrosilviculture and Silvopasture) differ significantly ($F_{2,87}$ 11.893 $P<0.05$). In order to check for individual differences between the systems, post hoc comparison was selected. The test indicates that agrosilvopasture (mean 385571.43 and standard deviation 102415.49) differs significantly from silvopasture (mean 193571.43 and standard deviation 151951.59). Agrosilviculture also (mean 334731.71 and standard deviation 84439.04) differs significantly from silvopasture. The mean difference was significant at the 0.05 level. However, no significant difference was detected between agrosilvopasture and agrosilviculture (Table 12) below is illustrative.

Table 11 presents the analysis of variance for household income in different agroforestry practices. The results show that there was no statistically significant difference in the contribution of household income through agroforestry practices in Kilombero (P>0.05).

Table 10: Household income from the agroforestry systems

ANOVA				
Household income TZS				
	df	Mean Square	F	Sig.
Between Groups	2	1.17E+11	11.893	0.0001
Within Groups	87	9 813 563 779		
Total	89			

Table 11: Household income from agroforestry practices

ANOVA				
Household income (TZS)				
	df	Mean Square	F	Sig.
Between Groups	3	4453255795	0.357	0.784
Within Groups	86	12486496374		
Total	89			

Table 12: Post hoc multiple comparison table on agroforestry systems

Agroforestry systems (Income TZS)	Mean	Std Deviation	F	Sig
Agrosilvopasture	385571.43	102415.49	11.893	0.0001
Agrosilvisulture	334731.71	84439.04		
Silvopasture	193571.43	151951.59		
	Systems differences			
Systems	Means difference	Sig		
Agrosilopasture - Silvopasture	192000	0.0001		
Agrosilviculture - Silvopasture	141160.28	0.002		

* The mean difference is significant at the 0.05 level.

3.4 Discussion

4.4.1 Diversification in agroforestry in increasing farmers' resilience against climate variability

The results on the agroforestry practices show that home garden and mixed intercropping are highly practiced and are preferred by the local community due to components arrangement which favors more crops on the same land. This diversification has been promoted as a strategy to achieve climate change resilience through food security. Similar results in Western Kenya showed that home garden and mixed intercropping have great potential for controlling soil erosion, hence improving product diversification, which in turn increases adaptive capacity (Repping, 2020). Respondents also pointed out that by diversifying crops, farmers increase the range of potential food and income available to them. During the focus group discussion, participants responded that, during the droughts of 2005 and 2006, crop diversification in the agroforestry land served as an important climate risk management strategy by integrating more than one crop into the agroforestry farmland, such as cassava, pineapple, maize and sweet potatoes. Similar results have been reported in Mwanga by Charles *et al*. (2013) who noted that in order to cope with the climate change variation, crop diversification is the best practice. Respondents also pointed out that the economic return of crop diversification tends to be highest for the farmer, despite the land size.

Agrosilviculture and agrosilvopasture were the most observed systems from the field. These systems involved herbaceous crop, trees and livestock, multiple diversifications of the three components increase the resilience towards the climate change adaptation. This is in line with the study conducted by Agyei and Frimong (2021) who noted that in Ghana, farmers employ diversification as a strategy not only to reduce crop failure but also to reduce the effect of climate change. Previous studies, for example Vicent *et al*. (2013), Makate *et al*. (2016) and McCord *et al*. (2015) reported that majority of farmers opted to adopt crop diversification and livestock keeping to increase productivity as well as enhance their resilience to climate change. In southern Ghana, similar results have been reported suggesting that farmers employ crop diversification to increase the adaptive capacity. In addition, presence of livestock and poultry to some communities has helped to diversify the source of their income. The results show that poultry, cows, pigs, goats and sheep are the common animals components in agroforestry systems and practices in Kilombero. These diversifications increase resilience towards climate variability. This result is similar to a study conducted by Charles *et al*. (2013) who reported that livestock usually have been used as a source of income since some livestock like goats have the ability to survive during drought.

3.4.2 Role of agroforestry trees in increasing farmers' resilience against climate change

During the survey, participants mentioned various uses of trees to enhance their resilience to climate change variability. Participants noted that most of the trees that they prefer have multiple uses, such as shade, fuel wood, fruits, windbreaks and sources of income (see Table 9). Participants during the focus group discussion revealed that many communities use tree products such as timber, fruits, and cocoa beans for income diversification and as an adaptation strategy to climate change variability. A similar study conducted by Paavola (2008) shows that climate change impact can be achieved through tree products such as firewood, fruits, spices, fodder, traditional medicine and timber. Through the use of trees in a farmland, improve soil depth for water and nutrient retention, which is beneficial to crops during droughts through their deep root systems (Verchot *et al*., 2007). Trees also provide shade for example *Theobroma cacao,* which is highly cultivated in Kilombero. This is because *Theobroma cacao* is sensitive to microclimate fluctuations. A study in Mexico shows that, shade decreases the temperature, humidity fluctuation and reduces vulnerability to water stress (Lin, 2010). Trees on crop land conserve water by decreasing insolation as well as controlling soil erosion. A study by Pramova *et al.* (2012) shows that trees have the potential to control soil erosion on farmland and make crop production more resilient to climate variability. In addition, trees on the farmland maintain the biodiversity. A study by Montagnini (2017) revealed that, trees in agroforestry serve the restoration and rehabilitation of degraded ecosystems.

Despite practicing agroforestry, respondents also pointed-out other strategies that increase resilience and overcome the climate change impact. The key strategy considered more applicable to many communities was planting drought resistant crops such as cassava. Similar results were observed by Fisher *et al*. (2015), Mwase *et al*. (2014) and Dapilah and Nielsen (2020) who suggested that farmers in drought prone areas should use improved varieties of crops that are drought tolerant and which are early maturing varieties. Other strategies pointed out were irrigation farming, destocking, soil conservation and livelihood diversification.

3.4.1 Income from agroforestry systems and practices in increasing the adaptive capacity

Generally, there was a statistically significant difference between the agroforestry systems. From the results, the difference existed between the silvopasture and the other two systems. This difference was influenced by the component present in the systems which affect its income generation. In Kilombero, farmers who are practicing silvopasture benefit from livestock, poultry, trees and very little from pastures. Multiple uses of trees provide diversification of income as well as products from livestock. A study by Montagnin *et al*. (2013) shows that trees provide fuel wood, which provides a stable supply for household consumption and increases income. Different from other agroforestry systems, in silvopasture there is no crop diversification. Therefore, farmers in Kilombero who practiced this system depended on two components only. Studies by Yamamoto *et al*. (2007), Murgueitio and Ibrahim (2009) show that farmers can benefit income from trees and fodder production for animals. Farmers in Kilombero do not invest much in pastures, they only benefit from livestock and trees. This makes silvopasture less practical compared to agrosilvopasture and agrosilviculture.

Furthermore, the results show further that there is no significant difference between agrosilvopasture and agrosilviculture. However, based on the mean, agrosilvopasture had a higher mean than agrosilviculture, implying that agrosilvopasture is more widely practiced than agrosilviculture due to the presence of animals. According to respondents, agrosilvopasture attracts rotation of components, both trees, crops and livestock. According to Schroth *et al*. (2000) and Avelino *et al*. (2011), tree products provide a buffer against income loss in the event of crop failure and are useful as animal fodder. Trees legumes have been documented to increase maize yield, which in turn increases farmers' income (Cannavo *et al*., 2011).

On the other hand, agrosilvopasture systems with three components were found to double maize yields relative to maize from the monoculture land across Africa due to availability of animal manure. A study by Thorlakson *et al*. (2012) pointed out that a farmer with agrosilviculture and agrosilvopasture suffered at an average of less than 1 month less food insecurity during the drought condition due to multiple incomes from the system components. Respondents urged that cocoa plantations also provide them with long term income. This is in line with the study conducted in Ghana which shows that agrosilviculture and agrosilvopasture are beneficial in terms of income generation through short term food production and long-term plantation establishment (Kalame *et al*., 2011).

On the other hand, the results from the analysis of variance show that there is no significant difference between the agroforestry practices in the contribution of households' income. During the survey, it was observed that farmers try to use the available minimal land to diversify crops in order to increase their income from the component’s arrangement. Where farmers miss one component, such as animals, they use the available components to maximize their income. For example, park land, boundary planting and mixed intercropping were rich in cash crops such as cocoa as well as food crops. A study in Mali shows that parkland contains trees and shrubs species that can play an important role in increasing farmers' resilience to climate change (Faye *et al*., 2010). Similar results by Quang *et al*. (2006) show that farmers can benefit from boundary planting agroforestry due to the presence of fruit trees and trees for timber production. Similarly, in mixed intercropping, trees play a key role in improving the productivity through reduced erosion, wind barrier and improving soil condition. A study conducted in Ethiopia concludes that mixed intercropping of multiple food crops with trees can increase resilience through diversification of income (Paudel *et al*., 2016). Generally, in this study, it is observed that all the agroforestry practices contribute equally to household income, and the difference in the mean income depends on how the components are arranged and managed on the land. Similar results in Indonesia pointed out that species variation, arrangement and their management contribute highly to farmers' income variation (Noldeke *et al*., 2021).

3.5 Conclusions

This study shows the way different agroforestry systems and practices can play a part in increasing the adaptive capacity to climate change impacts. This is achieved through crop product diversification, tree use, and income from agroforestry. During environmental extremes, multi cropping was found to be the best solution for buffering food security, which appears to be the major challenge resulting from climate change impacts. On the other hand, different tree uses on farmland and home land were also considered as an important means of increasing adaptive capacity since different trees play different roles during environmental extremes.

The study recommends that integration of all agroforestry components, which are herbaceous crops, wood perennials and animals together may increase the adaptive capacity. Therefore, farmers should be encouraged to integrate all the three components at once order to achieve and increase farmers resilience to climate variability through product diversification and income.

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CHAPTER FOUR

4 Factors influencing adoption of agroforestry systems and practices in Kilombero

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Abstract

Agroforestry systems and practices are perceived to improve livelihood and sustainable management of natural resources. However, factors influencing the adoption of various agroforestry practices in Kilombero necessitate additional research. This study was conducted in the Kilombero district to investigate factors influencing the adoption of different agroforestry systems and practices in the farmland. Different approaches were used for data collection, including household surveys, key informant interviews, and focus group discussion. A Multinomial regression analysis in SPSS was used for data analysis. The reference categories used were agrosilvopasture for agroforestry systems and home garden for agroforestry practices. The results show that different explanatory variables have statistical significance in the adoption of agroforestry systems and practices. Residence type and sex had a statistical significance difference in the adoption of agrosilviculture with reference to agrosilvopasture. Duration of stay in the village, availability of extension education, residence type and sex were found to be dominant factors influencing the adoption of agroforestry practices and were statistically significant differences. The study concludes that agroforestry will be more successful if the local priorities, which include social and economic characteristics, will be considered in designing systems and practices. There is a recommendation that social economic needs must be addressed by the government and other stakeholders in order to expand the adoption of agroforestry systems and practices.

Keywords: Agroforestry adoption, Agroforestry systems, Agroforestry practice, Agroforestry in Kilombero.

4.1 INTRODUCTION

In southern African countries, economic challenges are exacerbated by the rapid increase of population and increased food demand which have resulted to the tremendous amount of pressure on the land-base (Kwesiga *et al*., 1999). Many small-scale farmers are in a poor state and cannot afford inputs from industries to improve yields (Thangata *et al*., 2007). Food insecurities in tropical countries like Tanzania have been compounded by the pronounced environmental degradation and loss of natural resources such as forests. Moreover, land degradation and loss of soil fertility results from poor farming systems and low adoption of the strategies of managing the natural resources on the same land unity with food crops (Kwesiga *et al*., 1999; Mwase *et al*., 2015). Agroforestry systems and practices as conservation agriculture pose positive development response especially in conserving biodiversity. A study by Ajayi and Catacutan (2012) reported that agroforestry systems and practices are the most promising and low-cost technique which ensure crop production and at the same time conserving the natural resources. For both agroforestry systems and practices; apart from improving soil fertility and land quality they also ensure provision of non-timber forest products such as fruits, fuel wood, energy and fiber. Impacts of agroforestry as sustainable natural resources management arise as a result of integration of food crops, trees and or with livestock. Eneji *et al*. (2004) reported that the aim of agroforestry systems and practices is to optimize the positive outcome in order to obtain the diversified and more sustainable production systems from limited resources than other systems of land use. For this context, socio-economic study of the factor affecting the adoption of agroforestry systems and practices is highly important. For a country like Tanzania, this will help to ascertain opportunities for the development of agroforestry systems and practices. Sinclair and Walker (1999) reported that quantitative and predictive understanding of the agroforestry systems and practices make easy adoption. Developing strategies and encouraging farmers to plant trees on their farmlands can be designed only if the characteristics of the farm and farmer in relation to tree growing exist (Irshand *et al*., 2011). For that reason, this study identified the determinant factors for adoption of agroforestry systems and practices.

4.1 Materials and methods

4.1.1 Description of the study area

The study was conducted in Kilombero District, which is located in Morogoro Region between 8°15'0'' S and 36°25'0'' E with elevation ranging from 262 m to 550 m above mean sea level. Administratively, Kilombero District has five divisions, 19 wards and 46 villages. The district is bordered by Kilosa District in the North, the South East by Ulanga District, the West by the Iringa Region and in the East by the Lindi Region (URT, 2007).

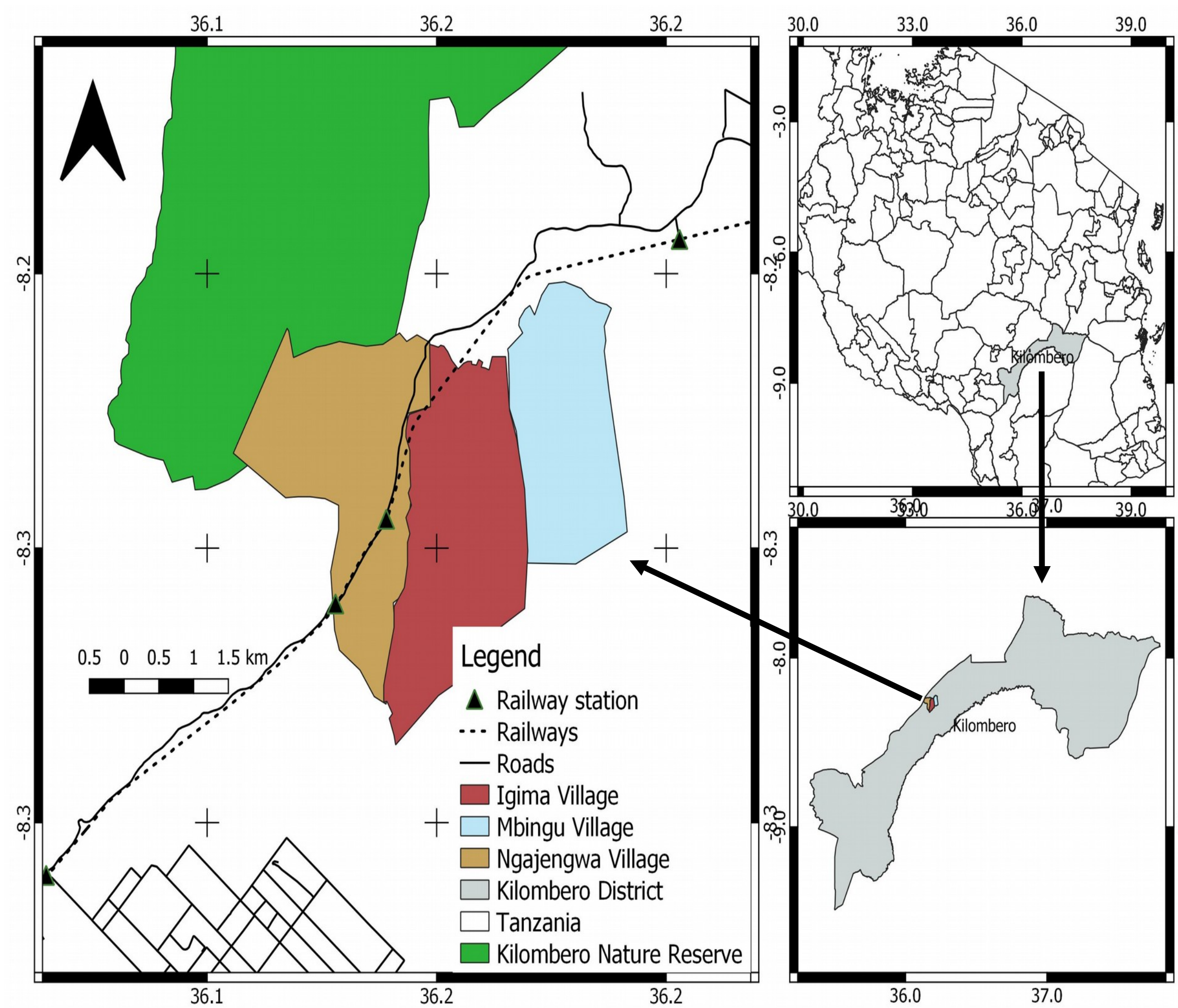

Figure 11: Kilombero District map showing the study area

4.1.1.1 Climate

The climate in the study area is marked by wet and dry seasons, which are further categorized into four sub seasons, hot wet season from December to March, the cool wet season from April to June, the cool dry season from July to August, and the hot dry season from September to November. The area receives between 1200 and 1800 mm of rainfall per year, and temperatures range from 26 to 32 °C (Balama *et al*., 2016).

4.1.1.2 Land use

Generally, the land use is categorized as village land, reserved land and general land as defined in the Village Land Act 1999 (URT, 2017). Meanwhile, Kilombero is considered as one of the fertile spots in Tanzania. The main economic activities in the area include cash crop cultivation, food crop cultivation, petty trading, and fishing in the Kilombero River (URT, 2007). Overall, cereals of the coast such as rice, millet and maize are widely grown. Also, vegetables such as sweet potatoes, yams, ground-nuts, melons, pumpkins, cucumbers and many other excellent food crops are grown. Tobacco is grown abundantly, sugar-cane, the castor oil plant, cocoa, and cotton are also cultivated (Bergius *et al*., 2020).

4.1.1.3 Population

According to the 2012 census, the population of Kilombero was 407 880, with 202 789 males and 205 091 females (URT, 2013). This area is currently experiencing a doubling of the human population over the years. It has been demonstrated that within Tanzania, population growth results in environmental degradation (Madulu, 2004). The large migration of farmers due to fertile land and livestock keepers due to the presence of animal fodder is the primary cause of population growth.

4.1.1.4 Soil

Geologically, the Kilombero is characterized by sedimentary basin infillings forming a seasonal alluvial floodplain dominated by Fluvisols (Beck,1964 and Daniel *et al*, 2017). Kilombero is covered by the flood plain. Since the area is characterized by wetland, the soil is mainly heavy black cotton (mbuga) soil that retains water over relatively long periods, with isolated patches of lighter sand soil. Annual flooding is a crucial factor in the maintenance of the fertility of the soil for vegetation. In other areas, soil originates from granites which are deeply weathered. Some parts of Kilombero soil are moderately acidic, poor, freely drained, and markedly compacted near the surface where there is often a very high coarse grained soil fraction. The soil is generally red loamy sand (latosol).

4.1.1.5 Vegetation

Natural vegetation in the Kilombero District depends on the gradients from the rivers. On the riverside, vegetation is often dominated by *Hyparrhenia spp.* and *Reed* (*Phragmites mauritianus Kunth*.), followed by the low-lying valley grassland with perennial grasses including Guinea grass (*Panicum maximum Jacq.*) marginal grasslands, *combretacoes* wooded grasslands, and last, miombo woodland and forests exist in the upper valley (Starkey *et al*., 2002). The natural forests and miombo woodlands occupy the large part of the district. Miombo is the Swahili word for the *Brachystegia* genus, which is the dominant tree in this natural environment together with *Julbernardia* and *Isoberlinia*, of the subfamily

Caesalpinioideae. Artificial grassland and shrublands are also present due to human activities (Frost, 1996)

4.1.2 Methods

4.1.2.1 Reconnaissance survey

A pre-visit as well as pre-testing of questionnaires and checklists for clarity, comprehensiveness, redundancy, and meaningfulness were conducted. Also, this enabled the researcher to be familiar with the study area. During the survey, two households from each of the identified villages were randomly selected and interviewed to pre-test the questionnaire so as to check reliability and validity of the questions. Some corrections were made to meet the research objectives. The research design for this study was cross-sectional as data were collected at once in the study area without repetitions.

4.1.2.2 Sampling procedure

Three villages were purposely selected due to the presence of agroforestry farmers. Random sampling procedure was adopted for selecting households with agroforestry systems and practices, and village registers were used as a sampling frame. The sampling unit for this study was the individuals chosen from the population as respondents to represent others, and the information obtained can be used to describe the characteristics of the entire population (Bryman, 2004 and Nkonoki, 2015).

4.1.2.3 Sample size Determination

Nachimias and Nachimias (1996) pointed out that sample size is the most important determinant of any survey estimates. The author continues to demonstrate that the greater the precision of the estimate and the confidence in the results, the larger the sample size is needed. These authors explain further that another factor equally important in determining the sample size is the amount of resources (time, money, and personnel) available for the study. Gay and Diehl (1992) describe that the number of respondents depends on the type of research involved, such as descriptive, correlational, or experimental. However, 30-unit subjects are good to establish the relationship in any research. This is similar to studies by Bailey (1998), Saunders *et al.* (2007), Mbeyale (2009) and Mtongani *et al*. (2014), who also indicated that a sample of 30 units is sufficient irrespective of the population size and constitutes a representative sample size for data collection and analysis. On the other hand, investigations into socio-economic studies in Sub-Saharan Africa require a sample size of between 80 to 120 household respondents (Jew and Bonnington, 2011; McClanahan *et al*., 2005; Mtongani *et al.*, 2014). Therefore, a total of 90 respondents were sampled from the three villages (Igima, Mbingu and Ngajengwa) for interviews and this sample size was considered sufficient to generate statistical inferences required for making study conclusions.

4.1.2.4 Data collection

Primary data was collected using a combination of methods. Household interviews, key informant interviews, and focus group discussions. The questionnaire was the main instrument for collecting the primary data from the agroforestry farmers and included both closed and openended questions. Focus group discussions enabled to get insights into the status of agroforestry in the villages. Key informant interviews enabled to get more clarification on particular issues raised during the focus group discussion and interviews.

4.1.2.5 Data analysis

The qualitative information was analyzed using content analysis, whereby raw data was broken down to generate meaningful units of information. Multinomial logistic regression was used to identify the determinants or factors determining the adoption of agroforestry practices which are agroforestry systems and practices. This model is suitable for determining the adoption when the dependent variables have more than two categories or levels (Ojo *et al*., 2013; Obadim *et al*., 2020).

Let πj denote the multinomial of an observation falling in the j^{th} category to find the relationship between the probability and the p - explanatory variables

$X_1 + X_2 + X_3 \ldots\ldots\ldots\ldots X_p$ ………………………………………………… Equation 1

The multiple logistic regression is given by:

$\log\left[\frac{\pi_j(x_1)}{\pi_k x_1}\right] = a_{oi} + \beta_{1j} x_{1j} + \beta_{2j} x_{2j} + \ldots\ldots\ldots\ldots\ldots\ldots \beta_{pj} x_{pj}$ ……………. …Equation 2

Where J= 1, 2…… (k - 1), I = 1, 2…...p

K stands for number of response or dependent categories where for this study dependent categories for agroforestry systems are agrosilvopasture, agrosilviculture and silvopasture.

For agroforestry practices dependent categories are home garden, mixed intercropping, parkland and boundary.

P = Number of explanatory variables included in the model.

When estimating the model, the coefficient of the reference group is normalized to zero (Rahij and Fakayode, 2009; Ojo *et al*., 2013). This is because the probability of the choice must sum up to unity; hence, for the choice of three categories (agrosilvopasture, agrosilviculture and silvopasture) only two sets of parameters were identified and estimated. For four categories (home garden, mixed intercropping, parkland and boundary) only three distinct sets of parameters were identified and estimated. In this study, the reference category for agroforestry systems was agrosilvopasture and for agroforestry practices, the reference category was home garden. The natural logarithm for the odd ratio for equation 1 and 2 gives the estimation equation below.

$$\log \pi_j(x_i) = \frac{\exp\left(a_{0i} + \beta_{1j} x_{1i} + \beta_{2j} x_{1i} + \ldots\ldots\ldots\ldots\ldots + \beta_{pj} x_{pi}\right)}{1 + \sum_{j-1}^{k-1} \exp\left(¿\, a_{0i} + \beta_{1j} x_{1i} + \beta_{2j} x_{1i} + \ldots\ldots\ldots\ldots\ldots + \beta_{pj} x_{pi}\right)¿} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

Equation 3

J= 1, 2, ………. K – 1 the model parameter is estimated by the method of multinomial logit.

The independent variable included

X_1Farming experience (Years),X_2House hold income (Tanzania shillings),X_3 Duration of stay in the village (years), X_4Residence type (1 native 2 other wise), X_5 Education level, X_6 Extension services, X_7House hold size,X_8 Sex (1 male 2 otherwise).

4.2 Results and Discussion

4.2.1 Results

4.2.1.1 Adoption of agroforestry systems

The results indicate that sex and residence type influence the adoption of agroforestry systems (P < 0.05). When compared to agrosilvopasture, native residents were less likely to adopt agrosilviculture (P<0.05). Therefore, native residences negatively influenced adoption of agrosilviculture with reference to agrosilvopasture and rate of adoption decreased at an odd ratio of 0.14.

On the other hand, males were found less likely to adopt agrosilviculture with reference to agrosilvopasture, therefore they were more likely to adopt agrosilvopasture at an odd ratio of 0.344 (Table 13). Furthermore, there was no statistically significant difference in the adoption of silvopasture with reference to agrosilvopasture table 14 is illustrative.

Table13: Determinants of adoption of Agrosilvitulture with reference to Agrosilvopasture

Parameter Estimates				
Agrosilviculture system	B	Std. Error	Sig.	Exp(B)
Farming experience	-0.048	0.03	0.115	0.953
Household income	0	0	0.313	1
Time to stay	0.05	0.026	0.059	1.051
Household size	-0.066	0.117	0.574	0.937
Education	-0.108	0.256	0.675	0.898
Extension services (Yes)	0.84	0.563	0.136	2.316
Residence (Native)	-1.963	0.729	0.007*	0.14
Sex (Male)	-1.068	0.528	0.043*	0.344

a The reference category is: Agrosilvopastore. * P<0.05

Table 14: Determinants of adoption of Silvopasture with reference to Agrosilvopasture

Parameter Estimates Silvopastural systems	B	Std. Error	Sig.	Exp(B)
Farming experience	-0.009	0.048	0.843	0.991
Household income	0	0	0.965	1
Time to stay	0.074	0.043	0.083	1.077
Household size	0.288	0.289	0.319	1.333
Education	0.692	0.405	0.087	1.998
Extension services (Yes)	-0.546	1.155	0.636	0.579
Residence (Native)	-1.364	1.214	0.261	0.256
Sex (Male)	-0.521	1.031	0.614	0.594

a The reference category is: Agrosilvopastore. * P<0.05

4.2.2 Adoption of agroforestry practices

The duration of stay in the village, residence type, extension education, and sex (P 0.05) were the factors that influenced the adoption of agroforestry practices with a statistically significant difference. In mixed intercropping, a unit increase in the duration of staying in a village in years leads to an adoption increase at an odd ratio of 1.064. Furthermore, the availability of extension education, information, and awareness to farmers increased adoption at an odd ratio of 4.052. Native residences were less likely to influence the adoption of mixed intercropping with reference to home gardens. This shows that those native residences are likely to adopt home garden practice at an odd ratio of 0.068. Furthermore, males were less likely found to influence the adoption of mixed intercropping with reference to home gardens. Therefore, males were less likely to adopt mixed intercropping at an odd ratio of 0.167 (see Table 15). Boundary planting and parkland agroforestry practices were influenced by explanatory variables, but there was no statistically significant difference with reference to the home garden (see Table 16 and Table 17).

Table 15: Determinants of adoption of Mixed intercropping with reference to Home garden

Parameter Estimates Mixed intercropping	B	Std. Error	Sig.	Exp(B)
Farming experience	-0.048	0.036	0.175	0.953
Household income	0	0	0.303	1
Time to stay	0.062	0.031	0.041*	1.064
Household size	-0.139	0.14	0.32	0.87
Education	-0.44	0.301	0.144	0.644
Extension services (Yes)	1.399	0.675	0.038*	4.052
Residence (Native)	-2.684	0.908	0.003*	0.068
Sex (Male)	-1.79	0.65	0.006*	0.167

a The reference category is: Home garden. * P<0.05

Table 16: Determinants for adoption of Boundary planting with reference to Home garden

Parameter Estimates Boundary practice	B	Std. Error	Sig.	Exp(B)
Farming experience	-0.064	0.053	0.229	0.938
Household income	0	0	0.125	1
Time to stay	-0.086	0.069	0.213	0.917
Household size	-0.123	0.376	0.744	0.884
Education	0.474	0.655	0.469	1.607
Extension services (Yes)	0.715	1.388	0.606	2.045
Residence (Native)	2.951	2.495	0.237	19.134
Sex (Male)	3.004	2.128	0.158	20.164

a The reference category is: Home garden* P<0.05

Table 17: Determinants for adoption of parkland with reference to home garden

Parameter Estimates Parkland practice	B	Std. Error	Sig.	Exp(B)
Farming experience	-0.18	0.138	0.192	0.835
Household income	0	0	0.077	1
Time to stay	0.141	0.093	0.13	1.151
Household size	0.018	0.256	0.944	1.018
Education	-18.36	0	.	1.06E-08
Extension services (Yes)	3.027	1.759	0.085	20.64
Residence (Native)	-24.553	0	.	2.18E-11
Sex(Male)	-0.722	1.7	0.671	0.486

a The reference category is: Home garden. * P<0.05

4.3 Discussion

4.3.1 Agroforestry systems in Kilombero

The results indicated that there was a negative correlation between native residences and the adoption of agrosilviculture with reference to agrosilvopasture indicating that native residences were more likely to adopt agrosilvopasture than agrosilviculture. During the survey, respondents pointed out that agrosilvopasture is better than agrosilviculture as it allows the diversification of all three components. In addition, during focus group discussion, respondents pointed out that non-natives are less likely to engage in agroforestry systems because many of them spend a short time and move to an area. A study by Obeng and Weber (2014) reported that non-native farmers are less likely to adopt agrosilvopasture due to their shorter horizon. Sex was another factor which shows the statistical significance difference in adoption of agrosilviculture with reference to agrosilvopasture. In this study, males were less likely to adopt agrosilviculture with reference to agrosilvopasture. Respondents pointed out that with the presence of trees and crop integration, livestock are also important, especially for income contribution when there is crop failure. Similar results have been observed in Malawi by Thangata and Alavalapati (2003) and in Kenya by Sanchez (2002) who indicated that female farm headed houses did not adapt to the agroforestry system compared to male farm headed houses because most males prefer trees as the long-term major source of income. Also, during the focus group discussion, few spouses were available to respond on behalf of the rest. The woman pointed out that men are always the heads of households, as a result, they make decisions on household affairs, such as controlling resource allocation and general land use management. According to Oino and Mugure (2013), male land ownership has put them in the forefront of decision making on land use systems such as the type of agroforestry systems to be practiced for the benefit of households. On the other hand, males also pointed out that females are always involved during the planning of land use but they cannot change the last decision made by males, and poultry were found to belong to females and livestock to males. Similar results have been observed by Merce (2004) who indicates that women are more involved practically in agroforestry systems than men, but they cannot make final decisions on the utilization of the land and agroforestry products.

4.3.2 Adoption of agroforestry practices.

The findings revealed that native residences had a negative correlation with the adoption of mixed intercropping with reference to the home garden. This indicates that native residences are more likely to adopt home gardens compared to mixed intercropping. A study by Irshad *et al*. (2011) pointed out that native residences have a high chance of succeeding in the implementation of home garden practice as it takes time to establish a permanent settlement. This result is similar to a study by Magugu *et al*. (2015) who pointed out that native residence is in a good position to attain land tenure and secure enough land for agroforestry, since agroforestry is a long-term investment.

Duration of stay in the village had a positive correlation with the adoption of mixed intercropping with reference to the home garden. This indicates that as the duration of stay in the village increases, farmers become more interested in adopting mixed intercropping than home garden. This result is similar to a study by Liniger *et al*. (2011) who pointed out that the duration of stay influences crop diversification, hence shifting from practicing agroforestry near the home to the farm land. Farmers with access to extension education were likely to adopt mixed intercropping over the home garden. During the survey, farmers practicing mixed intercropping argued that in their home gardens there was no proper arrangement of crops and trees, which made them less productive. Similarly, a study by Chija (2013) indicates that extension education is the most critical factor that enhances farmers' adoption of a particular agroforestry practice in consideration of the product and production. On the other hand, males were found less likely to adopt mixed intercropping with reference to home garden. During the survey, it was noted that the majority of the households were headed by males, and one of the roles of males is to ensure food security. In that respect, men preferred home gardens because most of the components in the home garden supplement for the household's food and income. In the study area, fruit trees served as the primary source of food, especially during droughts. The fruit trees found in the study area were *Mangifera* *indica*, *Percea americana* and *Cocos nucifera*. A similar study on the home garden by Mengistu (2008) confirmed that fruit trees in the home garden have a significant role in the family during environmental crises such as drought.

4.4 Conclusion

This research addresses the potential economic and social issues and their implications for the adoption of agroforestry systems and practices. The research findings prove that Agroforestry systems and practices are difficult to establish in Kilombero if the explanatory variables are not clearly addressed. Farmer-oriented factors are critical in the adoption of agroforestry practices and systems among rural farmers. The model did not provide statistically significant support to accept the influence of all the explanatory variables on farmers' decisions to adopt agroforestry systems and practices. But key factors that shows statistically significant in decision to adopt agroforestry systems and practices provide an empirical overview of the factors that should be given attention to the adoption of agroforestry practices and systems. Therefore, the study recommends that all the independent variables outlined require to be addressed in order to raise awareness and increase capacity building on the potential available in agroforestry systems and practices.

This study recommends that different stakeholders should be involved and these findings should be disseminated to enhance adoption. Furthermore, these findings may be replicated in other parts of tropical countries to improve the adoption of agroforestry systems and practices.

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CHAPTER FIVE

Carbon sequestration in agroforestry systems and practices as a strategy for climate change mitigation

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Abstract

Worldwide, agroforestry has been recognized as a potential greenhouse gas mitigation strategy under the Kyoto protocol due to its potential for carbon sequestration. There are several agroforestry systems and practices with different capacity for carbon sequestration. In that respect, carbon sequestration can depend on the type of system, practices, climate, time since land use change and previous land use. Our knowledge on carbon sequestration in agroforestry systems and practices from tropical countries such as Tanzania is however, limited. To improve understanding, a study was conducted in the Kilombero District, where the local communities are practicing various agroforestry systems and practices. The study evaluated the carbon sequestration in different agroforestry systems and practices and species' contributions to carbon sequestration. An ecological survey was conducted on 90 agroforestry farmlands which were considered as plots in different agroforestry systems and practices from three villages of different altitudinal ranges. A pivot table through Microsoft Excel was used in the analysis, and allometric models were used for computing biomass for carbon estimation. The result shows that Mangifera indica contributed highest carbon over all the tree species encountered during the ecological survey, with 70.57 Mg C ha^{-1}. Three agroforestry systems were identified with their carbon stocks. Agroforestry systems were agrosilviculture with 55.7Mg C ha^{-1}, agrosilvopasture with 115.3 Mg C ha^{-1} and silvopasture 81.5 Mg C ha^{-1}. The carbon stock obtained in agroforestry practices was 185.79 Mg C ha^{-1} for home gardens, 17.79 Mg C ha^{-1} for mixed intercropping, 26.75 Mg C ha^{-1} for parkland and 23.22 Mg C ha^{-1} for boundary. Findings revealed that home garden practice and the agrosilvopastural system contributed more to carbon sequestration.

This study concludes that agrosilvopastural systems and home garden practice have more potential to sequester more carbon than the rest of the systems and practice. Therefore, investing in agrosilvopasture and home gardens provides good results in mitigating the effects of climate change through carbon sequestration. This information is useful to inform practitioners and policy makers on the most effective agroforestry systems and practices for carbon sequestration, since agroforestry plays an important role in climate change mitigation.

Key words: Carbon sequestration, Climate Change Mitigation, Carbon stock, Agroforestry systems, Agroforestry practices.

5.0 INTRODUCTION

Agroforestry has been considered as a viable alternative to prevent and mitigate climate change. Trees as a means of mitigating climate change have been achieved by maintaining the existing trees on farmland and or by increasing the plantation of short-rotation or fast-growing trees on the farm fields (Gupta *et al*., 2013). Mitigating climate change through increased carbon sequestration in the soil can particularly become useful, especially when addressed in combination with other challenges that affect people's livelihoods, such as reversing land degradation and ensuring food security (Batjes, 2003; Feliciano *et al*., 2018).

Usually, potential carbon sequestration may occur in different land uses, including agricultural land use and forest land through improved land use management and conventions to land use with higher carbon storage in harvested products (IPCC, 2000). The IPCC recognized that agroforestry systems and practices have a high potential for sequestering carbon under climate change mitigation strategies (Gupta *et al*., 2013). Within agroforestry systems and practices, carbon can be stored above and below ground biomass (Nair *et al*., 2009). In that respect, agroforestry systems and practices accumulate more carbon than pure forest and pasture because they have both forest and grassland sequestration and active storage patterns (Sharrow and Ismail, 2004; Udawatta and Jose, 2011) but the sequestration potential of agroforestry depends on plant characteristics, tree species, age, crop, biodiversity and tree density. It is also affected by structural configuration and management factors such as fertilization, residuals, and harvesting regime. These factors, together with agroecological conditions as well as soil characteristics in the area where the agroforestry systems and practices are implemented, influence carbon sequestration (Nair *et al*., 2009;

Jose and Burdhan, 2012; Baah-Acheamfour *et al*., 2017; Marone *et al*., 2017). Jose and Burdhan (2012) also pointed out that if agroforestry systems and practices are to be used for climate change mitigation through carbon sequestration, then better information is required about above and below ground biomass and carbon stock. The aim of this study was to determine the carbon stock in different agroforestry systems and practices and also to determine which systems and practices have the best potential for long-term carbon sequestration.

5.1 Material and Methods

5.1.1 Description of the study area

The study was conducted in Kilombero District, which is located in Morogoro Region between 8°15'0" S and 36°25'0" E with elevation ranging from 262 m to 550 m above mean sea level. Administratively, Kilombero District has five divisions, 19 wards and 46 villages. The district is bordered by Kilosa District in the North, the South East by Ulanga District, the West by the Iringa Region and in the East by the Lindi Region (URT, 2007).

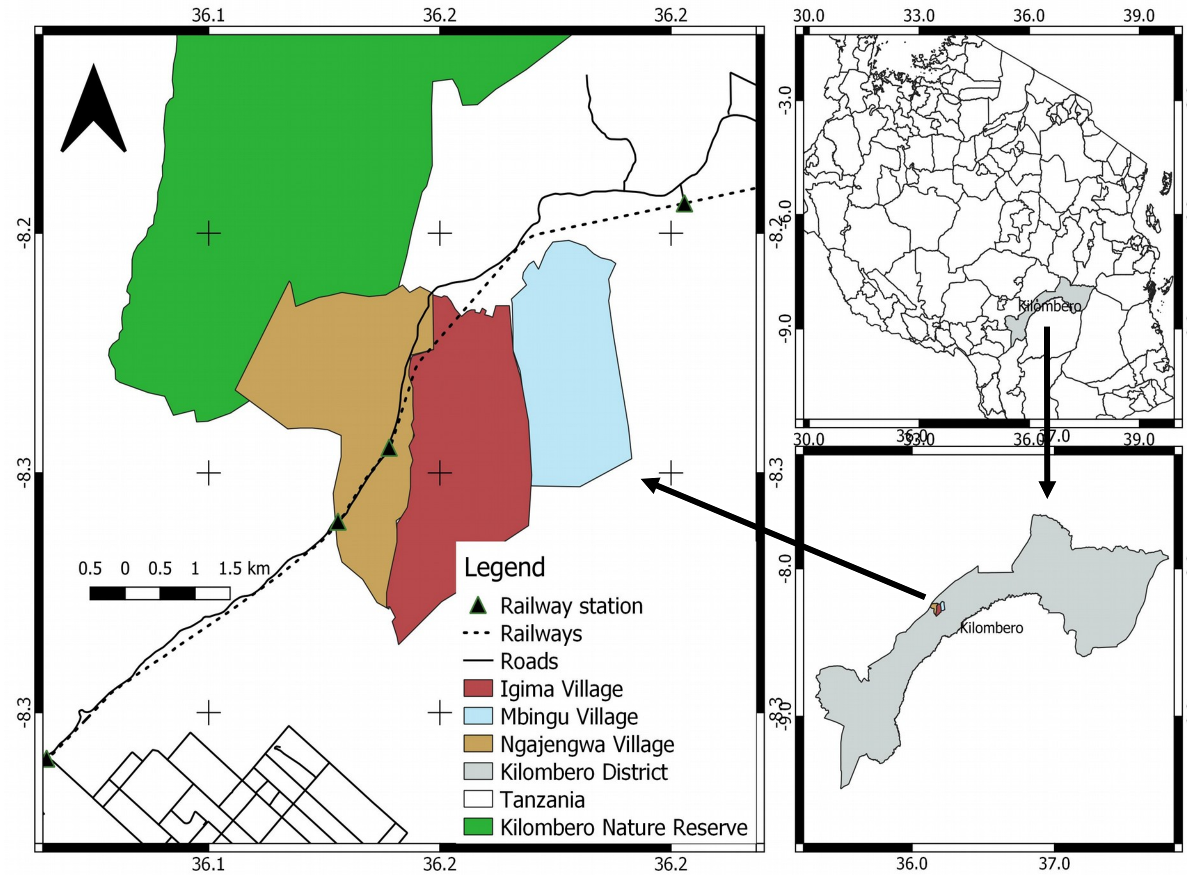

Figure 12: Kilombero District map showing the study area

5.1.1.1 Climate

The climate in the study area is marked by wet and dry seasons, which are further categorized into four sub seasons, hot wet season from December to March, the cool wet season from April to June, the cool dry season from July to August, and the hot dry season from September to November. The area receives between 1200 and 1800 mm of rainfall per year and temperatures range from 26 to 32 °C (Balama *et al*., 2016).

5.1.1.2 Land use

Generally, the land use is categorized as village land, reserved land and general land as defined in the Village Land Act 1999 (URT, 2017). Meanwhile, Kilombero is considered as one of the fertile spots in Tanzania. The main economic activities in the area include cash crop cultivation, food crop cultivation, petty trading, and fishing in the Kilombero River (URT, 2007). Overall, cereals of the coast such as rice, millet and maize are widely grown. Also, vegetables such as sweet potatoes, yams, ground-nuts, melons, pumpkins, cucumbers and many other excellent food crops are grown. Tobacco is grown abundantly, sugar-cane, the castor oil plant, cocoa, and cotton are also cultivated (Bergius *et al*., 2020).

5.1.1.3 Population

According to the 2012 census, the population of Kilombero was 407 880, with 202 789 males and 205 091 females (URT, 2013). This area is currently experiencing a doubling of the human population over the years. It has been demonstrated that within Tanzania, population growth results in environmental degradation (Madulu, 2004). The large migration of farmers due to fertile land and livestock keepers due to the presence of animal fodder is the primary cause of population growth.

5.1.1.4 Soil

Geologically, the Kilombero is characterized by sedimentary basin infillings forming a seasonal alluvial floodplain dominated by Fluvisols (Beck,1964 and Daniel *et al*, 2017). Kilombero is covered by the flood plain. Since the area is characterized by wetland, the soil is mainly heavy black cotton (mbuga) soil that retains water over relatively long periods, with isolated patches of lighter sand soils. Annual flooding is a crucial factor in the maintenance of the fertility of the soil for vegetation. In other areas, soil originates from granites which are deeply weathered. Some parts of Kilombero soil are moderately acidic, poor, freely drained, and markedly compacted near the surface where there is often a very high coarse grained soil fraction. The soil is generally red loamy sand (latosol).

5.1.1.5 Vegetation

Natural vegetation in the Kilombero District depends on the gradients from the rivers. On the riverside, vegetation is often dominated by *Hyparrhenia spp.* and *Reed* (*Phragmites mauritianus Kunth*.), followed by the low-lying valley grassland with perennial grasses including Guinea grass (*Panicum maximum Jacq.*) marginal grasslands, *combretacoes* wooded grasslands, and last, miombo woodland and forests exist in the upper valley (Starkey *et al*., 2002). The natural forests and Miombo woodlands occupy the large part of the district. Miombo is the Swahili word for the *Brachystegia* genus, which is the dominant tree in this natural environment together with *Julbernardia* and *Isoberlinia*, of the subfamily *Caesalpinioideae*. Artificial grassland and shrublands are also present due to human activities (Frost, 1996)

5.1.2 Methods

5.1.2.1 Reconnaissance survey

Pre-visiting was conducted as well as pre-testing of inventory equipment. This was also conducted so as to familiarize with the study area and observe the nature of the agroforestry farmland. The research design for this study was cross-sectional as data was collected at once without repetitions.

5.1.2.2 Sampling Procedure and sample size determination

Three villages were purposely selected due to the presence of agroforestry practices. Random sampling procedure was adopted for selecting households with agroforestry systems and practices, and village registers were used as a sampling frame. For the forestry inventory in the farmland, a systematic sampling procedure was expected to be adopted with 10×125m plot size in case the farm land encountered had more than two hectares. But all encountered farm land had less than two hectares, thus an average of 0.18 ha mean (± 0.016 S. E) and therefore the whole farmlands were considered as a plot (Charles *et al*., 2014). Since 30-unit subjects are good to establish the relationship in any research, as indicated by Bailey (1998); Saunders *et al.* (2007); Mbeyale (2009) and Mtongani *et al*. (2014), then 90 households were randomly selected for farm field visit and inventory from three villages.

5.1.2.3 Data collection

A total of 90 agroforestry farm lands were visited in this study. Data for biomass were species, number of trees, diameter at breast height (DBH) for trees, height and diameter at 0.3m for *Theobroma cacao* trees (Mbobda *et al*., 2016; Nadege *et al*., 2019). Height was measured by a suunto hypsometer and diameter by a caliper.

5.1.2.4 Data analysis

Information obtained from the biophysical survey, mainly inventory data, was recorded in Microsoft Excel for biomass calculation and carbon estimation. Since similar trees were found in both agroforestry systems and practices, tree data was analyzed based on systems and practices separately. Allometric equations were used to convert the field measurement attributes, mainly height and diameter, into stand biomass. A species-specific allometric model was used for trees with allometric equations and a general allometric model was used for trees without specific equations (see Table 18). Most of these models have been developed for Tanzanian tree species and vegetation types. Carbon stock was computed as the product of total biomass and a factor of 0.5 (Munishi and Shirima, 2013).

Table 18: Allometric equation for different tree spicesTree species	**AGB**	**Sources**	**BGB**	**Sources**
Tectona grandis	$0.3356 \times D^{2.1651}$	Zahabu *et al.*, 2016 a	$0.0279 \times D^{1.7430} \times H^{0.7689}$	Zahabu *et al.*, 2016 a
Theobroma cacao	$0.1208 \times d^{1.98}$	Hairiah *et al.*, 2011	AGB×0.25	MNRT, 2015
Cocos nucifera	$3.7964 \times H^{1.8130}$	Zahabu *et al.*, 2016 b	$13.5961 \times H^{0.6635}$	Zahabu *et al.*, 2016 b
Anacardium occidentale	$0.3152 \times D^{1.7722} \times H^{0.5003}$	Zahabu *et al.*, 2016 c	AGB×0.25	MNRT, 2015
Other trees	$0.051 \times (D^2 \times H)^{0.93}$	Henry *et al.*, 2009	AGB×0.25	MNRT, 2015

Where ABG = Above ground biomass, BGB =Below ground biomass, D= Diameter at 1.3m, d = diameter at 0.3m above the ground and H=height of a tree.

5.2 Results and discussion

5.2.1 Results

On farm trees and carbon stock

During the biophysical survey, a total of 37 tree species from 16 families were found in the study area. Carbon sequestration per individual tree was calculated to determine which tree species contributed the most in all agroforestry practices and systems. The *Mangifera indica* species were found to have high carbon sequestration at 70.57 Mg C ha^{-1} followed by *Cocos nucifera* 68.01 Mg C ha^{-1}. *Theobroma cacao* and *Vertex doniana* had 0.0013 Mg C ha^{-1} and 0.0008 $MgCha^{-1}$ had lesser carbon sequestration than all species studied (see figure 13).

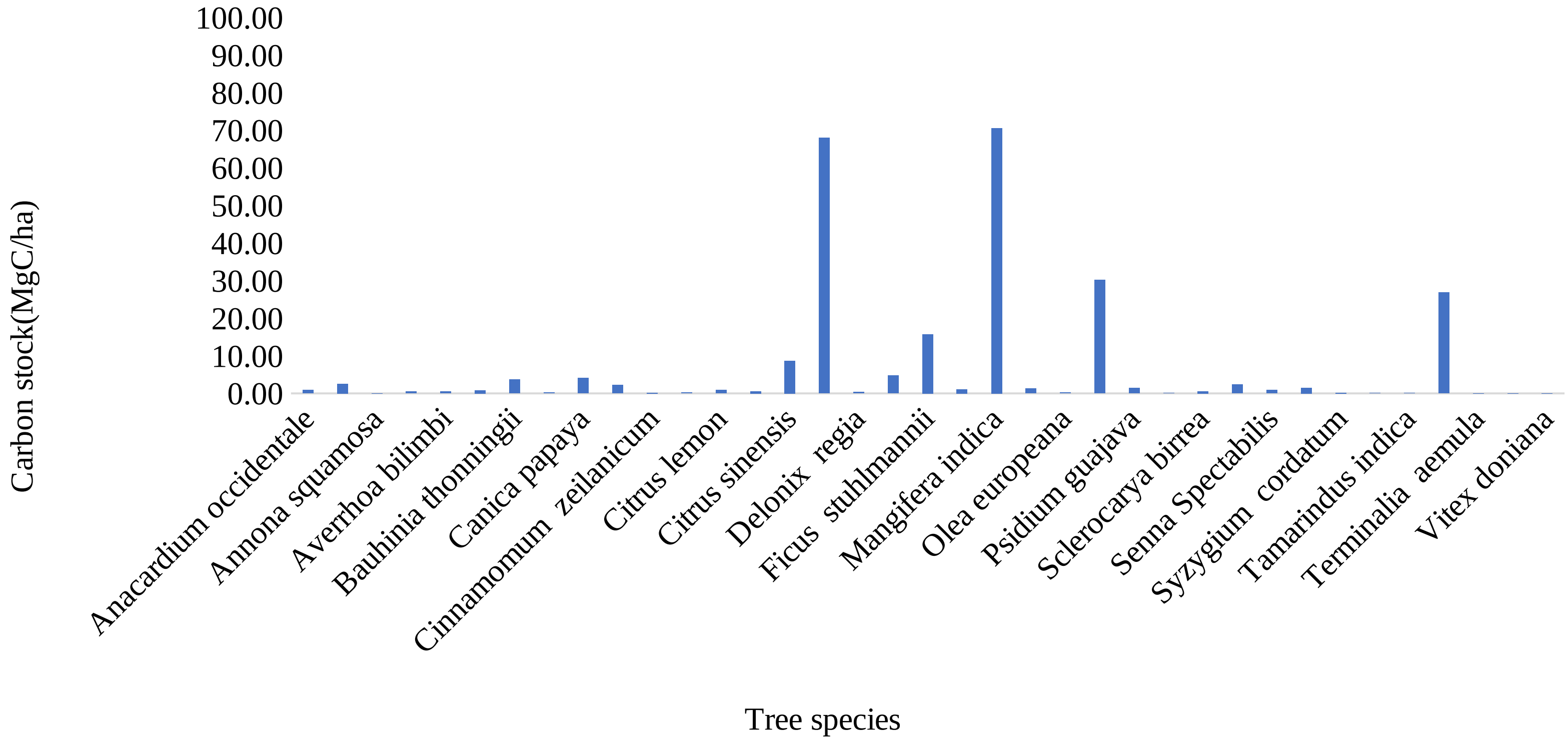

Figure 13 : Carbon storage in different tree specie

5.2.2 Carbon stock in different agroforestry systems

On the other hand, different agroforestry systems were identified during the survey. Agroforestry systems identified were agrosilviculture, agrosilvopasture and silvopasture. On the basis of agroforestry systems, agrosilvopasture sequestered more carbon than agrosilviculture and silvopasture did. Figure 14 below is illustrative.

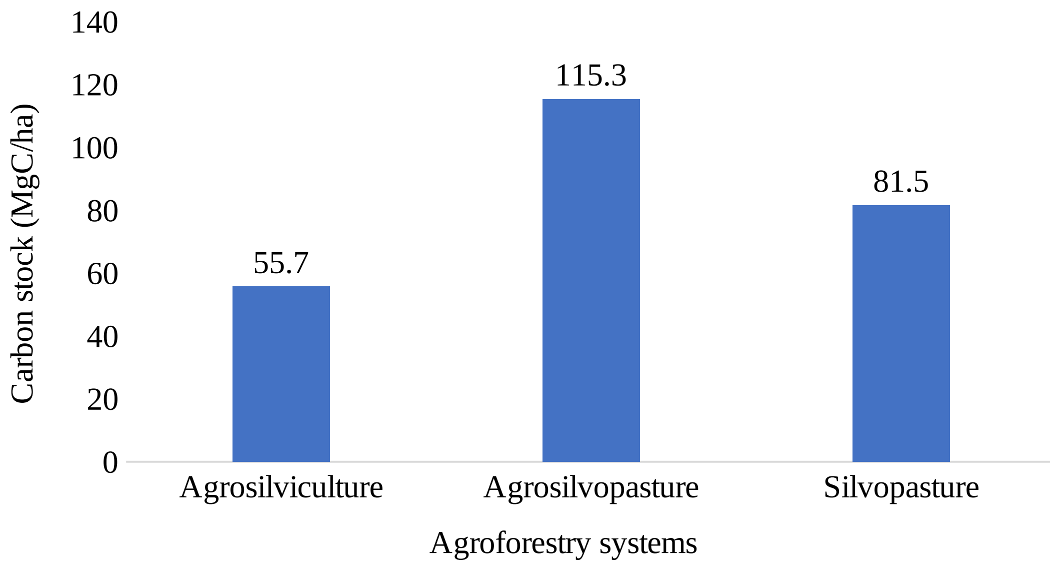

Figure 14: Carbon stock in different agroforestry systems

In agroforestry systems, different species were encountered and their carbon stocks were computed. The species were then grouped based on the agroforestry systems, and the amount of carbon sequestered was identified based on the species available in every agroforestry system. In agrosilviculture, the species which sequestered high amount of carbon was *Tectona grandis* with 19.04 $MgCha^{-1}$ (see table 19). In agrosilvopasture was *Mangifera* *indica* with 37.06Mg C ha^{-1} (see table 20) and silvopasture was *Cocos nucifera* with 32.29Mg C ha^{-1} (see table 21).

Table 19: Carbon stock for different tree species in Agrosilviculture system

Botanical name	Local name	Frequency	Sum of C
Tectona grandis	Mtiki	98	1
Mangifera indica	Muembe	67	9
Cocos nucifera	Mnazi	68	9
Ficus stuhlmannii	Mkuyu	15	8
Percea americana	Mparachichi	44	4
Anacardium occidentale	Mkorosho	5	0
Sclerocarya birrea	Mng'ong'o	3	0
Delonix regia	Mkirismasi	3	0
Senna siamea	Mjohoro pori	6	0
Khaya anthotheca	Mkangazi	4	0
Artocarpus heterophyllus	Mfenesi	4	0
Citrus sinensis	Mchungwa	9	0
Citrus reticulata	Mchenza	1	0
Brachystegia boehmi	Myombo	2	0
Citrus lemon	Mlimao	10	0
Psidium guajava	Mpera	6	0
Averrhoa bilimbi	Mbilimbi	1	0
Syzygium cordatum	Mnyonyo	2	0
Canica papaya	Mpapai	4	0
Cinnamomum zeilanicum	Mdalasini	12	0
Olea europeana	Mzaituni	2	0
Annona murcata	Mstafeli	5	0
Tamarindus indica	Mkwaju	1	0
Cedrella odorata	Msedrela	1	0
Milicia excelsa	Mvule	1	0
Annona squamosa	Mtopetope	2	0
Syzygium cumini	Mzambarau	1	0
Vitex doniana	Mfuru	3	0
Theobroma cacao	Mkokoa	901	0

Table 20: Carbon stock for different tree species in Agrosilvopasture system

Botanical name	Local name	Frequency	Sum of C(Mg/h
Mangifera indica	Muembe	96	37.06
Cocos nucifera	Mnazi	105	25.99

Percea americana	Mparachichi	23	12.56
Tectona grandis	Mtiki	57	7.32
Citrus sinensis	Mchungwa	25	7.09
Elaeis guineensis	Mchikichi	27	4.79
Canica papaya	Mpapai	10	4.03
Bauhinia thonningii	Msegese	3	3.71
Annona murcata	Mstafeli	11	2.49
Cedrella odorata	Msedrela	7	2.21
Senna siamea	Mjohoropori	8	1.95
Milicia excelsa	Mvule	3	1.24
Senna Spectabilis	Mjohoro	7	0.92
Azadirachta indica	Mwarobaini	5	0.85
Khaya anthotheca	Mkangazi	8	0.71
Ficus stuhlmannii	Mkuyu	11	0.43
Citrus lemon	Mlimao	12	0.39
Citrus reticulata	Mchenza	7	0.36
Averrhoa bilimbi	Mbilimbi	3	0.35
Artocarpus heterophyllus	Mfenesi	3	0.26
Citrus autatiifolia	Mndimu	1	0.17
Syzygium cordatum	Mnyonyo	2	0.08
Sclerocarya birrea	Mng'ong'o	1	0.06
Cinnamomum zeilanicum	Mdalasini	5	0.06
Syzygium cumini	Mzambarau	1	0.05
Psidium guajava	Mpera	3	0.05
Saraca asoca	Mwashoki	2	0.04
Tamarindus indica	Mkwaju	1	0.03
Terminalia aemula	Mkulungu	1	0.03
Annona squamosa	Mtopetope	2	0.03
Anacardium occidentale	Mkorosho	2	0.02
Theobroma cacao	Mkokoa	131	0.00

Table 21: Carbon stock for different tree species in Silvopasture systemBotanical name	Local name	Frequency	S C(M
Cocos nucifera	Mnazi	21	3
Mangifera indica	Muembe	24	2
Percea americana	Mparachichi	17	1
Ficus stuhlmannii	Mkuyu	6	
Sorindeia obtusifolia	Mpilipili	2	
Citrus sinensis	Mchungwa	3	
Psidium guajava	Mpera	2	
Tectona grandis	Mtiki	7	
Citrus lemon	Mlimao	1	

Olea europeana	Mzaituni	2
Citrus autatiifolia	Mndimu	2
Annona murcata	Mstafeli	2
Citrus reticulata	Mchenza	1
Averrhoa bilimbi	Mbilimbi	1
Artocarpus heterophyllus	Mfenesi	1
Theobroma cacao	Mkokoa	70
Vitex doniana	Mfuru	1

5.2.3 Carbon stock in different Agroforestry practices

Different practices contribute to biomass and carbon sequestration differently (see figure 15). Home garden was the practice with the highest carbon stock with 185.79 Mg C ha^{-1} followed by Parkland with 26.75 Mg C ha^{-1}, Boundary with 23.22 Mg C ha^{-1} and then mixed intercropping with 17.79 Mg C ha^{-1}.

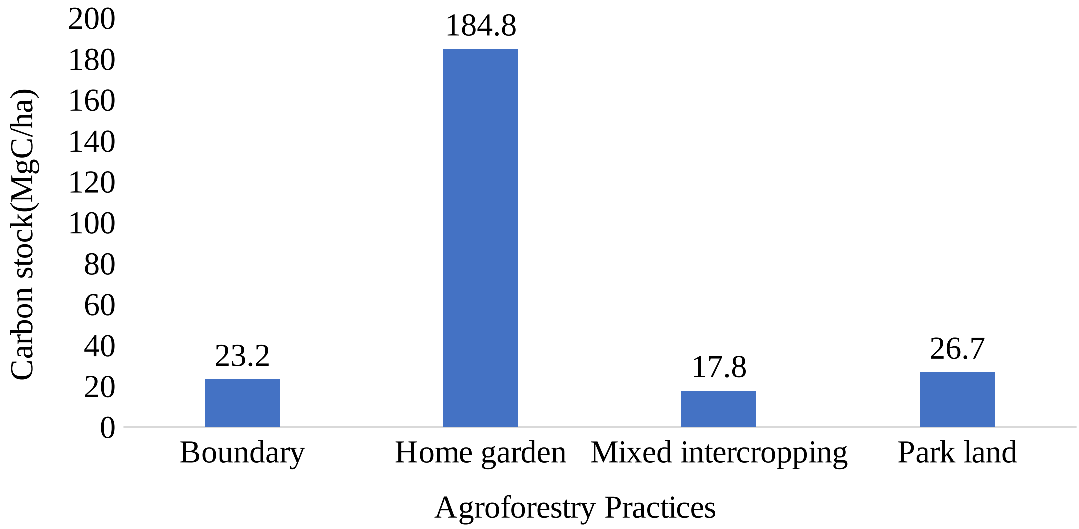

Figure 15: Carbon stock in different agroforestry practices

Different tree species sequestered different amounts of carbon in agroforestry practices. Since not all tree species were available in all the practices, here are the species identified in different agroforestry practices with their carbon estimation. The following table shows the species and carbon stocks available in each agroforestry practice Table 22,23,24 and 25 is illustrative.

Table 22: Carbon sequestration in different tree species	Local Name	Frequency	Sum C(Mg/

identified in Boundary planting agroforestry Botanical name			
Tectona grandis	Mtiki	45	10.
Ficus stuhlmannii	Mkuyu	5	5.9
Mangifera indica	Muembe	14	3.4
Cedrella odorata	Msedrela	3	1.8
Sclerocarya birrea	Mng'ong'o	3	0.5
Delonix regia	Mkirismasi	2	0.3
Psidium guajava	Mpera	2	0.1
Khaya anthotheca	Mkangazi	1	0.0
Tamarindus indica	Mkwaju	1	0.0
Vitex doniana	Mfuru	2	0.0
Theobroma cacao	Mkokoa	2	0.0

Table 23: Carbon sequestration in different tree species identified in Parkland agroforestry Botanical name	Local name	Frequency	Sur C(M
Cocos nucifera	Mnazi	21	
Tectona grandis	Mtiki	13	
Mangifera indica	Muembe	17	
Percea americana	Mparachichi	6	
Ficus stuhlmannii	Mkuyu	1	
Azadirachta indica	Mwarobaini	1	
Citrus reticulata	Mchenza	2	
Artocarpus heterophyllus	Mfenesi	2	
Cedrella odorata	Msedrela	1	
Brachystegia boehmi	Myombo	1	
Anacardium occidentale	Mkorosho	1	
Averrhoa bilimbi	Mbilimbi	1	
Citrus sinensis	Mchungwa	1	
Citrus lemon	Mlimao	1	
Vitex doniana	Mfuru	1	
Theobroma cacao	Mkokoa	8	

Table 24: Carbon sequestration in different tree species identified in Home garden agroforestry practices

Botanical name	Local Name	Count of Local name	Sum
Mangifera indica	Muembe	114	
Cocos nucifera	Mnazi	119	
Percea americana	Mparachichi	41	
Citrus sinensis	Mchungwa	28	
Ficus stuhlmannii	Mkuyu	16	
Tectona grandis	Mtiki	62	
Elaeis guineensis	Mchikichi	27	
Canica papaya	Mpapai	11	
Bauhinia thonningii	Msegese	3	
Annona murcata	Mstafeli	14	
Senna siamea	Mjohoro pori	8	
Sorindeia obtusifolia	Mpilipili	2	
Psidium guajava	Mpera	5	
Milicia excelsa	Mvule	3	
Senna Spectabilis	Mjohoro	7	
Citrus lemon	Mlimao	14	
Khaya anthotheca	Mkangazi	8	
Azadirachta indica	Mwarobaini	4	
Averrhoa bilimbi	Mbilimbi	4	
Citrus reticulata	Mchenza	7	
Citrus autatiifolia	Mndimu	3	
Olea europeana	Mzaituni	2	
Cedrella odorata	Msedrela	4	
Syzygium cordatum	Mnyonyo	2	
Sclerocarya birrea	Mng'ong'o	1	
Cinnamomum zeilanicum	Mdalasini	5	
Syzygium cumini	Mzambarau	1	
Artocarpus heterophyllus	Mfenesi	3	
Saraca asoca	Mwashoki	2	
Tamarindus indica	Mkwaju	1	
Terminalia aemula	Mkulungu	1	
Annona squamosa	Mtopetope	2	
Anacardium occidentale	Mkorosho	2	
Theobroma cacao	Mkokoa	185	
Vitex doniana	Mfuru	1	

Table 25: Carbon sequestration in different tree species identified in Mixed intercropping agroforestry practicesBotanical name	Local name	Count of Local name	Sum
Cocos nucifera	Mnazi	54	
Mangifera indica	Muembe	42	
Percea americana	Mparachichi	37	
Tectona grandis	Mtiki	42	
Ficus stuhlmannii	Mkuyu	10	
Anacardium occidentale	Mkorosho	4	
Senna siamea	Mjohoro pori	6	
Khaya anthotheca	Mkangazi	3	
Citrus sinensis	Mchungwa	8	
Citrus lemon	Mlimao	8	
Artocarpus heterophyllus	Mfenesi	3	
Syzygium cordatum	Mnyonyo	2	
Cinnamomum zeilanicum	Mdalasini	12	
Olea europeana	Mzaituni	2	
Brachystegia boehmi	Myombo	1	
Canica papaya	Mpapai	3	
Annona murcata	Mstafeli	4	
Psidium guajava	Mpera	4	
Milicia excelsa	Mvule	1	
Delonix regia	Mkirismasi	1	
Annona squamosa	Mtopetope	2	
Syzygium cumini	Mzambarau	1	
Theobroma cacao	Mkokoa	907	

5.3 Discussion

5.3.1 Carbon stock in tree species

From the results, 37 species were obtained during the biophysical survey. *Mangifera indica* had the highest capacity to sequester carbon with 70.57 Mg C ha^{-1} followed by *Cocos nucifera* with 68.01Mg C ha^{-1}. The high amount of carbon in this species is explained by dominance as well as diameter at breast height. A study by Mitra *et al*. (2018) proved that a high amount of carbon may be due to its dominance as a result of the high demand for mango tree products as well as palm tree products (fruits and coconut juice) for both domestic and local market demand. A study conducted in the Philippines on carbon sequestration revealed that *Mangifera indica* can sequester 100.71 Mg C ha^{-1}(Janiola and Marin, 2016). This is higher than the amount obtained in this study. In fact, Brown (2002) and Gibs, (2007) reported that Dbh is 95% determinant of the total biomass, and in this study, *Mangifera indica* presents biomass and carbon sequestration which can be due to its average diameter and height. Other species like *Theobroma cacao* and *Vertex doniana* had lesser carbon sequestration due to smaller average diameter and height.

The number of occurrences of trees in the plots can also be used to justify the amount of carbon stored in a particular species (Janiola and Marin, 2016). The top most trees with the highest biomass were tree species used for food (*Cocos nucifera*), fruits (*Mangifera indica and Persea americana*), timber production, (*Tectona grandis*) and one mostly used for shade (*Ficus stuhlmannii*). The variety of species documented and observed during the field display the potential for agroforestry to enhance the resilience of farmers to present and future climate risk. For example, farmers in both villages maintain different varieties of trees for timber, fruits and animal fodder to support livestock during drought. A similar study conducted in Kenya shows that the majority of small-holder farmers maintain trees not only for food support but also for soil and water conservation (Faye *et al*., 2011 and Reppin *et al*., 2020). High tree species diversity was found in home gardens where multipurpose trees for various purposes such as animal fodder, shade, timber, and food are grown. For example, trees with a high frequency in the home garden were *Mangifera indica*, *Cocos nucifera, Persea americana, Tectona grandis and Ficus stuhlmannii*. Moreover, high economic value trees were widely spread on the farm land.

5.3.2 Carbon sequestration in agroforestry systems

In agroforestry systems, carbon is also stored below and above ground. Studies in India have shown that different agroforestry systems have a sequestration potential of 68 - 228 Mg C ha^{-1} (Dixon *et al*., 1994; Murthy *et al*., 2013), and these values may always vary in different regions depending on the biomass production. Based on the results, the agrosilvopasture shows high carbon sequestration over silvopasture and agrosilviculture. Under this study, Silvopasture is the second agroforestry system with high potential source of carbon sequestration. The integration of livestock and forests benefits both systems by reducing and offsetting greenhouse gas emissions from the agriculture sector. On the other hand, the presence of livestock lowers the animal's emission level (Nair *et al*., 2011) by improving pasture quality, which can then reduce methane from enteric fermentation (Bernardi *et al*., 2016). In addition, the presence of a high amount of carbon in agrosilvopasture is influenced by litter input on the soil surface (Olson and Al-Kaisi, 2015).

The introduction of integrated crops, livestock and forest systems enhances carbon sequestration due to the presence of different components which increase root volume and promote greater production of vegetal biomass (Tonucci *et al*., 2011). In Kilombero, the silvopasture had the potential to store 81.5 Mg C ha^{-1} of carbon. These results may be influenced by geographical location, age, and management (Nair *et al*.,2009). A similar study conducted in Latin America indicates that the silvopastural system can store about 0.31- 91.8 Mg C ha^{-1} (Montagnini *et al*., 2013). This range reflects the heterogeneity of the silvopastural system, which differs in its design, species and site conditions (Montagnini *et al*., 2013). Species used in silvopasture are mostly consumed by animals as fodder, either harvested or browsed by cattle. Therefore, standing biomass composed principally of branches and foliage remains low and sometimes leads to low carbon sequestration compared to other systems (Montagnini *et al*., 2013). Agrosilviculture in Kilombero sequester 55.7 Mg C ha^{-1} which is less compared to other identified systems. A study by Murthy *et al*. (2013) pointed out that the amount of carbon sequestered in agrosilviculture depends highly on the age of a tree and the tree species available. For example, the agrosilviculture of *Dalbergia sissoo* of 11-year age is able to accumulate 48 - 52 Mg C ha^{-1} (Newaj and Dhyani, 2007). The carbon dynamic in agrosilviculture is described by different operations on trees, such as pruning to open the tree canopy. This study also revealed that the low amount of carbon in agrosilviculture may be the result of the small number of trees on the farm land.

5.3.3 Carbon sequestration in agroforestry practices

A number of studies have shown that agroforestry in the tropics has higher carbon stock than any crop field or pasture (Albech and Kandji, 2003; Nair *et al*., 2009). From the result home garden had higher carbon sequestration with 185.79 Mg C ha^{-1}. This result is highly influenced by the mixture of components of agroforestry such as livestock, the high occurrence of trees and agricultural crops. In other ways, home garden has been observed as a potential practice for carbon sequestration due to the fact that it sequesters carbon above and below ground biomass, reduces fossil fuel burning by encouraging fuelwood production and reduces pressure on natural forest. Furthermore, biomass is not completely removed in home gardens (Gajasen and Gasajen, 1999; Kumar, 2006). Similarly, a study conducted in India shows that a home garden of 12–17-year-old accumulates 55.8 - 162Mg C ha^{-1}(Roshetko *et al*., 2002). According to Kumar and Sharma (2015) agroforestry practices study, a home garden can sequester carbon at a rate of 68-228 Mg C ha^{-1} depending on species composition, soil, and climate. Mixed intercropping which involves wood perennial and herbaceous crops was observed to store 17.79 Mg C ha^{-1}. Because of the addition of carbon pools in trees and increased soil carbon pools as a result of carbon input from litter fall and fine root turn over, carbon in the mixed intercropping system is higher than that in the sole cropping system (Oelbermann, 2002). Mixed intercropping can store 121-125 Mg C ha^{-1}, which can be attributed to higher growth and assimilation rates (Piechl *et al*., 2006). Parkland practices were observed to store 26.75 Mg C ha^{-1}. In parkland, unlike mixed intercropping, trees are not arranged in accordance with crops but few trees are left on the crop land.

A study conducted in Guinea shows parkland carbon sequestration may also range from 22 - 70.8 Mg C ha^{-1} (Luedeling and Neufeldt, 2012). Parkland agroforestry is very stable (long standing) and has high carbon storage (Takimoto, 2007). In this study, boundary agroforestry practice stored 23.22 Mg C ha^{-1}. Boundary planting has a positive effect on soil characteristics, crop production and carbon sequestration (Albrecht and Kandji, 2003). Hooda *et al*. (2007) indicate that tree boundary and herbaceous crops can have carbon storage ranging from 18.53 - 116.29 Mg C ha^{-1}. Another study indicates that greater potential of carbon sequestration was found in the boundary plantation of *Populus deltoides* and

Eucalyptus hybrid (Marthy *et al*., 2013). In this study, carbon stock does not differ greatly from other studies, but the only difference in the carbon stock can be explained by factors such as the allometric equation, which could be a limitation resulting in a large variation in such an estimate (Swai *et al*., 2014). Low cutting of trees in the field could also be the source of a high amount of carbon. Many trees observed were for various purposes, such as food, fruits, shade, wind break and for boundary, hence were maintained for a long time, resulting in a high amount of carbon.

5.4 Conclusion

Agroforestry systems and practices can play an important role in climate change mitigation. This study concludes that there are benefits in terms of carbon sequestration from the implementation of agroforestry systems and practices, and those benefits are most relevant in the tropical climate. In this study we also found that carbon sequestration is determined by the components found in the farm land. Fruit trees were the most abundant trees, suggesting multipurpose uses and quick economic benefit. Therefore, understanding the drivers of tree selection can help to meet local food, fuel and global climate regulation needs. Furthermore, the study reveals that agrosilvopasture systems and home garden practices had the highest potential to sequester carbon. Therefore, the study recommends that it is important to provide education to farmers on the opportunities available in carbon sequestration, such as the carbon market. Farmers should also be encouraged to use such systems and practices in order to increase above- and below-ground carbon stocks.

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CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Generally, this study describes agroforestry systems and practices as strategies for climate change adaptation and mitigation. Findings show that agroforestry systems increase resilience through the contribution of income. This indicates that components of agroforestry need to be considered during planning for implementation of agroforestry. The components certainly add the diversity dimension through agriculture production, which in turn improves the income and food security of a household's farm, hence increasing the adaptive capacity. In addition, farmer-oriented factors were observed to be critical in the adoption of agroforestry systems and practices, and they were observed to be either fertile ground for an implementation or obstacles for the same. Trees on farms also play a vital role in mitigating the effect of climate change through carbon sequestration. Carbon sequestration varies considerably between agroforestry practices and systems, and this study shows the contribution of different tree species on carbon storage in different agroforestry practices and systems. Therefore, this indicates that there is a need to consider trees when establishing agroforestry systems or practices. Furthermore, this can be achieved by considering the above and below ground tree components in order to obtain the realistic values that will provide accurate estimates over greater land areas.

6.2 Recommendations

In general, this study recommends that there is a great potential for climate change adaptation and mitigation in agroforestry systems and practices through increasing resilience and carbon sequestration. Government and non-government organizations should address to farmers the potential impacts of agroforestry to global climate change. Furthermore, the government needs to address the social economic factors such as extension education, land conflict, land availability, and agriculture inputs, which are key critical factors for the development of agroforestry. Furthermore, farmers should focus on the integration of these components, namely trees, crops, and animals, in order to increase resilience to climate change variability. In order to increase carbon sequestration potential, the study recommends that farmers should be encouraged to practice agrosilvopasture systems and home garden practices since they have high potential for carbon sequestration. This study also recommends that there is a need for the government, other private stakeholders and development agencies to intervene by providing information and training to farmers on the importance of agroforestry on carbon trading. This study also recommends further research on quantification of the above and below ground carbon content of matured trees and fruit trees at the end of their rotational age in agroforestry systems and practices. This will improve the future tree carbon pool estimates.

APPENDICES

Appendix 1: Socio-economic survey for households practicing agroforestry in SAGCOT

Questionnaire Serial Number………………………

Date………………………………

Village……………………… District………………………

Region……………………………

Section A – General Information

1. Name of the Interviewee…………………...…………sex (a) Male (b) Female
2. Marital status

    a) Single (b) Married (c) Widowed (d) Divorced

3. Head of the household

    a) Husband (b) Wife (c) Sister/Brother (d) Others (specify)……………….

4. Highest level of education in the household.

    a) Primary (b) Secondary (c) College/University (d) Other (Specify)

5. Occupation of the head of the household

    a) Farming (b) Employed (c) Self-employed in……………… (d) Pastoralist

    (e) Other Specify…………

6. Size of the household

    a) 2 people (b) 3–6 people (c) 7–10 (d) More than 10 people

7. Are you native in this village?

    i. Yes (ii) No

If the answer is YES, how long have you stayed in the village?

a) 1–3 years (b) 3–5 years (c) 6–10 years (d) More than 10 years

8. Apart from the household occupation what are the other sources of income for the house hold

S/ No	Sources of income	Ranking in number
1	Pastoralist	
2	Agropastoral	
3	Crop trading	
4	Casual labor	
5	Employed	
6	Petty business	
7	Collection and selling forest product	
8	Fishing	
9	Beekeeping	
10	Handcraft	
11	Agroforestry	
12	Others (Mention)	

Income	Frequency		
	Daily	**Weekly**	**Monthly**
a) < 100,000			
b) 100,000 – 300,000			
c) 300,001 – 500,000			
d) > 500,000			

9. Main sources of food in the household?

a) Own produce from agriculture

b) Purchase from market

c) Gathering from the wild

10. Amount consumed per season/year (last 12 months) from each source above

Source	Quantity (last season)	Price per unit (Tshs)	Total earnings (Tshs)
Own produce from agriculture			
Purchase from market			
Purchase from market			
Other sources			

11. Do you own land?

    i. Yes (ii) No

    If yes what is the size of the land do you own.

    a) Less than 1 acre (b) 1-2 acres (c) 3-5 acres (d) 6-10 acres (e) More than 10 acres

12. How did you acquire the land?

S/N	Land use type	Size in acre	Acquisition Method
1	Plot building a home		
2	Land for annual crop production		
3	Land grazing		
4	Other uses (mention)		

Key for Acquisition Methods

1) Inherited (2) Bought (3) Rented (4) Allocated by village government (5) Illegal clearing forest.

13. Do you practice agroforestry in your village? (i) Yes (ii) No

14. When did you start (Year)?

    ……………………………………………………………………

15. What influenced you to engage in agroforestry?

    …………………………………………......…………

    ……………………………………………………………

    …………………………………………………………..

    ……………………………………………………………

16. Are there any stakeholders who influenced the agroforestry farming in this village?

    (i)Yes (ii) No

    If Yes mention them

a) …………………………..

b) ………………………….

c) ……………………………

d) ……………………………..

e) ………...………………..

17. Do the District Council and TFS support the agroforestry in this village?

(i)Yes (ii) No

If yes What supports do they provide

a) ……………………………….

b) ……………………………

c) ……………………………..

d) ……………………………..

SECTION B: Information Related to the climate change adaptation

1. Are you aware of the climate change?

i) Yes (ii) No

2. Does your village participate in climate change adaptation?

i) Yes (ii) No

If Yes, what are the activities implemented to facilitate in climate change adaptation(s)?

(a) ………………………………………

(b) …...…………………………………….

(c) …………………………………………

(d) ……………………………………………

3. What benefit do you get from climate change adaptation?

(a) ……………………………………… (b) …..……………………………………

(c) ……………………………………… (d) ……………………..………………..

4. Is the presence of agroforestry farming in the village contributing to positive impact to climate change?

i. Yes (ii) No

If yes what are the positive impacts?

(a) ……………………………………… (b) …..……………………………………

(c) ……………………………………… (d) ……………………..………………..

5. In case of any negative impacts, what action did you take to overcome such a problem?

(a) ……………………………………… (b) …..……………………………………

(c) ……………………………………… (d) ……………………..………………..

6. Which among the following services do the villagers get from the agroforestry?

S/N	Services	Rank
1	Sources of water	
2	Climate amelioration	
3	Soil erosion prevention	
4	Biodiversity maintenance	
5	Energy for cooking	
6	Sources of food production	
7	Income	
9	Others (specify)	

7. Does the village collect any revenue from the agroforestry farmers?

i. Yes (ii) No

8. Do you think that practicing agroforestry create any opportunity/product for you and the adjacent communities?

(i) Yes (ii) No

9. In case of any opportunities/products, can you mention them?

(a) …………………….

(b) …..…………………

(c) ……..………………

(d) ……………………..

10. Have you experienced any challenge in establishing the agroforestry?

i) Yes (ii) No

If yes what are the main challenges?

(a)………………………………………

(b) …..…………………………………….

(c)………………………………………

(d) ………………………..……………………..

11. Are there any measures taken by Government/NGOs to address the challenges you have mentioned?

i. Yes (ii) No

If the answer is yes what are those measures.

a) ………………………………………

(b) …..…………………………………….

c) ………………………………………

(d) ………………………..……………………..

d) …………………………………………….

12. Are there any by-laws specifically for agroforestry implemented in your village?

i) Yes (ii) No

If yes how are those by laws being implemented at the village level?

(a) ………………………………………

(b) …..…………………………………….

(c) ………………………………………

(d) ……………………..………………….

13. Do you think there are any other strategies that may be more effective for implementing agroforestry in the village forest reserves than policy and by-laws?

(a) ………………………………………

(b) …..…………………………………….

(d) ………………………………………

(d) ……………………..………………….

SECTION C. Community groups or NGOs to participate in the extension services

1. Do you have any community-based groups engaged in Agroforestry extension?

i) Yes (ii) No

2. Are you or any other person in the family a member of the community group or organization?

i) Yes (ii) No

3. (If NO why people in your village avoid to join agroforestry extension groups)?

(a) No need (b) Do not know how to join

(c) No group organization (d) Too expensive

(e) Lack of sensitivity (f) Other specify

4. Is there any Organization dealing with implementation of agroforestry projects in the village?

    i) Yes (ii) No

   If yes who established the group?

    a) Government (b) Private individual

    c) Nongovernmental organization(specify) (d) Other specify

5. What are the responsibilities of these NGOs in the agroforestry?

    (a) ………………………………………

    (b) …..…………………………………….

    (c) ………………………………………

    (d) ……………………….……………………..

6. What are the benefits obtained from the group?

    (a) ………………………………………

    (b) …..…………………………………….

    (c) ………………………………………

    (d) ……………………….……………………..

7. Do you have access to extension services?

    i) Yes (ii) No

    If yes what are those services?

    (a) ……………………………

    (b) …..…………………………………….

    (c) ……………………………

    (d)……………………….……………………..

Thank you very Much!

Appendix 2: Checklist for Key Informants for NGO and other stake holders

1. What is the name of your organization/association/institution/club partnership/group……………..……. When did it start…………………….…...?

2.How many villages do your organization operate?

3. What were the objectives of the organization?

4. What activities are done by the organization in relation to agroforestry?

5.What are responses of the community towards the implementation of agroforestry?

6. What are the challenges that your organization faces in implementing the agroforestry?

7Does government support the NGO effort towards implementing the agroforest projects?

8. What are those efforts?

9. What do you think could be the solutions towards the challenge towards implementing the agroforestry?

10. How have the communities benefited from your organization?

11. Are there any other organizations that you are linked with? Mention them

12. What are the roles played by other organizations in climate change adaptation.

18.Is there any comment you wish to add?

Appendix 3: Checklist for key informants: District Natural Resources Officer, District

Planning Officer and District Agricultural Development Officer

Date……………………………

1. Name……………………………………………….

2. Title…………………………………………………………………………

3. District……………………………………………………………

4. For how long have you been in the district?

5. How have you been observing the agroforestry in the district.

6. Which are the main extension education do you provide to this farmer?

7. How do you term the agroforestry in this area? Either traditional or innovative.

8. Which trees are mostly preferred in agroforestry?

0.1………………… 0.2……………………… 0.3………………………

Why?..

9. If there are both traditional and innovative which one is the best and more practiced.

10. What could be a reason for people to practice agroforestry and the rest not practicing it?

0.1…………………. 0.2………………………. 0.3……………………

11. Do people experience food shortage in this area? Yes ---------- No -----------

12. If yes what are the coping strategies applied by people? ....

14. What is the average size of agroforestry a household can hold in terms of ha?

Appendix 4: Data collection form for Trees

Inventory data form for Trees

Date…………………Recorder…………………Village……...……………..…

Plot No… Location-Eastings……………. Northing……...…………...Area(ha)…………...

Number of plots	Tree number	Botanical name	Local name	Dbh	Height	Tree Uses

Appendix 5: Data collection form for cocoa trees

Inventory data form for cocoa

Date……………………Recorder……………………. Village...…………….……………

Plot No……………… Location-Eastings……………. Northing………...Area(ha)………...

Age <10 Years ………………. CAS System (Innovative /Traditional) ………………………

10-20 Years……………….

>20 years………………… …..

Number of plots	No cocoa tree	Diameter at 0.3 meter	Observation 1	Observation 2

Appendix 6: Tree species with total biomass and carbon stock presented in tons per hectare per species.

Botanical name	Local name	Family	Frequency	Biomass	Carbon stock
Mangifera indica	Muembe	Anacardiaceae	187	141.15	70.57
Cocos nucifera	Mnazi	Aracaceae	194	136.01	68.01
Percea americana	Mparachichi	Lauraceae	84	60.35	30.18
Tectona grandis	Mtiki	Lamiaceae	162	53.75	26.87
Ficus stuhlmannii	Mkuyu	Moraceae	32	31.58	15.79
Citrus sinensis	Mchungwa	Rutaceae	37	17.33	8.66
Elaeis guineensis	Mchikichi	Aracaceae	27	9.57	4.79
Canica papaya	Mpapai	Caricaceae	14	8.26	4.13
Bauhinia thonningii	Msegese	Fabaceae	3	7.42	3.71
Annona murcata	Mstafeli	Annonaceae	18	5.18	2.59
Senna siamea	Mjohoropori	Fabaceae	14	4.67	2.34
Cedrella odorata	Msedrela	Meliaceae	8	4.47	2.24
Sorindeia obtusifolia	Mpilipili	Anacardiaceae	2	3.06	1.53
Psidium guajava	Mpera	Myrtaceae	11	2.92	1.46
Milicia excelsa	Mvule	Moraceae	4	2.49	1.25
Khaya anthotheca	Mkangazi	Meliaceae	12	2.13	1.06
Anacardium occidentale	Mkorosho	Anacardiaceae	7	1.92	0.96
Citrus lemon	Mlimao	Rutaceae	23	1.86	0.93
Senna Spectabilis	Mjohoro	Fabaceae	7	1.83	0.92
Azadirachta indica	Mwarobaini	Meliaceae	5	1.70	0.85
Sclerocary abirrea	Mng'ong'o	Anacardiaceae	4	1.17	0.59
Citrus reticulata	Mchenza	Rutaceae	9	1.14	0.57
Artocarpus heterophyllus	Mfenesi	Moraceae	8	1.04	0.52
Averrhoa bilimbi	Mbilimbi	Oxalidaceae	5	0.94	0.47
Delonix regia	Mkirismasi	Fabaceae	3	0.79	0.39

Olea europeana	Mzaituni	Oleaceae	4	0.50	0.25
Brachystegia boehmi	Myombo	Fabaceae	2	0.40	0.20
Citrus autatiifolia	Mndimu	Rutaceae	3	0.39	0.19
Syzygium cordatum	Mnyonyo	Myrtaceae	4	0.36	0.18
Cinnamomum zeilanicum	Mdalasini	Lauraceae	17	0.31	0.15
Tamarindus indica	Mkwaju	Fabaceae	2	0.13	0.06
Syzygium cumini	Mzambarau	Myrtaceae	2	0.10	0.05
Saraca asoca	Mwashoki	Myrtaceae	2	0.09	0.04
Terminalia aemula	Mkulungu	Combretaceae	1	0.06	0.03
Annona squamosa	Mtopetope	Annonaceae	4	0.06	0.03
Theobroma cacao	Mkokoa	Malvaceae	1102	0.003	0.001
Vitex doniana	Mfuru	Verbenaceae	4	0.002	0.001