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Stand structure, woody species diversity and carbon stocks in urban forests of a West African Sahelian Zone: A Case of Niamey and Maradi Cities, Niger

By

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A Thesis submitted to the Department of Civil Engineering,

College of Engineering

in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

CLIMATE CHANGE AND LAND USE

JUNE, 2019

Certification

I hereby declare that this submission is my own work towards the PhD in Climate Change and Land Use and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Kwame Nkrumah University of Science and Technology, Kumasi or any other educational institution, except where due acknowledgment is made in the thesis.

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ABSTRACT

Urbanization is a driver of deforestation, which results in the loss of biodiversity and ecosystem services. However, through the development of urban forests some of these losses can be regained in cities. Many studies report of the role urban forests play in biodiversity conservation and climate change mitigation. Nevertheless, there is paucity of information about the role of urban forests in West African Sahel cities in biodiversity conservation and carbon storage in the literature. This study determined the woody species diversity, stand structure, and carbon stocks in urban forests of Niamey, and Maradi (two important cities in Niger) across seven-land use/land cover (LULC) types. Data was collected through an inventory of 30.70 ha and 20.25 ha of urban forests in Niamey and Maradi respectively based on a stratified random sampling approach. Biodiversity indices and structural parameters were used to determine the woody species diversity and stand structure of the forests across the different LULC types. Allometric equations were used to estimate the aboveground biomass (AGB) and root shoot ratio for belowground biomass. A total of 4689 trees and shrubs belonging to 115 species in 35 families was found in the two cities. Eighty-six species belonging to 69 genera with 33 families were inventoried in Niamey, while in Maradi, 91 species belonging to 70 genera with 30 families were enumerated. Mean Shannon diversity index (H') for Niamey was (H'= 2.31 ± 0.43) and in Maradi (H'= 2.14 ± 0.74). The similarity index of the two urban forests was 70% suggesting close resemblance of the cities' urban forests. *Fabaceae* was the dominant family in both cities. Exotic species accounted for 62 and 77% of all trees in Niamey and Maradi respectively. *Azadirachta indica* accounted for 41 and 54% of all trees respectively in Niamey and Maradi. The species diversity and structural characteristics varied among the LULC types ($p < 0.05$) with residential areas having a higher species richness than other land uses. Urban forests in built areas of the cities had higher species richness than peri-urban forests. There were more trees than shrubs in both cities. The three most dominant species in terms of AGB were *Azadirachta indica* (47%), *Faidherbia albida* (16%), and *Khaya senegalensis* (12%) in Niamey. In Maradi, the equivalents were *Azadirachta indica* (61%), *Terminalia mantaly* (7%), and *Faidherbia albida* (6%). Exotic species represented 60 and 78% of the total carbon stocks in Niamey and Maradi respectively. The overall urban forests carbon stocks were 31.63 (15.63, 47.64) t/ha in Niamey and 58.30 (13.10, 103.50) t/ha in Maradi and were not significantly different. However, carbon stocks varied significantly across the LULC types in each city. The neem tree alone constituted 54% and 61% of carbon stocks in urban forests of Niamey and Maradi respectively. The conversion of peri-urban forests into urban forests led to carbon gain. This study showed that urban forests in Niamey and Maradi are important source of woody species diversity and carbon sinks and may therefore be important in climate change mitigation and other ecosystem services. The study recommends the promotion of the use of native species in urban forests in Niamey and Maradi for a dual benefit of carbon and native species conservation that is at present lacking in the two cities. Also carbon stocks in urban forests in Niger should be integrated into the national carbon stock accounting for sustainable urbanization.

Keywords: Biodiversity, Sustainable cities, climate change, ecosystem services.

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LIST OF ABBREVIATIONS

AGB	Aboveground biomass
ANOVA	Analysis of variance
BA	Basal area
BGB	Belowground biomass
BMBF	German Federal Ministry of Education and Research
CCLU	Climate Change and Land Use
CI	Confidence Interval
cm	centimetres
CNEDD	Conseil National de l'Environnement pour un Développement Durable
CO_2	Carbon dioxide
CV	Coefficient of variation
DBH	Diameter at breast height
df	degree of freedom
DOM	Dead organic matter
FAO	Food and Agriculture Organisation of the United Nations
GHG	Greenhouse gas
GPS	Global positioning system
INRAN	Institut National de la Recherche Agronomique du Niger
INS	Institut National de la Statistique du Niger
IPCC	Intergovernmental Panel on Climate Change
km	kilometres
KNUST	Kwame Nkrumah University of Science and Technology
LN	Natural logarithm
LULC	Land use and land cover

MELCD	Ministère de l'Environnement et de la Lutte Contre la Désertification
p	probability
SD	Standard Deviation
SDG	Sustainable development goals
SE	Standard Error
SOM	Soil organic matter
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation
WASCAL	West African Science Centre on Climate Change and Adapted Land Use

DEDICATION

To my teachers from the primary school to the universities. To those who have the love of nature conservation in general and in particular urban forestry. To my parents, my wife and children.

ACKNOWLEDGEMENTS

My sincere appreciation goes to the Federal Ministry of Education and Research (BMBF) and West African Science Centre on Climate Change and Adapted Land Use (WASCAL) for providing the scholarship and financial support for this programme.

I would express my profound gratitude to my supervisors: Prof. Boateng Kyereh from KNUST, Dr Abasse Tougiani from National Agricultural Research Institute, Niger and Dr. Shem Kuyah from Jomo Kenyatta University of Agriculture and Technology, Kenya. I honestly acknowledge your continuous support and encouragement, and the provision of long-lasting motivation. I am also most grateful to you all sirs, for your tremendous professional support and moral guidance without which this work would never have been accomplished. I will always remain indebted for your invaluable personal and professional support.

I want to express my gratitude to all WASCAL CCLU KNUST staff, especially the Director, Prof. Samuel Odai and the Coordinator, Prof. Wilson Agyei Agyare and our dynamic secretary Diana Cobbinah Osei (Mrs.) for the support. Big thanks to my WASCAL CCLU local and international lecturers. I also thank Richard Bruce Lamptey for the support. I acknowledge my host Prof. Dr. Eike Lüdeling and his team for the enabling environment enjoyed at the Department of Horticultural Sciences, University of Bonn, Germany. I thank also the National Agricultural Research Institute, Niger for hosting me.

My most sincere thanks go to my parents for supporting me constantly throughout my studies and for their understanding when I told them that I am going to study in Ghana for three years. My special thanks go to my wife Nafissatou Salifou Elhadji Aboubacar for her patience. I acknowledge the support of my field assistants. My most sincere thanks go to the Professors Saadou Mahamane, Ali Mahamane, Yacoubou Bakasso, Dr.

Karim Saley, Dr. Salamatou Abdourahamane Illiassou and Arzika Taminoune for the support. I cannot forget the support of my colleague WASCAL students. Special thanks to you for the discussion and contributions. Finally, my heartfelt thanks go to Ghana people for their support and encouragement during my stay in Kumasi and to all others who directly or indirectly contributed to the success of the study.

CHAPTER 1: GENERAL INTRODUCTION

1.1. Background to the Study

Climate change, resulting principally from emission of greenhouse gases (GHGs), is one of the most serious environmental issues of our time, with threats to agricultural production, world economy and ecosystems (Intergovernmental Panel on Climate Change (IPCC), 2014). Carbon dioxide (CO_2) is the primary GHG, representing about 76% of the global GHG emissions of which forestry and other land uses account for 11%, while the rest (65%) is produced from fossil fuel and industrial processes (IPCC, 2014).

Land use change is therefore a significant source of CO_2 emissions and for that matter a contributor to climate change. One of the important land use change pathways globally is urbanisation. About 55% of the world's people are in urban areas, and this figure is projected to rise to 68% by 2050 (United Nations (UN), 2018). About 90% of this urban population rise will take place in Africa (UN, 2018). Urbanization is associated with many environmental problems such as anthropogenic CO_2 emissions (Seto *et al.*, 2014), air pollution (Peng *et al.*, 2012; Nowak *et al.*, 2013a), modification of local and regional climate (Zhou *et al.*, 2014; Melaas *et al.*, 2016) and loss of natural habitats and biodiversity (Seto *et al.*, 2012; Elmqvist *et al.*, 2016). Urbanization contributes significant amounts of anthropogenic GHG emissions due to increased burning of fossil fuels (in industrial processes, transport, mechanization of agriculture, waste treatment, conversion of natural forests to urban centres and increased energy use (Seto *et al.*, 2011).

In the West African Sahelian region urbanization leads to total destruction of vegetation cover around cities (Sené, 1993). Delwaulle and Roederer (1973) reported little natural regeneration of vegetation within a radius of 15-20 km, and severe desertification occurring within a radius of 40-50 km of Niamey city.

However, the urban landscape is not totally devoid of vegetation cover and the presence of green spaces, especially those in the form of urban forests, have been found to play important environmental roles. These include biodiversity conservation sometimes involving remnant vegetation types and threatened indigenous species (McKinney, 2002; Elmqvist *et al*., 2016); development of a collection of exotic flora (Riley *et al*., 2018) and protection of cities against wind and water erosion. Urban forests are also source of food to urbanites (Davies *et al.*, 2011; Clark and Nicholas, 2013). Other ecosystem services provided by urban forests are nature-based recreation, local climate regulation or clean air (Borelli and Conigliaro, 2018) and flood control (Xiao *et al.*, 1998; Livesley *et al*., 2014).

The rising concern about the greenhouse effect has stimulated interest in the potential for urban forests to help reduce the level of atmospheric CO_2. Urban forests can lower atmospheric carbon directly, via sequestration and indirectly, via savings in the cooling and heating energy of buildings. Furthermore, urban forests can contribute to the slowing down of climate change as they act as carbon sink (Nowak *et al.*, 2013b). In this regard planting trees in urban landscapes is being promoted among other things to offset CO_2 emissions into the atmosphere (FAO, 2016).

1.2. Statement of the Problem

Although urban forests hold much potential for climate change mitigation through carbon sequestration, this potential may be context specific (Chen, 2015) and needs to be studied on city and regional bases. The potential of urban forests in climate change mitigation is poorly understood because the biomass of the urban woody plant is poorly quantified due to the lack of data on biomass carbon in urban trees.

Empirical studies across the world report of urban areas being rich in tree populations and species diversity. In peri-urban areas, in North America, high tree densities and species are documented for many cities such as the metropolitan area in Minnesota (Berland, 2012) and the City of Syracuse in New York (Nowak *et al.*, 2016). Similar findings are reported for cities in other continents such as Beijing in Asia (Yang, 2016; Yan and Yang, 2017) and Adelaide in Australia (Tait *et al*., 2005). Urban forests in African cities also have a diversity of woody species as reported in Lomé in Togo (Raoufou *et al*., 2011), Abuja in Nigeria (Agbelade *et al.*, 2017), Kumasi in Ghana (Nero and Callo-concha, 2018) and Nairobi in Kenya (Nyambane *et al*., 2016). These studies report on woody plant species used in urban forestry, their abundance, growth characteristics and diversity, species coexistence and functional relations with green spaces. They do not however, provide information on the extent to which cities differ in their urban forest characteristics. Also lacking in the literature is information on how urban forests differ across different land use/ land cover (LULC) types found in cities. Besides, there are no reports in the international literature on the composition and structure of urban forests and their carbon stocks, in the Sahelian region. This impedes effort to generalise urban forest characteristics across different climatic zones as well as regions with contrasting cultures and socio-economic development.

There is currently no study in Niger that investigates the carbon stocks of urban forests for climate change mitigation. This situation has led to poor understanding of the ecosystem services provided by urban forests that are related to climate change mitigation. Therefore, there is a need to quantify the urban forest stocks in Niger cities for climate change mitigation and sustainable urban forest management; one of the ways of meeting the sustainable development goals (SDG) (Borelli and Conigliaro, 2018).

1.3. Justification of the Study

The study addresses the important challenge of determining the role of urban forest in climate change mitigation and woody plants conservation. The urban forests of Niamey and Maradi cities provide multiple ecosystem services such as carbon sequestration, air purification, microclimate, recreation, fruits and firewood (Ministère de l'Environnement du Niger, 2010). In addition, they are the green belt against wind and water erosion (Ministère de l'Environnement du Niger, 2010).

At a time when urban forests are increasingly being acknowledged for such multi-functionality, evaluation of the potential of urban forests of Niamey and Maradi for climate change mitigation in the Sahel is urgently needed. One of the major challenges in mainstreaming urban forests in biodiversity and climate discussions is the lack of data (for example reference level carbon emissions and uptake). This study is to help overcome this challenge and equip policy-makers and researchers with data that can close the gap, which has thus far limited evidence-based management of urban forests in climate change mitigation.

Ascertaining the current state of urban forest woody species diversity is key to biodiversity conservation. For instance, countries are encouraged to develop their City Biodiversity Index such as native biodiversity in the city and ecosystems services such as carbon storage provided by urban forests in the city. Furthermore, estimates of carbon stocks and stock changes in tree biomass are important for reporting to the United Nations Framework Convention on Climate Change (UNFCCC). UNFCCC encourages its member states to update their national GHG inventories of emissions by sources and removals by sinks (IPCC, 2006a). In addition, the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD+) encourages also its country members to assess their carbon stocks for climate change mitigation. Thus, the findings from this study will provide baseline information that can be used, for example by the Niger Ministry of Environment to evaluate the contribution of urban and peri-urban forestry projects promoted to mitigate climate change, and for sustainable urban forest management. The study provides carbon emission factor from the conversion of the peri-urban forests of Sahelian zones to urban centres; this is useful for the Niger's national carbon budget and national urban planning.

Many studies evaluating carbon sequestration potential of urban forests have expressed the need to further investigate the carbon stocks of urban forests for better understanding of the role of urban forests in climate change mitigation (Stoffberg *et al.*, 2010; Davies *et al.*, 2011; Nowak *et al.*, 2013b; Chen, 2015; Nero and Callo-concha, 2018). This study tried to do so in Niger where no study has attempted to assess the carbon stocks in urban forests.

The two cities (Niamey and Maradi) chosen for this study have peculiar characteristics that could influence the urban forest diversity and structure distribution. Niamey is a political capital of Niger, largest city in terms of urban population and most urbanised city in Niger. Niamey has no land to sell as it has already exhausted all lands in its administrative territory (Niger's Ministry of Habitat and Urbanization, 2018). In addition Niamey has 10 major public green spaces (one green belt of 2,500 ha and nine green spaces of 42 ha) (Ministère de l'Environnement du Niger, 2010) and some public botanical gardens. Niamey also has some water networks. For example, it is traversed by Niger River.

Maradi is the economic capital and third largest city of Niger in terms of urban human population (Institut National de la Satistique du Niger (INS), 2016). It is the second city after Niamey in terms of physical urbanization and urban green spaces. It has consumed its administrative territory (Regional direction of Habitat and urbanization of Maradi, 2018). Maradi possesses 11 block forest plantations according to Gambo (2013). Maradi has two botanical gardens (2.69 ha) in the Regional Agricultural Research Centre of Maradi (INRAN) and the newly created botanical garden of Université Dan Dicko Dankoulodo, Maradi. There exist also some water bodies in Maradi. Niamey and Maradi face the challenge of massive migration from the rural areas of Niger. The above characteristics have been reported as some of the determinant factors of urban forest development (Sanders, 1984; Alvey, 2006) thus justifying the choice of the two cities.

1.4. Research Objectives/Questions and Hypothesis

1.4.1. Research Objectives

The main objective was to assess the differences in diversity and stand structure of urban forests across various land use/land cover types and their associated carbon stocks for climate change mitigation in Niamey and Maradi.

The specific objectives of the study were to:

(i) Quantify the diversity of woody plants, stand structure as well as characteristics of urban forests across the different land use/land cover types;

(ii) Estimate the change in carbon stocks and carbon emission factors due to conversion of peri-urban forests to urban forests;

(iii) Assess the amount of carbon storage of the multi-purpose *Azadirachta indica* relative to the other tree species of urban forests of Niamey and Maradi.

1.4.2. Research Questions

The study addressed the following questions:

i. How do forest structure and woody species biodiversity vary among urban forests of Niamey and Maradi and in the different LULC types of the cities?

ii. What is the amount of carbon stocks in the urban forests found in the various land use and land cover types and the level of carbon emission associated with the conversion of peri-urban forests to these urban forest types in Niamey and Maradi?

iii. Do the neem trees store more carbon than all other species in the cities' urban forests?

1.4.3. Hypotheses

The study tested the following hypotheses:

i. There are no significant differences in biodiversity indices and structural parameters of urban forests across the urban forests of the various LULC types of Niamey and Maradi;

ii. Urban forests of Niamey and Maradi do not differ in carbon stocks, neither do their LULC types;

iii. Neem trees store more carbon than all other species in the urban forests of Niamey and Maradi.

1.4.4. Scope of the Study

The study is restricted to Niamey and Maradi Cities of Niger and their periphery. In these communities, the study is limited to natural or artificial plantation within the urban and peri-urban areas. The study population was the woody species within and at the periphery of the two cities which define the urban forests (FAO, 2016).

1.4.5. Limitations to the Study

The study population was urban and peri-urban forests in Niamey and Maradi cities. The target population was any woody species (tree or shrub), and semi woody plant found within or at the periphery of Niamey and Maradi Cities of Niger and their carbon stocks. One of the limitations of the study was the lack of existing allometric model for estimating urban forest biomass that can fit the urban forest in Niger. The presidential areas, ministries, military areas, embassies, some private gardens and some houses in Niamey and Maradi were excluded from the sample because the permission for entry was not granted.

1.4.6. Description of the study area

1.4.6.1 Location, size and population

The study areas are Niamey and Maradi which are situated in the Sahel Zone of Niger (Conseil National de l'Environnement pour un Développement Durable (CNEDD), 2016). Niamey is the political capital and largest town in Niger with an extended area of over 552.27 km^2, an urbanized area of 297.46 km^2 and a population of 1,026,848 people (INS, 2017). It is located between latitude 13°20'-13°35' N and longitude 2°00'-2°15' E in western Niger (Figure 1.1). On the other hand, Maradi is the economic capital of Niger covering an area of over 86 km^2, an urbanized area of 64 km^2 and a population of 565,791 people (INS, 2016). Maradi city is located in south-central Niger (latitude 13°29′- 13°49' N and longitude 7°5′ -7°09'E) (Figure 1.1).

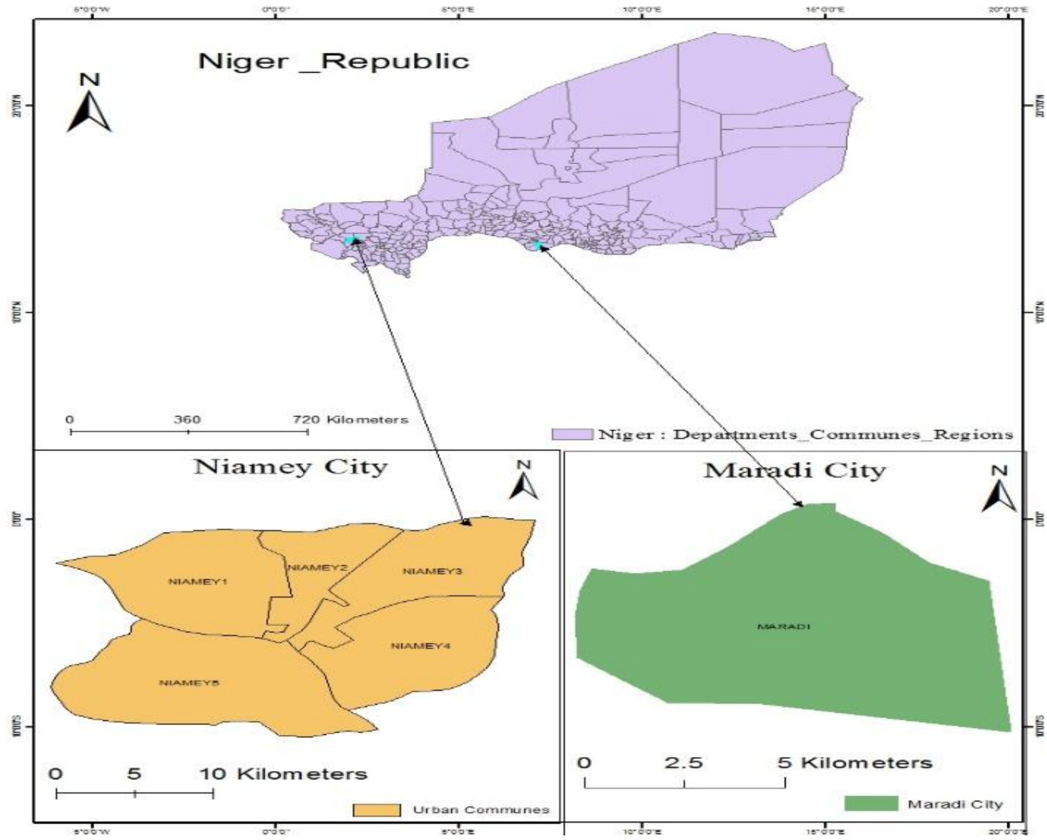

Figure 1. 1: Map of the study area

1.4.7 Rainfall and Temperature of the two cities

Niamey and Maradi are situated in the Sahel zone, where the annual mean rainfall varies from 150 mm to 350 mm (CNEDD, 2016). Based on data from 1984 to 2014 collected by the National Agency of Meteorology, the mean monthly rainfall, minimum, maximum, and mean temperature of Niamey and Maradi between 1981 and 2014 period are shown in (Figure 1.2 and 1.3). The average monthly minimum and maximum temperature in Niamey is 23.2°C and 36.5°C from 1981 to 2014. The average monthly rainfall is shown in (Figure 1.2) also for Niamey city. The mean annual rainfall and its standard deviation of Niamey city from 1981 to 2014 was 517.9 ± 103 mm.

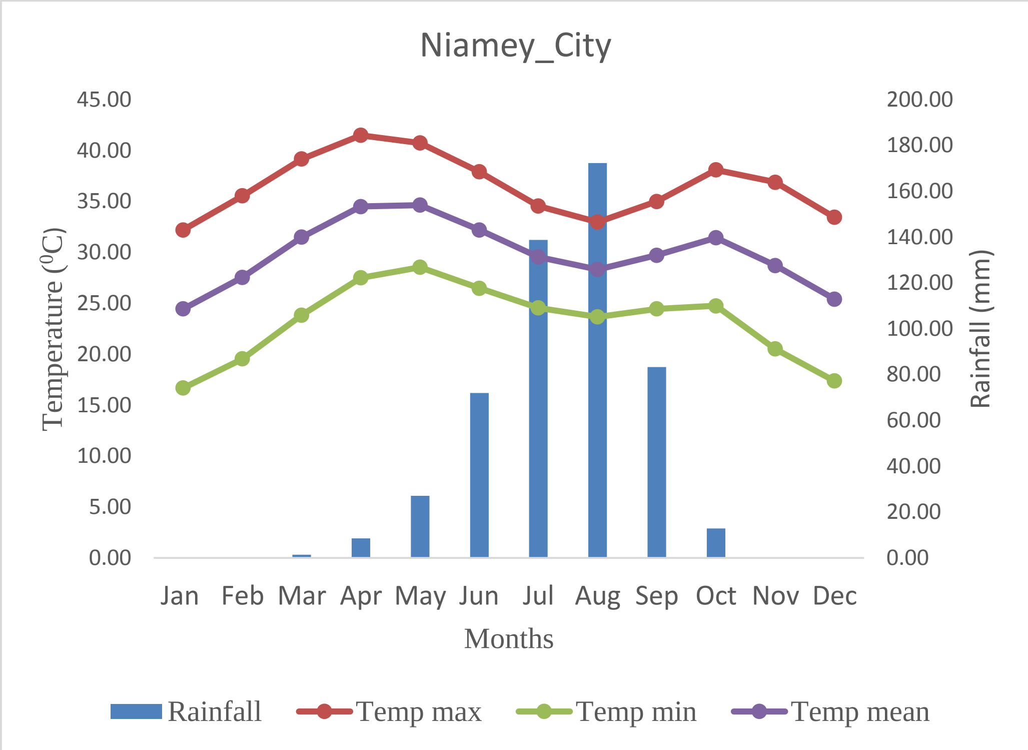

Figure 1.2. Mean monthly rainfall, minimum (min), maximum (max) and mean temperature (Temp) of Niamey city between 1981 and 2014.

The mean monthly rainfall, minimum, maximum and mean temperature of Maradi city between 1981 and 2014 period are shown in (Figure 1.3). The average monthly minimum and maximum temperature in Maradi is 21.10 °C and 35.10 ° C from 1981 to 2014 (Figure 1.3). The average monthly rainfall is shown in (Figure 1.3) for Maradi city. The annual mean rainfall and its standard deviation of Maradi city from 1981 to 2014 was 477 ± 101 mm.

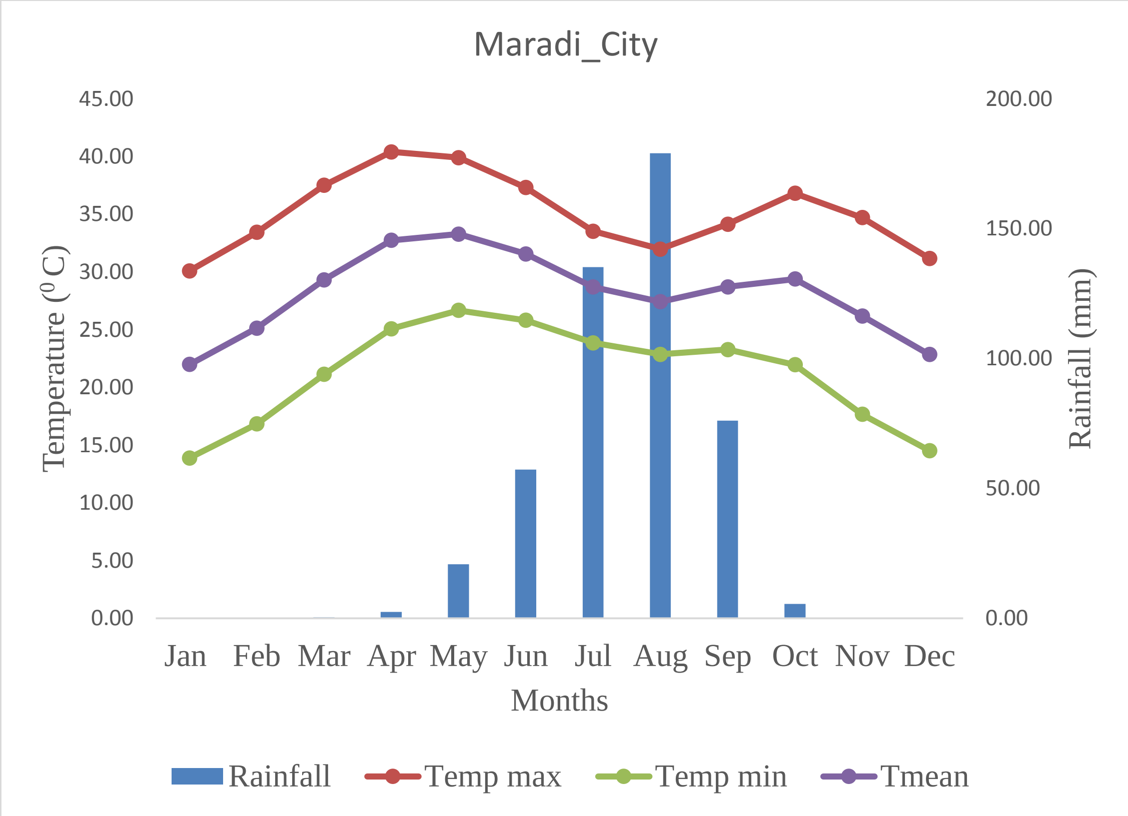

Figure 1.3: Mean monthly rainfall, minimum (min), maximum (max) and mean temperature (T) of Maradi city between 1981 and 2014.

1.4.8. Socio-economic activities of the urban people in the two cities

In addition to the usual economic activities characteristic of West African cities such as commerce and clerical work (INS, 2017), urban agriculture is an important livelihood activity in Niamey and Maradi. Agricultural production consists of cultivation of cash and food crops throughout the year either under rainfed or irrigated conditions in both built and peri-urban areas. Animal husbandry is also an important component of urban agriculture. Urban forestry is practised in the two cities by private and public institutions for various purposes such as wood, food, forage and other ecosystem services in urban and peri-urban settings.

1.4.9. Flora and Vegetation

Vegetation cover across the two cities is made up of a mosaic of steppe and short grass savannah, tree plantations, greenbelts and gardens (Saadou, 1990). The vegetation of Niamey city belongs to the South Western Sahelian compartment (B_1) where vegetation types consist of *Combretum* thicket on the plateau lateritic soils and steppe found on sandy terraces, in dry valleys and on the dunes (Saadou, 1990). Natural vegetation in Niger consists also of gallery forests on the Niger River and some urban wetlands (Saadou, 1990). Remnant natural vegetation is also dominated by *Combretaceae,* shrubs and savannah grassland (Wezel *et al*., 2000). At the periphery of the city, the vegetation consists of agroforestry parklands.

Inside the city, the vegetation consists of the green belt of Niamey and other green spaces such as roadside plantations and many urban woodlots. The natural vegetation of Maradi city belongs to the Southern Central Sahelian (B_2) with some vegetation types, such as savannah on the southern sandy terraces, steppes on dunes and dry valleys, and *Combretum* thicket on lateritic plateaus (Saadou, 1990). The droughts of 1970 and 1984 (Nicholson *et al*., 1998) and historical factors such as prior land use, colonial administration have influenced urban flora in Niamey and Maradi (Moussa *et al.*, 2018). Much of the woody vegetation cover has been lost due to drought and cutting trees for firewood (Saadou, 1990) at urban and peri-urban sites of the two cities. Urban forestry is practised in the two cities by the urban people and city authority in the two cities for various purposes such as shade, wood, food, forage and other ecosystem services in both urban and peri-urban settings. Anthropogenic activities that influence urban vegetation in Niamey and Maradi are overexploitation and species introductions or removals (Moussa *et al.*, 2018). The woody flora of the two cities is diverse and dominated by exotic woody species. Some common species found in the both cities are *Azadirachta indica*, *Balanites* *aegyptiaca*, *Terminalia mantaly, Faidherbia albida* and *Vachellia nilotica* (Moussa, 2019). Urban forests in both cities include (i.e. Green belt of Niamey city, Sékou Touré green space of Maradi city, botanical garden etc.), agroforestry systems and gallery forests (Moussa, 2019).

1.4.7. Organization of the Thesis

The thesis is composed six of chapters. The first two **chapters** are general introduction and literature review. **Chapter 1** gives a background to the study, research objectives/hypothesis, justification of the study, and limitation to the study. **Chapter 2** provides an overview of the concepts related to the urban forestry, biomass estimation methods, urban forest diversity and structure, urban forest, and climate change. **Chapter 3** describes the woody species diversity and structure in urban forests across different land use types in Niamey and Maradi. While, **chapter 4** covers carbon stocks and carbon emission factors in the study areas. **Chapter 5** describes the carbon stocks of neem tree species compared to the all other species in the two cities. Lastly, **Chapter 6** is general discussion, conclusions and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter summarizes an analysis of the contents of literature review in terms of urban forests systematic composition and structure, urban forests carbon stock assessment, carbon emission factors from the conversion of peri-urban forests to urban areas of Sahel cities, Niamey and Maradi in Niger, West Africa.

2.2. Concepts Related to the Study

a. Urban Forests is defined as a network or systems that comprise all woodlands, group of woody plants (trees or shrubs) found in urban and peri-urban areas (FAO, 2016). These include roadside woody plants, and woody plants in green belts, gardens, botanical gardens, peri-urban forests, and woodlands, urban agricultural plots, cemeteries and wetlands. Urban forests can be private or public. In Niger urban forest is composed of public green belts, avenue and boulevard woody plants, trees or shrubs in the markets, in derelict corners, residences, public and private services, at the front of shops, residences, mosques, churches, remnant natural vegetation, urban agricultural areas, cemeteries, botanical gardens (Moussa *et al.*, 2018). In general, urban forest is defined as a collection of woody species found within urban and peri-urban areas that provide several ecosystem services to the urban society.

b. Carbon stock is defined, according to FAO (2018), as the absolute amount or quantity of carbon contained in a reservoir at a specific time. This means a pool or network that has the ability to store or release carbon. Urban forest carbon stocks refer to the quantity of carbon in standing stocks held within an urban forest.

c. Sahelian zone: The word Sahel comes from Arabic sāḥil, shore, which means border or coast of the Sahara. The sahelian zone in Niger represents about 12% of the country's surface and receives 150 to 350 mm of rain in a year (CNEDD, 2016).

d. Urban centres: are defined according to Niger’s 2001 general census (INS, 2016) as the chief human settlements of the regions and departments. Three criteria namely demographic, administrative factors and the existence of certain facilities were used to measure the urbanization of a given geographical area in Niger. According to the Order No. 2010-55 September 17, 2010 of Niger on the status of municipalities with special status or cities, the urban commune is defined as an agglomeration which has a population of at least one hundred thousand (100,000) inhabitants which may be elevated as a municipality with a special status or city. Urban areas refer to cities, towns and suburbs (Elmqvist *et al.*, 2013). However, the definition of city and town varies with countries.

2.3. Urban Forestry in Niger

Niger is a French colony therefore its urban forestry started with the French administration. The urban forestry during the colonial and post-colonial period consisted of introduction of exotic and local woody species to urban and rural areas in Niger (Hungerford and Moussa, 2017). The fruit tree nursery at Yantala in Niamey was created in 1950 with the purpose of developing arboriculture through which the fruit trees, such as *Psidium guajava* L., *Mangifera indica* L., *Averrhoa carambola* L., and some ornamental plants such as *Bougainvillea spectabilis* Willd and *Nerium oleander* L. were introduced to Niger (Yacouba, 1999). The colonial administration also used some local tree species such as *Khaya senegalensis* (Desr.) A. Juss. as avenues tree in Niamey and Maradi (Dan Barria Soumaila, personal communication, 2018). After the independence of Niger, the first republic continued the urban greening programmes. This was the period of massive introduction and reintroduction of some exotic woody species. For instance, in 1963 *Eucalyptus* spp. were introduced to Niger, at the same time as *Azadirachta indica* A. Juss. and *Anacardium occidentale* L. were reintroduced. This was followed by the introduction of *Dalbergia sissoo* Roxb. and *Gmelina arborea* Roxb. in 1964 (Yacouba, 1999).

Before even the first United Nations Conference on the Human Environment was held in Stockholm, Sweden from June 5-16 in 1972, environmental issues were of national concern in Niger. For example, the creation of the Green Belt of Niamey in 1965 (Ministère de l'Environnement du Niger, 2010) where 2,500 hectares of neem plantation were established to protect Niamey city against desertification. Further, Independence Day in the Republic of Niger is commemorated on August 3, marking the nation's independence from France in 1960. Since 1975, the military regime declared 3 August as Arbor Day or National Tree Day (Fête Nationale de l'Arbre), as trees are planted across the nation to combat desertification. The military administration continued to fight desertification with some programmes such as Operation Green Sahel (Operation Sahel Vert) in 1980 with massive use of exotic and local species plantations in urban and rural areas in Niger. For instance, the military regime created in 1982 the Sékou Touré Green Space (Place Sékou Touré) in Maradi city (Dan Barria Soumaila, personal communication, 2018). This green space is composed of neem tree, *Acacia nilotica* (L.) Willd. ex Del. After the conference of Maradi in 1984, afforestation programmes have been intensified to combat desertification with Operation Green Sahel.

The democratic regime has continued the afforestation programmes, mostly the Arbor Day at which several urban green spaces have been created in urban and rural areas of Niger.

Urban green spaces in Niamey and Maradi comprise also the botanical gardens of the Universities and the research institutes. For instance, there are the botanical gardens of Agrhymet, INRAN, and University of Maradi and of Niamey. Those botanical gardens are composed of local and exotic species. There are also some public and private school green spaces in the two cities for various purposes such as timber production and food production. *Eucalyptus camaldulensis* Dehnh. and neem trees are used for timber production within the two cities. Mango trees and species of *Citrus*, *Annona*, *Diospyros* and *Moringa* among others are used for food production in the two cities. In addition, the population of the two cities introduced some exotic species for medicinal and ornamental purposes. Examples include *Gliricidia sepium* (Jacq.) Walp. introduced to Maradi city from Katsina, Nigeria and *Coccoloba uvifera* introduced from Benin to Maradi for aesthetic reasons. Regardless of the national effort to increase urban green areas, today some of the green spaces are under threat due to human activities such as deforestation, illegal occupation, fires, buildings and some are waste dumps (Ministère de l'Environnement du Niger, 2010).

2.4. Urban Forest Values

Urban forests provide many services to the urban society (Livesley *et al.*, 2016; Nowak *et al.*, 2016; Greene and Millward, 2017). These include cooling of urban areas and provision of food to the urban people (Handel *et al.*, 2015). In addition, urban forests are key to climate change mitigation (Chen, 2015) and adaptation (Lwasa *et al.*, 2014). For instance, urban forests protect urban areas against wind and water erosion. Further, urban forests are important to the health of urban people (McMorris *et al.*, 2015). For example, urban forests mitigate urban air pollution (Escobedo *et al.*, 2011) and conserve biodiversity (Elmqvist *et al*., 2016). However, urban forests could be a source of some diseases such as allergies, and damage on infrastructure (Escobedo *et al.*, 2011; Livesley *et al*., 2014; Greene and Millward, 2017). In West African cities urban forests provide forage to the urban animal husbandry (Fuwape and Onyekwelu, 2011).

2.5. Composition and Structure of Urban Forests

2.5.1. Urban Forests Systematic Composition

A good knowledge of woody species composition is essential for sustainable urban forest management and planning purposes. Woody plant species refer to the plants that are ligneous while systematic composition refers to the number of species (alpha diversity or species richness), genera and families found within an ecosystem at given time (Moussa *et al.*, 2016).

Woody floral diversity of urban forests plays an important role in urban ecosystems. Urban forest ecosystem services are a function of its floral diversity (Nowak *et al.*, 2016). For instance, urban resilience has to do with urban forest species diversity. Species diversity in urban forests plays an important role in climate change mitigation and adaptation (Borelli and Conigliaro, 2018). Because of its key to ecosystem services (Nadrowski *et al*., 2010) such as carbon sequestration (Noumi *et al.*, 2018). Species diversity also enhances the resilience of ecosystems (Riley *et al.*, 2018) and provides several benefits to the urbanites to adapt to climate change (Lwasa *et al.*, 2014). This is the target of nature based solutions initiative and the SDGs.

To characterize urban forest species diversity many authors conducted urban forest inventory and used plant diversity indices such as species richness Shannon-Wiener diversity index (H′), species evenness (J) and species similarity index to characterize the urban woody flora of their study areas (Agbelade *et al*., 2016; Nero, 2017).

Urban forests are a woody species diversity hotspot. For example, Raoufou *et al*. (2011) found that the woody flora consisted of 297 plant species belonging to 141 genera and 48 families in the urban forest of Lomé, Togo.

Urban forests are noted as sites of native woody species conservation across the world cities. Nyambane *et al*. (2016) reported that indigenous tree species contributed 82% of the flora of urban green spaces of Nairobi in Kenya. Also, Yan and Yang (2017) reported that native woody species accounted for 76% of urban forest trees in China. Meanwhile, urban forest is the home of huge exotic woody species. Raoufou *et al*. (2011) who found that 69% of the woody flora of Lomé city was exotic confirmed this. Similar observations have been made in European cities and USA. For instance, Heezik *et al*. (2014) recorded 273 woody species in Dunedin in South Island of New Zealand. Of the identified species, 93 were native (34.4%) and 179 (66.3%) were exotic. In USA, Clemants and Moore (2001) recorded 4,159 plant species in the eight urban areas. Of this total, 1,451 (34.9%) species were exotic to the urban areas, and 2,708 (65.1%) species were native. These studies emphasized the role of urban forests in woody biodiversity conservation (in and ex situ). But, Pysek (1998) reported that urban flora richness is determined by city size, latitude, climate and effect of region.

Two main factors that drive urban forest diversity are anthropic and natural. The former includes ecological knowledge, which influence the choice of plant species (Barthel et *al*., 2010), culture (Kurz and Baudains, 2012), socioeconomic (Hope *et al*., 2003; Heezik *et al.*, 2014) such as income level and colonization history and political governance influence on urban forests diversity (Hungerford and Moussa, 2017) and religion (FAO, 2016). The latter, mainly due to climate, has impact on urban forests (Ordóñez and

Duinker, 2014). Wu (2008) reported also that urban forest diversity depends on site availability, species availability and species performance.

Kühn *et al*. (2004) concluded that the level of biodiversity in urban forest is higher than those found in natural ecosystems. Urban forests are reported to have highest number of woody species than natural forests (Konijnendijk *et al.*, 2004). This view was demonstrated by Agbelade *et al*. (2017) who reported that urban forest in Abuja city had more woody species diversity than peri-urban forests. However the woody species richness reported to be higher than other ecosystems the urban areas are dominated by exotic species (Alvey, 2006).

The predominance of exotic species in cities was reported to lead to biotic homogenization (Nadrowski *et al*., 2010), which is a great concern for conservation (Mckinney, 2006). But exotic species predominance contributes to the urban forests diversity and ecosystem services (Riley *et al*., 2018). Moreover, the high species richness of cities was not only due to exotic plants, the native species also contribute the diversity of city flora (Kühn *et al*., 2004). Aronson *et al*. (2014) highlighted the scarcity of urban biodiversity data from tropical urban areas and the urgent need for research in the domain of urban ecology, as well as plant diversity in urban areas (Clemants and Moore, 2001).

2.5.2. Structure of Urban Forests

Urban forest structural data are important for the sustainable management and utilisation of urban forests. Nowak *et al*. (2008) defined forest structure as biophysical element of a forest such as number of woody plants (shrubs or trees), their size, location, crown cover, diameter at breast height, height, canopy cover, basal area, bio-volume, biomass, stem density, number of branches and fruit load, and growth form (i.e. tree or shrub).

Empirical urban forest studies reported several urban forests characteristics (Nowak *et al.*, 2016; Onyekwelu *et al.*, 2016; Nero and Callo-concha, 2018). Suleiman *et al*. (2018) using stem density and growth form to determine the urban forest structure on Kwara State University Malete campus. Suleiman *et al*. (2018) concluded that *Azadirachta indica,* is the most frequent tree and the most dominant growth form in the study area. Agbelade *et al*. (2016) used basal area and bio-volume to determine the structure of urban forest in Ibadan, Nigeria. Agbelade *et al*. (2016) revealed that *Delonix regia* and *Azadirachta indica* showed the highest basal area in Ibadan, Nigeria. Agbelade *et al*. (2017) concluded that urban forests in Abuja city showed high basal area and bio-volume than in peri-urban forests. Avolio *et al*. (2015) assessed the urban forest structure in Sothern California through the number of trees, fruit trees and tree cover, which varied across the land use types.

Many studies have shown that urban forest structure is determined by human activities and natural factors (Sanders, 1984; Nowak *et al.*, 2016; Leong *et al.*, 2018) such as climate, management, urban land morphology, planting preferences and education level. In this regard, Avolio *et al*. (2015) reported that there were greater numbers of trees in the wealthier urban areas. Positive relationships have been reported between tree cover and income (Clarke *et al*., 2013), educational level (Kendal *et al*., 2012) and home or neighborhood age (Lowry *et al*., 2012). Moreover Lowry *et al*. (2012) found greater tree cover in areas of higher precipitation.

Ecological functioning of the urban forest is driven by its structure (Zipperer *et al*., 1997). Nowak and Dwyer (2007) reported that the structure of an urban forest influences its ecosystem services such as reduction of urban runoff (Livesley *et al*., 2014), removal of air pollution (Nowak *et al.*, 2013a) and provision of microclimate which influences building energy consumption and CO_2 emission (Akbari, 2002). Furthermore Lu (2018) reported that urban forests structure influences the walking behaviour of urbanites and students' performance (Sivarajah *et al.*, 2018). For example, urban forests structure provide a habitat to the urban biodiversity such as birds (Burghardt *et al*., 2009; Lerman and Warren, 2011). Added to that trees and shrubs can provide habitat for small mammals (Dickman and Doncaster, 2012). Native urban forest structure is also key to local animal biodiversity. For example, Ikin *et al*. (2012) assessed the influence of native versus exotic streescape vegetation on the spatial distribution of birds in subsurbs and reserves, and reported that there were more native birds and native invertebrates in native urban vegetation than in exotic. Moreover, the (World Health Organization (WHO), 2010) suggested that every urban areas should have a minimum of nine square metres of green areas per person.

Several indicators have been used by different authors to characterize urban forest structure. These include basal area, stem density, biomass (Moussa *et al.*, 2018; Noumi *et al.*, 2018), urban forest canopy and tree cover (Nowak *et al.*, 1996; Zipperer, Sisinni and Pouyat, 1997; Moussa *et al.*, 2018).

Among these indicators, tree cover and urban forest canopy have been reported to play important roles in environmental management and ecosystem service provision. By providing shade, these parameters moderate urban surface temperature (Greene and Millward, 2017) and indirectly reduce CO_2 emissions (Akbari, 2002). Other benefits include provision of microclimate for biodiversity enhancement and urban landscape beauty, reduction of wind and water erosion and protection of urban infrastructure against wind speed (Xiao *et al.*, 1998; Raoufou *et al.*, 2011; Elmqvist *et al.*, 2013).

2.6. Urban Areas and Climate Change

Urban areas are not just subject to climate change impacts; they are also drivers of climate change. Urban spatial expansion leads to temperature and precipitation changes in and near urban areas (Seto and Shepherd, 2009). One of the evidences of temperature changes due to the urban land use and cover changes is urban heat island (Bounoua *et al.*, 2015). Urbanization influences also on the precipitation (Shem and Shepherd, 2009). For instance, urban areas are source of 75% of global anthropogenic CO_2 emissions (Seto *et al.*, 2014; UN, 2017). Urban areas are home to several industrial activities, which are associated with aerosol, pollutants and greenhouse gas emission that have considerable impact on climate. Unsustainable urbanization reinforces the vulnerability of urban society to climate change. Despite the role of urban areas in greenhouse gases emission, urban areas are also key to climate change mitigation through urban forests.

2.7. Carbon Pools

According to the IPCC, 2006a carbon pool has been classified into five main categories namely living aboveground biomass (AGB), living belowground biomass (BGB), dead organic matter (DOM) in wood, DOM in litter and soil organic matter. The category of carbon pool to be included in climate change debate depends on data availability, costs of the fieldwork and the level of conservativeness required (Macdicken, 1997). However, AGB in woody plants responds more quickly and considerably to anthropogenic activities than other carbon pools. Therefore, much attention is giving to the woody plant AGB. According to Vashum and Jayakumar (2012), AGB is the major carbon pool among all the carbon reservoirs (Picard *et al.*, 2012). Weissert *et al*. (2014) reported that there is scanty information about the role of urban forests carbon reservoir across climate zones.

2.8. Urban Forests and Climate Change

Urban forests play an important role in climate change mitigation and adaptation. For instance, urban forests reduce the impacts of climate change in the urban society (Livesley *et al*., 2014). In addition, urban forests are crucial to the ecosystem-based adaptation. For instance, urban forests go with the sustainable development goals 11, which targets sustainable, resilient cities (Borelli and Conigliaro, 2018). To illustrate that, the 2018 world's forest day theme was forests and sustainable cities. Furthermore urban forests cover protect cities against water erosion and reduce the risk of flooding (Livesley *et al*., 2014). Moreover urban forests regulate urban air temperature (Greene and Millward, 2017) which lower urban energy use and consequently reduce carbon emission from urban areas (Akbari, 2002; McPherson and Simpson, 2003). In addition, urban forest is of great importance in atmospheric carbon dioxide offset (Nowak *et al.*, 2013b; Weissert *et al*., 2014) and air pollution mitigation (Dhadse *et al.*, 2011; Nowak *et al.*, 2013a; Nowak *et al*., 2017). For instance, urban forests sequester 23 million tonnes of carbon yearly in USA (Nowak and Crane, 2002). Urban forests are also important to the resilience and adaptation of urban area to climate change (Borelli and Conigliaro, 2018).

However, urban forests are also sources of GHG emissions with the loss of leaves. Some plants release volatile organic compounds which are drivers of climate change (Peñuelas and Staudt, 2010). The maintenance of urban forests may also release carbon depending on the type of urban forest management regime (Nowak and Crane, 2002). Sukopp and Wurzel (2003) reported that some native tree species are not adapted to the microclimate of many cities of Europe.

2.9. Urban Forests Biomass and Carbon Stock Assessment

2.9.1. Methods of Biomass Estimation

Biomass plays an important role in estimating vegetation carbon stocks. The biomass estimation is the first phase of carbon assessment. Ravindranath and Ostwald (2008) mentioned three methods of biomass estimation. Woody biomass can be estimated using direct or indirect approaches. Direct method or destructive method consists of cutting down the plants to develop allometric models and represents the most accurate approach to assess biomass (Brown, 1997). However, harvesting a sufficient number of trees to represent the size and species distribution in an ecosystem is time consuming, destructive, labour intensive, expensive and difficult to implement in remote areas (Brown, 2002). In addition to that, the destructive method cannot be used to quantify carbon stocks at large geographical scales (Henry *et al.*, 2011). Also, destructive methods can lead to the loss of plant species and its associated services such carbon storage, which can also contribute to climate change. This highlights the dangers of the use of destructive methods to species conservation. The method is also not suitable for degraded ecosystem containing threatened species. This may be the case of urban forests in Niamey and Maradi where some types of urban forests such as the green belt of Niamey and Sékou Touré green space of Maradi are under threat from unregulated urbanization (Ministère de l'Environnement du Niger, 2010) and privately owned. However, the destructive approach is more useful for constructing allometric models for estimating biomass on a large-scale as reviewed by Návar (2009); Segura and Kanninen (2005). The above disadvantages underpin the preferential use of indirect methods, which refer to the use of allometric models and remote sensing - based methods (Vashum and Jayakumar, 2012).

Carbon stock estimation for various vegetation types is key to implementing effective climate change mitigation policy. Total woody biomass (ABG and BGB) are often assessed indirectly via allometric models. There exist allometric models i.e. mixed species in a location, region or global; or species-specific for a site, region or global for estimating AGB.

The accuracy of estimation rests on the availability of reliable allometric equations to assess woody vegetation biomass (Henry *et al.*, 2011; Kuyah, 2012a). Each type of model has its own strengths and weaknesses. In general, the model inputs are diameter at breast height, total height, wood density, and crown area. However, the model inputs vary according to the model. For instance, Kuyah *et al*. (2012a) combined crown area, height and wood density to develop model for assessing tree AGB in agricultural landscapes of western Kenya.

Brown *et al*. (1989) developed a generic regression allometric model based on the combination of diameter at breast height, total height and woody density to estimate AGB of tropical forests. Chave *et al*. (2005, 2014) also developed a generalized pantropical model that was used widely for estimating AGB. These include studies by Dayamba *et al*. (2016) on carbon stocks in different land use types in the Sudanian Zone of Burkina Faso, and Nero and Callo-concha, (2018) for carbon stocks in urban green spaces of Kumasi city, Ghana.

Vegetation specific models, which was developed, include those of Sawadogo *et al*. (2010) on the Sudanian savannah-woodland of West Africa in Burkina Faso and Kuyah (2012a) on agricultural landscapes of western Kenya. In Ghana, Aabeyir (2016) generated a model for estimating woody species AGB from the forest-savannah transition.

Despite the existence of generic and vegetation types allometric models, researchers continue to develop species-specific models (Bayen *et al.*, 2016; Dimobe *et al.*, 2018; Moussa and Mahamane, 2018). Available species-specific models include those of *Jatropha curcas* in Burkina Faso developed by Bayen *et al*. (2016), *Faidherbia albida* and *Prosopis africana* in agroforestry parklands in drylands of Niger (Moussa and Mahamane, 2018) and *Vitellaria paradoxa* in the Sudanian savannah of Burkina Faso (Dimobe *et al.*, 2018).

For urban forests with diverse species, generic allometric models may be more appropriate for biomass estimation since it avoids the need to develop allometric models for each urban forests. Using generalized allometric models to estimate the biomass of combined species has been highly effective in the tropics (Brown, 2002). Grouping all species reduces the variability of the biomass due the species differences (Henry *et al.*, 2011; Picard *et al*., 2012) and the effects of the logarithmic transformation which can lead to a misleading statistics (overestimation or underestimation of the biomass) (Picard *et al*., 2012).

However, Mugasha *et al*. (2016) recommended the use of wood density for improved estimate accuracy, such as the general pantropical model of Chave *et al*. (2014) which combines diameter at breast height, total height and wood density. This model performed well across vegetation type and bioclimatic conditions (Chave *et al.*, 2014). The forest biomass can also be estimated by using a bio-volume approach or basal area (Brown *et al*., 1989; Picard *et al*., 2012) and functional branch analysis (Picard *et al*., 2012). Suryawanshi *et al*. (2014) used this method to quantify urban forest biomass at the Maharashtra University Campus in India.

2.9.3. Belowground Biomass

BGB is an important carbon reservoir for many vegetation types as reported by the IPCC, (2006a). Many researchers multiplied AGB by the root shoot ratio to estimate BGB in urban forests (Nowak *et al.*, 2013b; Suryawanshi *et al.*, 2014; Nero, 2017). However, the value of the root shoot ratio varied with latitudinal zone, soil texture, species differences, and human activities (i.e. silvicultural treatments) according to (Cairns *et al*., 1997; Kuyah *et al.*, 2012b; Koala *et al.*, 2017) who developed root biomass allometric model for the world's upland forests, and allometric models for BGB of four key woody species in West African savannah-woodlands in Burkina Faso agricultural landscapes in Kenya. The root biomass model of Cairns *et al*. (1997) was used to estimate the BGB in Kpashimi Forest Reserve, Niger State, Nigeria (Jibrin *et al*., 2014) and green spaces in Kumasi (Nero, 2017). The models of root biomass are rare within the literature (Koala *et al.*, 2017). However, IPCC, (2003) provides Tier 1, 2 and 3 approaches for assessing carbon stocks if the local estimates are not available.

2.9.4. Carbon Stocks and Carbon Dioxide

Carbon content of wood varies with vegetation types, climatic and edaphic conditions (Martin and Thomas, 2011; Koala *et al.*, 2017). There exist several carbon content values. For instance, Macdicken, (1997) reported a value of 0.50 of vegetative biomass as carbon whilst the default carbon content value of biomass in tropical species recommended by (IPCC, 2006b; Martin and Thomas, 2011) is 0.47. The latter value was used in this study.

CHAPTER 3: DIVERSITY AND STRUCTURE OF URBAN FORESTS OF SAHEL CITIES IN NIGER

Abstract

The need for sustainable and resilient cities under a changing climate calls for intensive research on urban forests. This study assessed urban forests in Niamey and Maradi, two important cities of Niger, West Africa for differences between the cities and across LULC types in terms of species diversity and stand structure. Woody species were inventoried in 357 plots in urban forests located across seven land use/land cover types. Stem diameter at breast height of trees and shrubs > 2.5 cm, total height and crown diameter were measured. Eighty-six species belonging to 69 genera with 33 families were inventoried in Niamey, while in Maradi 91 species belonging to 70 genera with 30 families were enumerated. *Fabaceae* was the dominant family in both cities. The majority of the species documented in the two cities were exotics representing 52% of all species encountered. Mean Shannon diversity index (H') and standard deviation was 2.31 ± 0.43 for Niamey and 2.14 ± 0.74 for Maradi. The similarity index of the two cities was 70%. Urban forests of Maradi had significantly higher levels of species richness and evenness as well as tree density and canopy cover than urban forests of Niamey ($p < 0.05$). Across LULC types, canopy cover varied significantly ($p < 0.05$) but basal area had a marginal variation whilst, stem density was not significantly different. Species richness had significant effects ($p < 0.05$) on basal area and canopy cover across the LULC types in both cities. The study shows that land use/land cover types influence the characteristics of urban forests and differences exist in their diversity and stand structural characteristics in the two cities. Future development of urban forests in the two cities must target native species to improve the conservation value of their urban forests.

Keywords: Biodiversity; Conservation; Floristic composition; Maradi; Niamey.

3.1. Introduction

Rapid urbanization and changes in peri-urban land use are the leading causes of shifts in vegetation cover. Urbanization causes loss of agricultural lands (Bolca *et al.*, 2007), destruction of natural habitats (He *et al.*, 2014) and is responsible for loss of forest cover and introduction of new species to cities (Elmqvist *et al.*, 2013). Vegetation in peri-urban areas is often cleared for construction of roads, settlements or industries (Su *et al.*, 2014). Consequently, agricultural land is converted into residential and other utilities (He *et al.*, 2014) leading to displacement of agricultural frontiers to marginal areas (McKinney, 2002). Urbanization therefore appears to occur at the expense of sustainable environment.

The need for sustainable urbanization has led to increased research on urban forests (Kabisch *et al*., 2015; Arnberger *et al.*, 2016). This is due to the potential of urban forests to mitigate impacts of land use change in peri-urban areas and urban lands (Elmqvist *et al.*, 2013) and provide a variety of ecosystem services (Dingaan and du Preez, 2010; Nowak *et al.*, 2013ab; Boukili *et al.*, 2017). Trees and shrubs in urban forests improve air quality, and provide food, habitat for animals, aesthetic appeal, as well as places where people go to socialize, exercise, or connect with nature (Borelli and Conigliaro, 2018). They also mitigate climate change through carbon sequestration, create microclimates and reduce floods (Livesley *et al*., 2014; Livesley *et al*., 2016; Greene and Millward, 2017). The challenge then is what scientific information is needed to facilitate the development and management of urban forests on sustainable basis.

Empirical studies across the world report of urban areas being rich in tree populations and species diversity. In peri-urban areas in North America, high tree densities and species are documented for many cities such as the metropolitan area in Minnesota (Berland, 2012) and the City of Syracuse in New York (Nowak *et al.*, 2016). Similar findings are reported for cities in other continents such as Beijing in Asia (Yang, 2016; Yan and Yang, 2017) and Adelaide in Australia (Tait *et al*., 2005). Urban forests in African cities also have a diversity of woody species as reported in Lomé in Togo (Raoufou *et al*., 2011), Abuja in Nigeria (Agbelade *et al*., 2017), Kumasi in Ghana (Nero and Callo-concha, 2018) and Nairobi in Kenya (Nyambane *et al*., 2016). These studies report on woody plant species in urban forests, their abundance, growth characteristics and diversity, species coexistence and functional relations with green spaces. They do not however, provide information on the extent to which species diversity in urban forests are linked to their structural characteristics. Also lacking in the literature is the inclusion of peri-urban vegetation in urban forestry analysis as well as differences in urban forests between cities. Besides, there are no reports in the international literature on the composition and structure of urban forests in the Sahelian region. This impedes effort to generalise urban forest characteristics across different climatic zones as well as regions with contrasting cultures and socio-economic development.

Niamey and Maradi are two important cities in Niger, a country which lies right in the heart of the Sahel. With a population growth rate of 3.9% and mass migration of people from rural to urban areas (INS, 2016), Niger's urban population has increased from 7.5% of the country's total population in 1967 to 19% in 2017 (INS, 2016). Faced with the challenges of limited access to housing, problems of urban mobility and employment, the two cities are expanding through development of formal and informal settlements and infrastructure (Ynaut, 1987). The resultant zoning and infrastructural development of such cities is posited to alter woody species richness and density, resulting in either homogenization or depletion of biodiversity (Blair, 1999; Mckinney, 2006) or enhanced heterogeneity of the landscape over time (Nowak and Dwyer, 2007; Yan and Yang, 2017).

Assessment of the woody flora in these cities can provide data that address these uncertainties. Focusing on woody species, this study aimed to determine the differences in floristic composition and structure of urban forests between Niamey and Maradi and across seven land use/land cover (LULC) types. The objectives of the study were to determine (i) differences in biodiversity indices, and stand structure of urban forests of Niamey and Maradi and (ii) the variation in diversity and structural characteristics of urban forests across the various LULC types in the two cities. The study tested the following hypotheses: (i) Urban forests in Niamey and Maradi are rich in woody biodiversity which is associated with stand structure; (ii) there are differences between the species diversity and stand structure of urban forests of Niamey and Maradi; (iii) there are differences in urban forest richness and structural parameters (basal area and canopy cover) in the two cities across the LULC types.

3.2. Materials and Methods

3.2.1. Data Collection

3.2.1.1. Survey of Floristic Composition and Forest Structure

A stratified random sampling approach was used for the inventory. In each city the study area was stratified into seven LULC types:(1) commercial area that included market, shops, restaurants and garages; (2) forested areas consisting of urban agricultural plots, green belt, urban wetlands, irrigated urban farmlands and botanical gardens; (3) residential areas covering houses, mosques and churches; (4) schools covering private and public training and learning institutions such as primary schools, secondary schools, universities, polytechnics, training colleges; (5) administrative areas such as governments offices and private offices; (6) roads covering the main streets and boulevards. These six LULCs formed the built areas or urban forests in the two cities. (7) peri-urban forest areas consisting of peri-urban croplands, peri-urban wetlands and pastoral field. The peri-urban forests started from the end of the city (where there were no buildings) to a distance of 4 km away into the non-built area. The LULC types were randomly selected from five communes in Niamey and three communes in Maradi. A random list for sampling was prepared from an inventory of schools, administrative posts, urban green spaces, roads, markets and residential compounds obtained from directorates of education, environment, urban equipment and habitat of the communes in Niamey and Maradi.

Floristic composition and vegetation structure were assessed through a survey of plants in plots of 50 m x 50 m, consistent with guidelines for inventories in the Sahel (Thiombiano *et al.*, 2016). The plot size varied in some cases and was less than 0.25 ha if a randomly selected point could not allow a plot of a 50 m x 50 m to be demarcated without getting into another LULC type. In such cases, two smaller plots were used in place of one large plot.

All woody plants within a plot were inventoried. The minimum diameter of 2.5 cm is recommended for dryland areas (Pearson *et al*., 2007) where the landscape is dominated by small trees, and some of the species may not attain large diameter at breast height (DBH) at maturity (Thiombiano *et al.*, 2016). DBH was measured at 1.30 m from the ground using callipers or a diameter tape. Woody plants with forks below 1.3 m were considered as multi-stemmed; their individual stems were measured separately and the DBH calculated as the square root of the sum of squares of the individual stems (Thiombiano *et al.*, 2016). Crown diameter was measured crosswise with measuring tape. The longest diameter (d_1) and the diameter perpendicular to it (d_2) were measured.

Species names of all the measured woody species were recorded. The position of each plot was recorded with Global Positioning System.

Specimen and photographs were collected for plants whose identity could not be established in the field for later identification at the "Laboratoire de Biologie Garba Mounkaila", University of Niamey and at Department of Biology of University Dan Dicko Dankoulodo of Maradi. Angiosperm Phylogeny Group IV (2016) classification was used. For the *leguminosae*, the new classification, LPWG (2017) (The Legume Phylogeny Working Group (LPWG) , 2017) was used. The number of plots and areas are shown in (Table 3.1). The location of the plot is shown in Figure 3.1.

Table 3.1: Number of plots and area per LULC in two cities

Cities	LULC	Number of plots	Area(ha)
Niamey		21	3.98
	Administrative areas		
Maradi		24	3.6
Niamey	Commercial areas	9	1.87
Maradi		11	0.97
Niamey	Forested areas	33	7.37
Maradi		17	3.93
Niamey	Residential areas	51	3.75
Maradi		23	1.72
Niamey	Road	45	2.74
Maradi		42	1.7
Niamey	School	26	6.74
Maradi		26	5.34
Niamey	Peri-urban forests	17	4.25
Maradi		12	3
Niamey	Total	202	30.7
Maradi		155	20.25

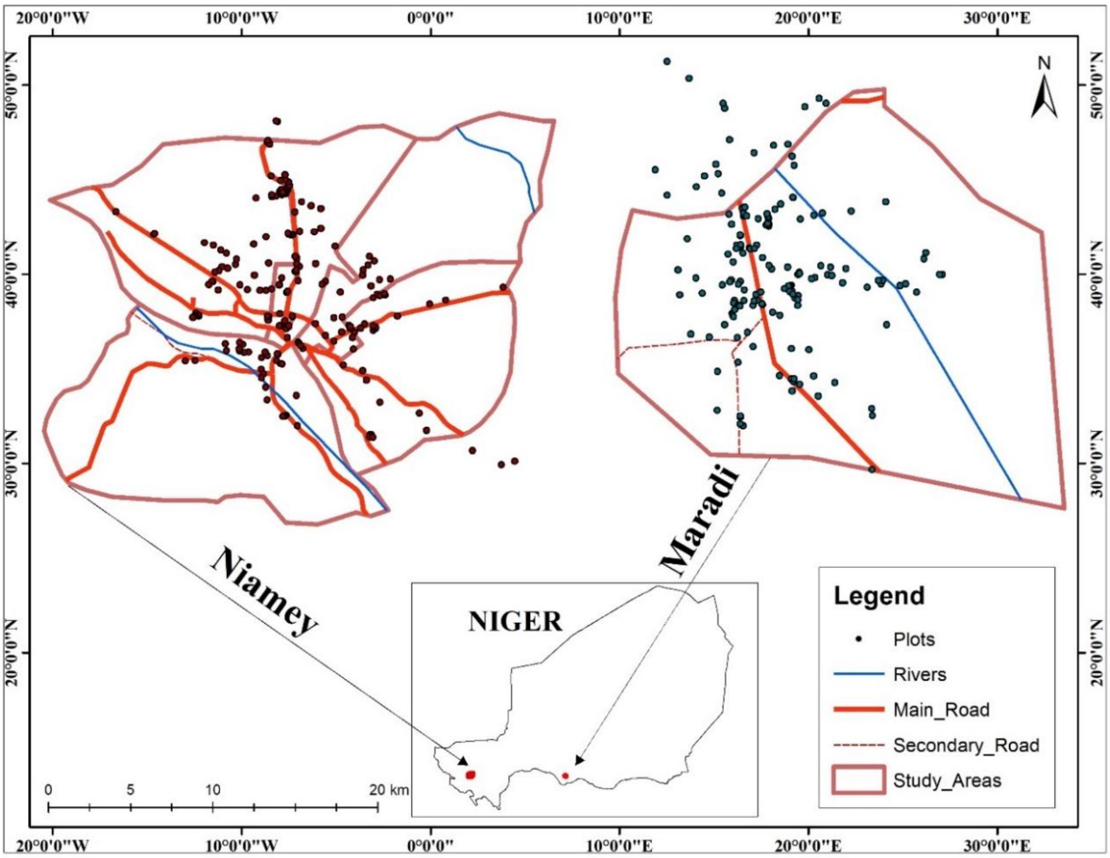

Figure 3.1: Location of the sampling plots in Niamey and Maradi.

3.2.2. Data Analysis

Shannon-Wiener diversity (H'), richness (S) and evenness (J) were calculated as indices of species diversity within and across different LULC types in the two cities. Richness was calculated as the total number of tree and shrub species in each LULC type. Shannon diversity index was calculated as the proportion of the species relative to the total number of species using the formula (Equation 3.1): $H' = -\sum [(ni/N)*Ln\ (ni/N)]$

[3.1]

Where ni is the number of individuals of species i, N is the total number of individuals per LULC types and *Ln* is the natural logarithm.

Pielou's evenness (J') was used as a measure of relative abundance of tree and shrub species, and was calculated using the formula (Equation 3.2): $J = H'/Ln(S)$ [3.2]

Where H' is the Shannon diversity index and S is the number of species.

Sorensen index was calculated for comparing the similarity between Niamey and Maradi using the formula (Equation 3.3) described in (Thiombiano *et al.*, 2016): $K = 2C/(2C+A+B)$ [3.3]

Where A is the number of species in one area (e.g. Niamey), B is the number of species in another area (e.g. Maradi) and C is the number of species common to the study sites. Basal area, density and dominance were used to describe the vegetation structure.

Basal area was calculated using (Equation 3.4) $BA\ (m^2) = D^2 * (\pi/4)$ [3.4]

Where $\pi = 3.14$, and D is the DBH.

Plant density was calculated as the total number of individuals of all species per unit area. Species density was also determined as the total number of individuals of a species per unit area. Crown area (ca) was calculated assuming an elliptical crown shape using (Equation 3.5) $(ca)\ (m^2) = \pi\{(d_1/2)x(d_2/2)$ [3.5]

Where d_1 is the largest crown diameter (m) and (d_2) is the diameter perpendicular to the larger crown diameter (m). Canopy cover (%) was calculated using (Equation 3.6) = $ca(100)/\text{Plot size}\ (m^2)$. [3.6]

Where ca is crown cover (m^2).

3.2.2.1. Statistical Analysis

Prior to the statistical analysis, the Ryan-Joiner test and Levene' test were used to check the normality and homogeneity of the data. One and two-way ANOVA were used to examine the difference in the biodiversity characteristics (Shannon, evenness) and structural characteristics (basal area, density, canopy cover) in each city and between cities across the LULCs at alpha 0.05 level of significance. Chi-square test was used to check weather the number of exotic and native stems, trees, shrubs and species were associated with LULCs in each of the city. A linear regression was used to determine the relationship between urban forest species richness and basal area and canopy cover in the two cities across the LULCs. Descriptive statistics was also used to determine the proportion of the number of exotic and native stems, trees, shrubs and species. Minitab version 17 and Excel were used for the statistical analysis.

3.3. Results

3.3.1. Floristic Composition (Trees and Shrubs) of Urban Forest Stands in Niamey and Maradi

Table 3.2 shows the diversity characteristics of urban forests of the various LULC types in the two cities. A total of 115 tree and shrub species belonging to 82 genera in 35 families were documented in 50.95 ha across the two study sites. In Niamey, 86 species belonging to 69 genera with 33 families were inventoried while in Maradi 91 woody species belonging to 70 genera with 30 families were enumerated. Mean Shannon diversity index (H') and standard deviation was 2.31 ± 0.43 for Niamey and 2.14 ± 0.74 for Maradi.

The majority of the species documented in the two cities were exotics representing 52% of all species encountered ($p < 0.001$). At the city level, Niamey had 52% of species being exotic, while equal numbers of exotic and native species were found in Maradi. In terms of the distribution of exotics and native species there was no significant difference between urban forests of the two cities ($X^2 = 0.0042$, df = 1 p = 0.94). However, at the city level, the distribution of indigenous and exotic species was found to be associated with LULC type in Niamey ($X^2 = 12.613$, df = 5, p = 0.027) and in Maradi ($X^2 = 58.720$, df = 5, $p < 0.001$).

The similarity index of the woody flora in the built areas of the two cities was 70% i.e., there were 62 species that were common to the two cities, 29 species were specific to Maradi while 24 were found only in Niamey.

The diversity characteristics (richness and evenness) varied significantly ($p < 0.05$) in each of the two cities across the LULC types (Table 3.2). The overall Shannon index was greater than 2 in each city (Table 3.2) though there were no significant differences in the mean Shannon index across the LULC types ($F = 4.14$, $df = 1$, $p = 0.06$ in Niamey and $F = 4.52$, $df = 1$, $p = 0.05$ in Maradi). Residential areas had the highest species richness in Niamey (45 species) and in Maradi (56 species) (Table 3.2). A particular example was a residence in Niamey with 10 species, the highest number of species found in a single plot within a land use. The lowest diversity indices were found in commercial areas ($H = 1.78$) for Niamey and in schools ($H = 0.84$) for Maradi (Table 3.2). The dominant families were *Fabaceae, Combretaceae* and *Verbenaceae* with 24, 5 and 6 species in Niamey, and *Annonaceae*, *Fabaceae*, *Euphorbiaceae*, *Arecaceae,* and *Combretaceae* with 24, 5, 4 and 4 species in Maradi (Figure 3.2). In built up areas in Niamey, the percentage of exotic species ranged from 6% to 23% whilst in peri-urban areas it was 6%. In Maradi, the range was from 12% to 29% in built up areas and 2% in peri urban forests.

Table 3.2: Floristic characteristics of woody species inventoried in Niamey and Maradi, Niger

		Species diversity			Origin of species	
Cities	LULC	Richness	Shannon	Evenness	Exotic	Native
Niamey	Administrative areas	38	2.79	0.77	22	16
Maradi		52	2.67	0.68	27	25
Niamey	Commercial areas	13	1.78	0.69	6	7
Maradi		30	2.40	0.71	17	13
Niamey	Forested areas	38	2.05	0.56	13	25
Maradi		41	2.60	0.70	13	28
Niamey	Residential areas	45	2.85	0.75	23	22
Maradi		56	2.67	0.66	35	21
Niamey	Roads	28	2.33	0.70	16	12
Maradi		31	1.33	0.39	17	14
Niamey	Schools	35	1.84	0.52	16	19
Maradi		29	0.84	0.25	14	15
Niamey	Peri-urban forests	25	2.50	0.78	6	19
Maradi		22	2.62	0.85	2	20
Niamey	Total	86	2.69	0.60	42	44
Maradi		91	2.45	0.54	44	47
Niamey	P-values	0.00	0.06	0.00	0.00	0.00
Maradi		0.00	0.05	0.00	0.00	0.00

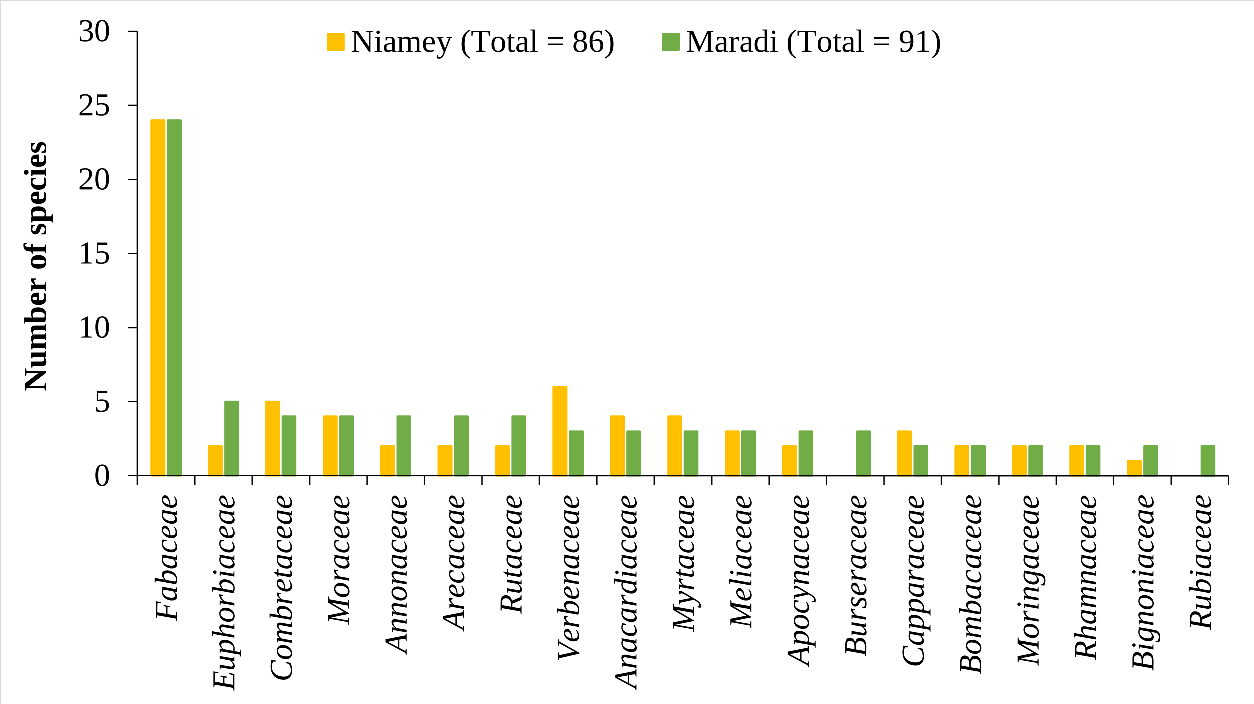

Figure 3.2: The distribution of tree and shrub species across different families inventoried in Niamey and Maradi, Niger.

3.3.2 Structural Characteristics of Urban Forests in the Two Cities

A total of 4,689 individual trees and shrubs (2,137 in Niamey and 2,552 in Maradi) were documented over an area of 50.95 ha (Table 3.3). There were more trees than shrubs in both cities (92% in Niamey and 90% in Maradi). With the exception of basal area, there were significant differences ($p < 0.05$) in the mean structural characteristics (density and canopy cover) between the two cities. The mean stem density (with standard deviation) in Maradi (142.9 ± 62.08 stems/ha) was higher than 70.60 ± 20.36 stems/ha obtained for Niamey ($F = 11.585$, df = 1, $p < 0.05$). The mean canopy cover was also higher in Maradi (53.67 ± 27.16) than in Niamey (37.90 ± 14.56) ($F = 6.57$, df = 1, $p < 0.05$). However, the stand mean basal area for Maradi (11.26 ± 5.70 m^2 /ha) was not significantly different from that for Niamey (8.60 ± 3.80 m^2 /ha) ($F = 2.88$, df = 1, $p > 0.05$).

Across LULC types in Niamey, stem density ranged from a high of 108 stems/ha along roads to a low of (48 stems/ha) in peri-urban areas. In Maradi, stem density was highest in residential areas (216 stems/ha) and lowest (43 stems/ha) in peri-urban areas. Considering the two cities stem density was not significantly different across the LULC types ($F = 1.704$, $df = 6$, $p > 0.05$). Basal area was marginally significantly different across LULC types ($F = 4.258$, $df = 6$, $p = 0.051$). Its highest value (19.36 m^2/ha) was observed in urban forests along roads in Maradi and the lowest (3.65 m^2/ha) in peri-urban forests of the same city.

There was significant effect of species richness on basal area in the urban forests in Niamey ($R^2 = 75$, Fsig = 0.08, $p = 0.005$) and in Maradi ($R^2 = 80$, Fsig = 0.04, $p = 0.02$). There was also significant effect of species richness on canopy cover in Niamey (R^2 = 81, Fsig = 0.004, $p = 0.002$ and in Maradi ($R^2 = 77$, Fsig = 0.06, $p = 0.00$). For canopy cover, urban forests in commercial areas and along roads in Maradi had the highest values (87.87% and 82.56% respectively) whilst peri-urban forests of the two cities recorded the lowest values (17.8-15.37%). Canopy cover had significant variation across LULC types in the two cities ($F = 6.574$, $df = 6$, $p < 0.05$). The distribution of the number of trees and shrubs was associated with LULC types in Niamey ($X^2 = 79.171$, $df = 12$, $p < 0.001$) and in Maradi ($X^2 = 206.113$, $df = 12$, $p < 0.001$). Schools were more associated with trees than other LULC in both cities. However, forested areas were more associated with shrubs.

In terms of relative abundance, (Table 3.3) more exotic than native tree and shrub were enumerated in Niamey (62%, N = 1,319) as well as in Maradi (77%, N = 1,967). Statistically urban forests in Maradi were associated with higher levels of trees of exotic origin than urban forests in Niamey ($X^2 = 295.94$, $df = 1$, $p < 0.05$). Schools had the higher individual exotic trees and shrubs than other LULC types. They had 27% and

29% respectively of all stems of exotic trees in urban forests of Niamey and Maradi respectively.

Azadiractha indica had the highest number of individuals in Niamey and Maradi, accounting for 41% and 54% of the total number of trees and shrubs documented, respectively from peri-urban to the built areas. In Niamey, other dominant species were *Balanites aegyptiaca*, *Terminalia mantaly*, *Faidherbia albida*, accounting for 8, 6 and 4%, respectively of the total number of trees and shrubs (Figure 3.3). In Maradi, the most abundant species next to *A. indica* were *T. mantaly*, *Vachellia nilotica* and *B. aegyptiaca* accounting for 3, 4 and 3%, respectively of the trees and shrubs enumerated in the built area. *F. albida* (21%) was the dominant peri-urban forest species in Maradi while *B. aegyptiaca* dominated in Niamey peri-urban forests.

Uncommon species, (i.e. those with a mean of less than one individual per species) were 21 in Niamey and 16 in Maradi in the built areas. Ten of them in Niamey were exotic while nine were native to Africa. In Maradi, eight uncommon species were exotic; the rest was native to Africa. These species were specific to the cities, and only *Vitellaria paradoxa* was common to both cities. In Niamey, *Mangifera indica*, *Ziziphus mauritiana*, *Vitex doniana*, *Adansonia digitata*, and *Hyphaene thebaica* were the five most common fruit species with a combined frequency of 8%. In Maradi, the five most common fruit species were *M. indica*, *Citrus lemon*, *A. digitata*, *Annona squamosa*, and *Moringa oleifera*, with a combined frequency of 7%.

Table 3.3: Structural characteristics of the two urban forests

		Counts		Structural characteristics		
Cities	**LULC**	**Shrubs**	**Trees**	**Stem density (stem/ha)**	**Basal area (m^2/ha)**	**Canopy cover (%)**
Niamey	Administrative areas	35	290	82	8.49	44.65
Maradi		66	503	158	15.37	58.95
Niamey	Commercial areas	1	94	51	6.79	40.5
Maradi		11	168	184	14.54	87.87
Niamey	Forested areas	39	437	65	6.4	23.1
Maradi		82	272	90	4.98	23.77
Niamey	Residential areas	35	211	66	5.78	41.1
Maradi		56	315	216	11.62	57.7
Niamey	Roads	8	288	108	16.3	62.05
Maradi		2	325	192	19.36	82.56
Niamey	Schools	20	477	74	10.35	36.11
Maradi		16	607	117	9.3	49.48
Niamey	Peri-urban forests	35	167	48	5.74	17.8
Maradi		33	96	43	3.65	15.37
Niamey	Total and mean ±SD	173	1964	70.60 ± 20.36	8.60 ± 3.80	37.90 ± 14.56
Maradi		266	2286	142.9 ± 62.08	11.26 ± 5.70	53.67 ± 27.16
Niamey	P-values	0.00	0.00	0.00	0.03	0.00
Maradi		0.01	0.00	0.00	0.00	0.00

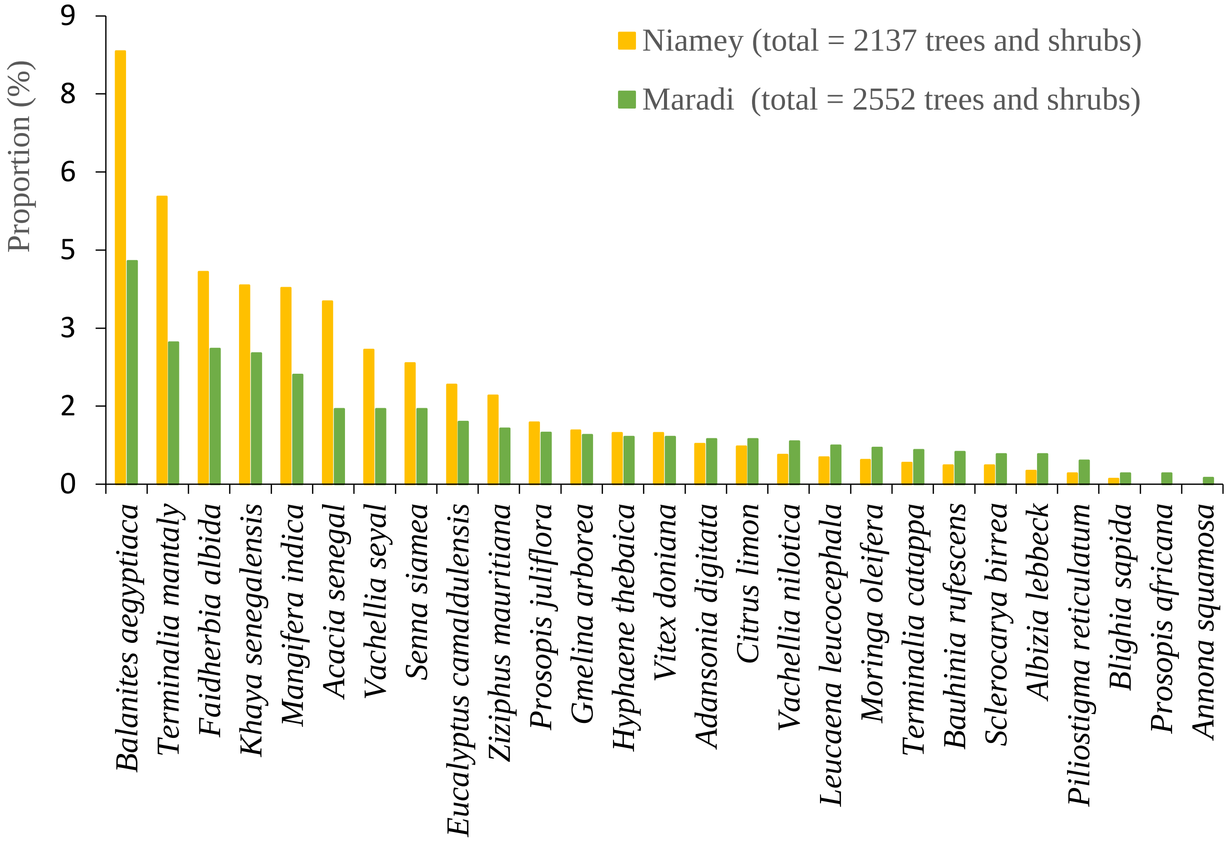

Figure 3.3: The distribution of trees and shrubs of different species inventoried in Niamey and Maradi within built areas. The proportion of *Azadirachta indica* was 41 and 54% of all the trees inventoried in Niamey and Maradi respectively and is therefore not shown in the figure 3.3.

3.4. Discussion

The results show a high species diversity in Niamey and Maradi. The Shannon diversity index for the two cities was greater than 2.0, which indicates medium to high diversity (Magurran, 2004). This demonstrates the importance of the two cities in woody species conservation. These results confirm the findings of Gillespie *et al*. (2017); Ortega-Álvarez *et al*. (2011) and Pickett e*t al*. (2001) who reported that urban areas are home to a diversity of woody species. Among the species recorded in the two cities are some of the IUCN’s list of vulnerable species such as *Khaya senegalensis* and endangered species such as *Combretum glutinosum*, *Senna singueana*, *Boswellia odorata*, *Prosopis africana*, *Anogeissus leiocarpus,* and *Daniella oliveri* in Niger. The presence of these species in the cities' urban forests lends credence to Conservation Visions' philosophy that cities can play a significant role in the conservation of threatened plant species (Elmqvist *et al.*, 2013). The high species diversity may have been achieved as a result of the Operation Green Sahel program that aimed at fighting desertification and during which many exotic species were introduced (Yacouba, 1999). It could also be related to the diversity of ethnic groups with different cultures found in the two cities. The area being cosmopolitan is likely to host different ethnic groups with diverse preferences of tree and shrub species (Dwyer *et al*., 1991). It emerged from the field discussion that some trees were introduced from outside Niger by migrants for reasons such as aesthetics e.g. *Coccoloba uvifera* and medicinal purposes (*Senna alata*). Hope *et al*. (2003) reported that diversity increases with urbanization because of human influences such as irrigation and ornamental landscaping. The high diversity determined for the two cities may contribute to ecosystem resilience (Kendal *et al*., 2014) and provision of multiple ecosystem services (Nowak and Dwyer, 2007). Urban forests with low diversity tend to be vulnerable to ecological disturbances, such as the effects of pests and diseases (Alvey, 2006) and impacts of climate change (Elmqvist *et al.*, 2013). Between the two cities, significant differences exist in species richness, Shannon index and evenness of the urban forests, with Maradi having higher values than Niamey except in the case of Shannon index. This may probably be explained by the fact that being the capital city, Niamey may have its tree planting being more formal and centrally controlled than Maradi. In that case, individual residents' influence on species choice will be limited in Niamey resulting in fewer species being planted than in Maradi.

With the exception of basal area, there were significant differences ($p < 0.05$) in the mean structural characteristics (density and canopy cover) between the two cities. This implies there were many smaller trees in Maradi and few larger trees in Niamey. It may be a reflection of age differences in the urban forests of the two cities with Niamey having an older history of urban forests than Maradi. However, other possibilities such as trees growing faster in Niamey than Maradi cannot be ruled out.

The study shows that the species richness varied significantly across the LULC types. For instance, residential urban forests had the highest species diversity in both cities suggesting that residents promote the number of woody species by choosing various woody species for their residential areas. Thus, in Niamey and Maradi, people plant multipurpose trees in their homes, and their preferences may vary according to ethnic, religious, and socioeconomic backgrounds or educational levels (Sanders, 1984; Dwyer *et al*., 1991; Hope *et al.*, 2003). Studies of other cities show that people maintain a variety of trees on their compounds for various reasons (Grimm *et al.*, 2008; Raoufou *et al*., 2011; Bigirimana *et al.*, 2012). This supports the results of Hope *et al*. (2003); Hungerford and Moussa, (2017); Wang *et al*. (2015) who reported that the household is a driver of plant species diversity.

The values of the Shannon diversity index were low in schools' urban forests in both cities This is an important observation because species diversity in schools has been found to impact on students' performance (Kweon *et al.*, 2017; Sivarajah *et al*., 2018). Therefore, school authorities have to address the problem and this could be an opportunity for youth urban forestry education in both cities. Lower Shannon index values were observed in the commercial areas in Niamey which confirmed the finding of Ortega-Álvarez *et al*. (2011) who observed fewer species diversity in commercial areas in Mexico city. Lower diversity seems not to be a surprise due to lack of space for planting trees in commercial areas especially markets. However, innovative ways can be found to improve the diversity by planting different woody species in the few spaces available.

The study recorded the presence of neem trees in peri-urban forests of the two cities and *Prosopis juliflora* in peri-urban forests of Niamey where the species are supposed to be naturally occurring. This may be the beginning of the invasion of peri-urban forests of Niger by the two species. Neem is noted as an invasive species in forest fragments of Southern Togo (Radji *et al*., 2010) whilst *P. juliflora* has invaded South Africa and India forests (Kumar and Mathur, 2014; Shackleton *et al*., 2015).

Fabaceae and *A. indica* were the dominant family and species respectively in both cities. The family *Fabaceae* is widespread in semi-arid areas on a wide range of soils and climate (Mudzengi *et al*., 2014) and this may explain its abundance in the cities. The dominance of *Fabaceae* is a good proxy for overall angiosperm diversity in many habitats (Raes *et al*., 2013). The list of *Fabaceae* species included some multipurpose species such as *Faidherbia albida*, *Tamarindus indica*, *Acacia senegal*, *Dialium guineense* and *Parkia biglobosa.* The multipurpose nature of these species may also contribute to the family's dominance in the urban forests. The dominance of the neem tree may be traced to its role as a major species for the Sahel greening under various tree planting programs (Ministère de l'Environnement du Niger, 2010) and its multi-purpose nature. Neem tree is used for construction, pest and disease control, traditional medicine and provision of shade among others worldwide (Raj *et al*., 2013; Ezzat *et al*., 2018).

Of the stand structural characteristics canopy cover was the one that varied most across the LULC types followed by basal area whilst stem density was not significantly different across the LULC types. This may be explained by the unequal distribution of shrubs and trees in the LULC types such that types with more trees will have higher canopy cover than those with relatively few trees. It may also be accounted for by the fact that in LULC types where trees are planted mostly for shade preference will be given to large crown trees, which provide high canopy cover. This preference may then create a difference in canopy cover among the LULC types even where they have similar tree density. The study shows that basal area varied significantly with species richness suggesting that diversity increases productivity measured by basal areas in the two cities. This matches the findings of Erskine *et al*. (2006) who reported that species richness had a significant effect on mean tree basal area. A possible explanation of the observation may be that tree enthusiasts may be the ones likely to plant many species and in the same way plant many stems thus creating a relationship between diversity, and basal area and canopy cover. This could also be due to inherent characteristics of forests whereby the more diverse a forest is the less inter stem competition and the greater the space for individual stems to grow larger resulting in higher basal area.

3.5. Implications of the high number of woody species in the Cities' urban forests

The study shows that in terms of species presence, there is statistically equal distribution of natives and exotics in both cities. Besides, some LULC types were more associated with exotics than natives. More exotic species were found in residential areas while native species were more in forested areas. Studies in other regions have shown that exotic species are preferred in residential areas because of the provision of different ecosystem services that may not be provided by indigenous species (Davies *et al.*, 2011; Riley *et al*., 2018). Many of the exotic species were introduced in Maradi and Niamey during the colonial period, and also within the national afforestation programs of 1965 and 1975 (Yacouba, 1999). Their high number suggests that many of the introduced species are well adapted to the Sahel climatic conditions. The presence of a variable number of exotic and native species in the cities indicates the mixed nature of the urban forests and may come with some advantages. For instance, the presence of exotic species can be crucial for urban food production (Riley *et al*., 2018) and the fight against urban human malnutrition (FAO, 2016). Nowak *et al*. (2017) reported the mix urban forest is important to mitigate urban air pollution and the presence of exotics can contribute to this species mix. However, the dominance of exotic species has implications for native species conservation. Ikin *et al*. (2012) reported of more native birds and native invertebrates in native urban vegetation showing the potential danger associated with having a few indigenous species in urban forests. According to Oliveira *et al*. (2011) and Uchiyama *et al*. (2015), the presence of native biodiversity is one of a city's biodiversity index, which is key to the sustainability of a city.

3.6. Conclusions

The findings show that Niamey and Maradi have high tree species richness but more than half of the woody flora population is made up of individuals of exotic origin. Between the two cities, significant differences exist in species richness, Shannon index and evenness as well as some stand structural characteristics (tree density and canopy cover) of the urban forests, with Maradi having higher values than Niamey except in the case of Shannon index. Maradi can therefore be said to possess better urban forests than Niamey in terms of these forest parameters. Across LULC types, species diversity and stand structure of the urban forests showed significant differences thus the location of urban forests within the city has influence on the species composition and basic stand structure. The results provide a baseline against which future assessments and monitoring can be done.

CHAPTER 4: WEST AFRICAN SAHELIAN CITIES AS SOURCE OF CARBON STOCKS: EVIDENCE FROM NIGER

Abstract

Urban forest has a huge impact on the global carbon balance. Nevertheless, much attention has been focused on the natural vegetation role in carbon offset. Specifically, in Niger, the estimation of carbon stock of urban forests remains unexplored areas for climate change mitigation. This study estimated the carbon stocks and carbon emission factors in Niamey and Maradi in Niger. Stratified random sampling was used across seven-land use and land cover types to measure carbon storage in both cities. Urban forests biomass was estimated using the generalized model. Stock-difference method was used for the carbon emission factor. Focusing on trees and shrubs with a diameter at breast height > 5 cm, 2,027 stems (78 species) were measured from 202 sample plots covering 30.7 ha in Niamey while in Maradi 2,456 stems (90 species) were measured from 155 plots with a total area of 20.25 ha. Woody species DBH, height and aboveground biomass were significantly different among land use and land cover types ($p < 0.05$). The total biomass (above and belowground biomass) carbon stock urban is Niamey is 31.63 (15.63, 47.64) and 58.30 (13.10, 103.50) t/ha in Maradi. The mean carbon stock was significantly different in each city ($p < 0.05$) across land use and land cover types. Exotic species contributed about 65% to the total carbon stocks in the two cities. The results show that conversion of peri-urban forests into urban forest in any of the LULC types is associated with carbon gain. This study illustrated the potential benefits of accounting for urban forest carbon stocks within Sahel cities under rapid urbanization. This study recommends that the urban forest carbon stocks should be included in climate change mitigation in Niger.

Keywords: Urban forest, Eco-urbanization, climate change mitigation, sustainable cities.

4.1. Introduction

Cities are expanding quickly in size. At present about 55% of the world's population lives in cities and this figure is projected to reach 68% by 2050 with 90% of the increase occurring in Asia and Africa (UN, 2018). Urban areas are extremely important for the global carbon balance as 75% of carbon emissions comes from cities (UN, 2017). This leads to climate change, which is a complex global environmental problem due to its impacts on ecological (Walther *et al.*, 2002) and socio-economic systems (Jin *et al.*, 2018). In most parts of the word, the expansion of cities involves conversion of forests and agricultural lands to urban land use. This impacts negatively on vegetation (Seto *et al.*, 2012) leading to a huge reduction in biomass (Arroyo-Rodríguez *et al.*, 2017) and therefore exerting influence on biogeochemical cycles (Wang *et al.*, 2017) and climate at regional and global scale (Seto and Shepherd, 2009).

Urban expansion pressure on forested areas is particularly high in the tropics where for instance, 5% of the annual carbon emissions are due to urban expansion (Seto *et al*., 2012). Urbanization however does not lead to total vegetation loss as city dwellers would normally establish and manage green spaces some of which may qualify as urban forests with a good level of tree cover. Such urban forests become important sources of carbon stocks in cities.

The initial attempts to estimate urban forest carbon stocks included studies by (Dorney *et al.*, 1984) who used allometric models to quantify urban forest carbon stocks in a suburb of Milwaukee. Since then studies of urban forest carbon stocks have become increasingly common across the world (Mitchell *et al.*, 2018). The limitation however, is that the majority of the studies have been done is North America, Europe and Asia notably Korea and China (Brown, 1997; Nowak *et al.*, 2013b; Weissert *et al.*, 2014; Chen, 2015; Wilkes *et al.*, 2018) resulting in limited information on urban forest carbon stocks across different climatic zones (Weissert *et al*., 2014). From some of these studies it has emerged that despite the fact that, urbanization drives carbon loss, in certain cases cities become important centres for biodiversity conservation and carbon storage, which are useful indicators for ecosystem service provision (Nadrowski *et al*., 2010). This suggests that cities may have complex relations with vegetation and by extension carbon sequestration and storage. Some studies already point out the importance of urban forests in carbon storage despite their small sizes (Davies *et al*., 2011; Nowak *et al*., 2013b; Mitchell *et al*., 2018). Building on such findings, it will be crucial to identify the patterns and trends that define urban forests distribution and therefore carbon storage. For example, which urban land use stores what amount of forest carbon will be an important data input for climate change policies especially in dry environments such as the Sahel where carbon stocks are generally low in even natural vegetation.

Again, the need to provide shade in the dry and hot climate that prevails in the Sahel has created a culture of tree planting whose impact may be significant in terms of carbon storage. It is thus important to understand the pattern of urban forest carbon distribution in the context of the heterogeneity of urban landscapes. Nevertheless, our understanding of urban carbon reservoir dynamics and specifically urban forest carbon stocks dynamics remains scarce (Tang *et al*., 2016).

Also, there is prolific literature on the carbon emission from urban expansion by urban people yet there is little work on carbon emission resulting from the conversion of peri-urban forests into urban space including its forests. Niamey and Maradi are two leading and rapidly urbanized cities in Niger but with different socio-economic attractions and cultures that may influence the way urban forests are perceived, valued and managed by people. These factors are determinant of urban forest structure (Sanders, 1984; Hope *et al.*, 2003) which are also the factors of urban forest services such as carbon stock (Nowak *et al.*, 2016). This study therefore presents an opportunity to address the knowledge gap that exists about the distribution of carbon stocks within cities and between cities, and the LULC types from which cities are created. Therefore, this paper aimed to assess the role of urban forests in the climate change debate by estimating the carbon stocks of urban forests and carbon emission factors from the conversion of semi-natural vegetation into urban forests in Niamey and Maradi, two important sahelian cities in West Africa.

4.2. Materials and Methods

4.2.1. Data Collection

The urban forest data collection was described in the materials and methods section of Chapter 3.

4.2.2. Data Analysis

Urban woody species data were grouped into three DBH classes [5-22.74], [22.75-40] and above 40 cm to provide the number of plants in each diameter class LULC in two cities. The mean diameter and height were calculated across land use and land cover types of the urban forests.

The estimation of biomass using species-specific equations was not feasible because of scarcity of species-specific equations in the literature (Henry *et al.*, 2013) mostly in urban areas where woody species diversity is high (Konijnendijk *et al.*, 2004). Therefore, through a critical review of the literature allometric models potentially suitable for estimating AGB in Niamey and Maradi were identified. The model is given as AGB (kg) $= 0.0673(\rho D^2H)^{0.976}$; [4.1]

where AGB = aboveground biomass in kg, ρ = wood density (gcm^{-3}), D = diameter in cm at breast height (1.3 m), H = total neem trees height (m). is used by authors when destructive methods are not applicable like the case of urban forests (Henry *et al.*, 2013). The wood density was obtained from the Global wood density database (Zanne *et al.*, 2009). For species without available wood density figures, Wood density of the genus or family was used. The model by Chave *et al*. (2014) has a diameter range of 5- 212 cm.
Species-specific allometric models for below-ground biomass are relatively scarce in the literature (Cairns *et al*., 1997; Koala *et al.*, 2017). Thus, belowground biomass (BGB) was quantified as a proportion of AGB using the equation BGB (kg) = (0.24)AGB [4.2] developed by Cairns *et al*. (1997) for tropical vegetation. The total urban forests biomass was obtained by summing up the AGB and BGB, which was multiplied by 0.47 (IPCC, 2006b) to obtain carbon content. Stock-difference method was used for the carbon emission factor. The carbon emission factor was calculated as using equation (4.3) EF = peri-urban forest carbon stocks – urban forest carbon stock (IPCC, 2006b) [4.3], where EF is the carbon emission factor in tonnes of carbon per hectares (t/C/ha).

4.2.2.1 Statistical Analysis

Prior to the statistical analysis, the Ryan-Joiner test and Levene test were used to check the normality and homogeneity of the data. The test of significance was determined at $p < 0.05$. One-way ANOVA test was used to test the differences in the mean H, DBH, carbon stocks, and carbon emission factors in each city across the LULC. A two-sample t-test was used to test the difference between the two urban forests mean carbon stock.

Descriptive statistics was also used to determine the contributions of species to the AGB. Excel was used for the statistical analysis.

4.3. Results

4.3.1 Aboveground biomass across land use and land cover types in the two cities

The study sampled 4483 stems with DBH ≥ 5 cm that belong to 108 species in both cities. About 2,027 stems (78 species) were measured from 202 sample plots covering 30.7 ha in Niamey and 2,456 stems (90 species) were measured from 155 plots with a total area of 20.25 ha in Maradi. Table 4.1 presents the mean DBH, H, AGB, and number of stems recorded in Niamey and Maradi across the LULC types.

The mean DBH, H, and AGB varied significantly across the LULC in Niamey and Maradi ($p < 0.001$) (Table 1). Among the LULC types, the mean DBH of the commercial areas (37.02 ± 1.99 cm) and that of roads (37.49 ± 1.35 cm) had trees with the highest mean diameter in Niamey (Table 4.1), while in Maradi this occurred along the roads (32.59 ± 0.84 cm) and in peri-urban forests (31.50 ± 2.01 cm). However, the trees of lowest diameter were observed in residential urban forests (27.92 ± 1.32 cm) in Niamey and in forested areas (23.82 ± 0.70 cm) in Maradi.

For tree height, the highest mean values were observed in commercial areas (10.38 ± 0.35 m) and roads (9.78 ± 0.21 m) in Niamey and in commercial areas (9.20 ± 0.36 m) in Maradi. For the AGB, the highest mean values were observed in commercial areas (109.9 t/ha) in Niamey and residential urban forests (235 t/ha) in Maradi. While the lowest mean values were observed in peri-urban forests in both cities. There were significant differences in the mean DBH, H, and AGB between the two cities (F-stats = 12.57, df = 2, $p < 0.001$). The average DBH across the two cities was 32.51 ± 1.35 cm in Niamey and 28.69 ± 1.36 cm in Maradi (Table 4.1). The average tree height in the two cities were 7.97 ± 0.26 m in Niamey and 7.74 ± 0.36 m in Maradi. The corresponding values of the mean AGB and its confidence interval at 95% were 55.3 (28.10, 82.5) t/ha for Niamey and 99.2 (22.3, 176.2) t/ha for Maradi (Table 4.1).

The three most dominant species in terms of AGB were *Azadirachta indica* (47%), *Faidherbia albida* (16%), and *Khaya senegalensis* (12%) in Niamey. While the three most dominant species in terms of AGB were *Azadirachta indica* (61%), *Terminalia mantaly* (7%), and *Faidherbia albida* (6%) in Maradi. The exotic species in the urban forests represented 60% of the total AGB in Niamey and 78% in Maradi.

The large diameter classes (DBH > 40 cm) was the leading class in terms of the diameter classes contributions to the AGB in the two cities while the small trees [5-22.74] cm class represented 0 and 1% of AGB in Niamey and Maradi respectively (Table 4.2). Tree size-class distribution profiles showed the greatest number of stems in the diameter classes above 40 cm having an overall percentage of 88% in Niamey. However, the [22.75-40] cm was dominant DBH classes in terms of the number of the stems in Niamey with 12% contributions to the AGB. A similar trend was observed in Maradi where the DBH classes greater than 40 cm are leading classes in terms of AGB contribution (59%) although the diameter class [22.75-40] represented the highest number of stems in Maradi.

Table 4.1: The total number of stems, Mean standard error (SE) of DBH (cm), Height (m) and Mean confidence interval of AGB (t/ha) by the LULC types surveyed in Niamey and Maradi are presented.

Cities	LULC types	Number of stems (DBH ≥ 5 cm)	Mean (SE) DBH (cm)	Mean (SE) Height (m)	Mean (95% CI) AGB (t/ha)
Niamey	Administrative areas	305	31.9 ± 1.13	9.12 ± 0.23	56.18 (45.35, 67.02)
Maradi		563	31.45 ± 0.68	7.90 ± 0.15	47.39 (31.31, 63.47)
Niamey	Commercial areas	93	37.02 ± 1.99	10.38 ± 0.35	109.9 (54.3, 165.4)
Maradi		176	28.25 ± 1.13	9.20 ± 0.36	116.8 (6.7, 226.8)
Niamey	Residential areas	233	27.92 ± 1.32	8.36 ± 0.23	31.25 (19.79, 42.71)
Maradi		349	23.97 ± 0.66	6.85 ± 0.15	235 (3, 467)
Niamey	Forested areas	443	31.86 ± 0.88	7.3 ± 0.16	32.31 (21.81, 42.81)
Maradi		340	23.82 ± 0.70	6.25 ± 0.16	26.74 (11.24, 42.23)
Niamey	Schools	482	29.54 ± 0.49	8.62 ± 0.14	54.1 (20.2, 87.9)
Maradi		617	29.27 ± 0.51	7.90 ± 0.09	70.73 (42.7, 98.8)
Niamey	Roads	293	37.49 ± 1.35	9.78 ± 0.21	75.03 (52.8, 97.3)
Maradi		325	32.59 ± 0.84	8.45 ± 0.15	182.8 (93.5, 272)
Niamey	Peri-urban forests	178	31.86 ± 1.81	6.26 ± 0.26	28.34 (13.74,42.94)
Maradi		86	31.50 ± 2.01	7.66 ± 0.33	15.13 (8.93, 21.33)
Niamey	Overall	2027	32. 5 1± 1.35	7.97 ± 0.26	55.3 (28.10, 82.5)
Maradi		2456	28.69 ± 1.36	7.74 ± 0.36	99.2 (22.3,176.2)
	P-values	-	0.00	0.00	0.00
		-	0.00	0.00	0.01

Table 4.2: Number of stems per DBH classes and the contribution of each size class above ground biomass (AGB).

Cities	DBH classes (cm)	[5-22.74]	[22.75-40]	> 40
Niamey	Number of Stems	690	788	549
	Contributions to the AGB (%)	0	12	88
Maradi	Number of Stems	904	1087	465
	Contributions to the AGB (%)	1	40	59

4.3.2. Carbon Stocks of the urban forests in the two cities

Table 4.3 presents the mean carbon stocks of the urban forest in the two cities. The mean carbon stock varied significantly (F-stats = 17.57, df =1, $p < 0.001$) among LULC types in Niamey. Urban forests store 34.13 (15.75, 52.52) t/ha more carbon than agroforestry parklands 16.65 (8.07, 25.23) t/ha around Niamey (F-stats = 21.72, df = 1, $p < 0.001$). The overall carbon stock in Niamey was 31.63 (15.63, 47.64) t/ha. A similar trend was observed in Maradi, the average carbon stock varied significantly (F-stats = 8.61, df = 1, p = 0.01) across the LULC. Urban forests stored (66.5 (16.2, 116.90) t/ha in Maradi which was more than peri-agroforestry parklands with (8.90 (5.25, 12.53) t/ha (F-stats = 9.55, df = 1, $p < 0.001$). The overall carbon stock in Maradi was 58.30 (13.10, 103.50) t/ha. There were no differences in the mean carbon stock between the two cities across the LULC (T test-Value = -1.36, p = 0.22, df = 7).

At LULC level, commercial areas had the highest mean carbon stock of 64.60 t/ha in Niamey (Table 4.3). The lowest average carbon stocks were observed in forested area, peri-urban forests and residential areas in Niamey (Table 4.3). A reverse trend was observed in Maradi, where residential areas (138.10 t/C/ha) and roads (107.40 t/C/ha) had the highest mean carbon stock (Table 4.3). The lowest mean carbon stocks were observed in forested areas and peri-urban forests in Maradi (Table 4.3).

Table 4.3: Mean carbon stock at confidence interval (CI) across the LULC in Niamey and Maradi cities

Cities	LULC	Mean Carbon stock (t/ha)
Niamey	Administrative areas	27.84 (13.07, 42.61)
Maradi		27.84 (18.39, 37.29)
Niamey	Commercial areas	64.60 (42.0, 87.1)
Maradi		68.60 (4.0, 133.2)
Niamey	Forested areas	18.98 (7.20, 30.76)
Maradi		15.71 (6.61, 24.81)
Niamey	Residential areas	18.36 (8.79, 27.93)
Maradi		138.10 (1.9, 274.2)
Niamey	Roads	43.24 (33.58, 52.91)
Maradi		107. 40 (55.0, 159.8)
Niamey	Schools	31.77 (18.24, 45.31)
Maradi		41.56 (25.09, 58.02)
Niamey	Peri-urban forests	16.65 (8.07, 25.23)
Maradi		8.90 (5.25, 12.53)
Niamey	P-values	0.00
Maradi		0.01

4.3.3. Carbon emission factors from the conversion of peri-urban forests to urban forests

Table 4.4 presents the carbon emission factors from the conversion of peri-urban forests to urban forests in Niamey and Maradi. There were no significant differences in the mean values carbon emission factor from the conversion of the peri-urban forests across the LULC types in Niamey (F-stats = 4.83, df = 1, $p = 0.06$), while there was significant difference in the mean carbon emission factor in Maradi (F-stats = 9.55, df = 1, p <

0.001). The mean carbon emission factor and standard error in Maradi (67.81 ± 20.5 t/ha) was higher than the mean carbon emission factor in Niamey (20.51 ± 7.93) (F-stats = 9.99, df = 1, p = 0.01). The conversion of peri-urban forests to the residential urban forests in Maradi leads to the highest carbon gain (129.21 t/ha) while the conversion to commercial urban forests leads to the highest carbon gain (47.95 t/ha) in Niamey. The conversion of peri-urban forests to the residential urban forests in Niamey shows small values of carbon emission factors (Table 4.4). In Maradi, the lowest values of carbon emission factors were observed from the conversion of peri-urban forests to the administrative urban forests (Table 4.4).

Table 4.4: Carbon emission factors from the conversion of peri-urban forests to urban forests.

LULC types	Cities	Carbon emission factors (EFs) (t/ha)
Residential areas	Niamey	-1.71
	Maradi	-129.21
Schools	Niamey	-15.12
	Maradi	-32.67
Commercial areas	Niamey	-47.95
	Maradi	-59.71
Roads	Niamey	-26.59
	Maradi	-98.51
Administrative areas	Niamey	-11.19
	Maradi	-18.95

4.4. Discussion

The results show variation in density of carbon stocks across LULC types in the two cities. This is an observation which is shared by Hutyra *et al*. (2011); Nero and Callo-concha (2018) and Raciti *et al*. (2012) who reported that urban forest carbon stocks were associated with LULC types in Seattle, Boston and Kumasi respectively. These variations in carbon stocks across LULC types may be explained by the need to balance the presence of trees and forests for specific purposes in the various LULC types with the desire to reserve enough space for urban infrastructure and human activities (McKinney, 2002). It may also reflect the age of the various urban forests whereby LULC types typical of older parts of the city such as commercial areas may hold more carbon stocks than those associated with newly developed areas. Also for safety reasons certain LULC e.g. administrative areas, may not be compatible with the retention of large trees which store more carbon and will therefore naturally differ in carbon stocks from areas where large trees are allowed to grow.

Between the two cities, no significant differences were found in carbon stocks held in urban forests. This was notwithstanding the fact that Maradi had 21% more stems/ha in its urban forests than Niamey. A plausible explanation to account for the lack of difference in carbon stocks may lie in the differences in the tree sizes between the two cities with Niamey being associated with larger trees than Maradi. Being the capital city Niamey may have a longer history of urban forests and therefore older and larger trees than Maradi.

The results show that Niamey and Maradi cities contain considerable amounts of aboveground biomass in their urban forests confirming the findings of Myeong *et al*. (2006) who concluded that cities are important areas of aboveground biomass. These results also give an indication of the fact that cities in the Sahel region may be important areas of tree biomass, and for that matter carbon stocks. The values in this study are higher than those recorded in the Sudano-Sahelian Woodlands in Burkina Faso (Karlson *et al.*, 2015) despite the higher annual rainfall received in the Sudano-Sahelian zone. Many factors could account for this but the differences in the attention and protection given to urban forests in the two countries may probably best explain why carbon stocks are higher in the present study. This study found an average carbon stock of 31.63 t/C/ha in Niamey and 58.30 t/C/ha in Maradi. Nowak and Crane (2002) found the national average urban forest carbon storage density is to be 25.1 t/C/ha in the urban forests of 10 cities in USA. Chen (2015) found also an average carbon stock of 21.34 t/ha for 35 major Chinese cities. The mean carbon stock found in Niamey and Maradi appear greater than those reported by these authors. May be methodological differences, size of trees and stems densities of the respective species may explain the apparent high levels of carbon stocks in the present study. Nonetheless, it may be reasoned that the hot dry climate of the Sahel zone may have created a culture of tree planting for shade making sahelian cities unique in their urban forest management. Trees of diameter greater than 40 cm held the highest percentage of AGB in the urban forests in both cities. The study confirmed studies which show that tree size classes with large diameters lead in AGB in temperate forests (Karlson *et al.*, 2015), miombo woodlands (Kuyah *et al.*, 2014) and urban forests in Kumasi (Nero and Callo-concha, 2018). These results demonstrate the importance of tree size in carbon conservation in both natural and man-made forests. In protected areas in Kenya, old large trees were found to store a huge amounts of biomass and their presence made a whole lot of difference in carbon stocks (Willcock *et al.*, 2016). This implies that in planting and nurturing trees for carbon sequestration and storage, an important selection criterion could be the species maximum attainable size. It must, however, be borne in mind that due to the potential hazard posed by large trees to urban infrastructure, property and people (Roy *et al*., 2012) their use in urban forests may be restricted.

Considering the contribution of exotic and indigenous species to carbon storage, this study revealed that, exotic species contribute about 65% of the total carbon stocks in the two cities. The results show the important role exotic species play in carbon storage in the cities. This may be a reflection of the popularity of exotics in urban forests due to their aesthetic appeal and ease of establishment (McKinney, 2002). The results also demonstrate the role of urbanization in species selection for planting and its implications for native species conservation. Probably a conscious effort to target native species for urban forest development could provide a dual benefit of carbon and native species conservation that is at present lacking in the two cities. In Agartala, Majumdar and Selvan (2018) reported that native species dominated the carbon stocks of urban and peri-urban forests. This contradicts these results and show that with conscious effort native species can be made to play a more significant role in urban forest carbon storage. The results also show that conversion of peri-urban forests into urban forest in any of the LULC types is associated with carbon gain. This implies that although urbanization has negative impacts on forest biomass as commonly known (Ren *et al.*, 2012; Seto *et al*., 2012) in the case of sahelian cities, city expansion may lead to less biomass and carbon losses if a little more effort can be made in urban forest development.

4.5. Conclusions

The study examined the importance and variations of above ground biomass in urban forests and its associated carbon stocks across land use and land cover types in two important sahelian cities in West Africa. Among LULC types, carbon stocks in urban forests vary significantly with forested areas playing a lesser role in carbon storage. The two cities did not differ in their mean carbon stocks despite a higher number of tree stems in Maradi. Large trees (> 40 cm DBH) were found to be more important for carbon stocks than others. Conversion of peri-urban forests into urban forests in any of the LULC types was associated with carbon gain suggesting urban forests may have a significant role to play in climate change mitigation projects for sustainable urban development.

CHAPTER 5: *Azadirachta indica* A. JUSS. A MULTI-PURPOSE TREE AS A LEADING SPECIES IN CARBON STOCKING IN TWO SAHELIAN CITIES OF NIGER

Abstract

The role of urban trees in the climate change discourse is not well articulated due to limited data. Understanding the factors that influence the role of urban forests and their species in carbon storage, an important issue in climate change will be essential in this respect. Arguing that multipurpose trees are likely to be preferred in urban forests in developing countries due to the varied and numerous benefits that planters derive from them, the study estimated the carbon stocks in Neem (*Azadirachta indica*) a multi-purpose tree in the urban forests of Niamey and Maradi in Niger across land use/land cover types. Data were collected on neem trees and all other species with a diameter at breast height > 5 cm using stratified random sampling. The total biomass (above and belowground biomass) and carbon equivalent in seven urban land use/land cover types were quantified using non-destructive methods. The findings showed that *A. indica* stored more carbon than any other species in the cities' urban forests. It accounted for 54% and 61% of carbon stocks in urban forests of Niamey and Maradi respectively with a mean of 26.66 ± 7.64 t/ha in Niamey and 34.66 ± 10 t/ha in Maradi. In both cities, the proportion of the urban forests' carbon stocks held in neem varied significantly across land use/land cover types ($p < 0.05$). In Niamey urban forests in commercial areas had the highest carbon stock (67.05 ± 27.49 t/ha) whilst in Maradi the highest carbon stock (78.02 ± 25.7 t/ha) was found in urban forests along roads. The results suggest that carbon stocks enhancement in urban forests can be promoted through the use of multipurpose trees.

Keywords: Climate change mitigation, Urban forest, Maradi, Niamey

5.1. Introduction

Cities are important sources of CO_2 emission leading to global climate change (UN, 2017). Nonetheless, cities may play an important role in atmospheric CO_2 reduction via carbon sequestration by trees and other woody species in urban forests. Urban trees provide various other ecosystem services relevant to climate change mitigation to the urbanites. For example, they influence urban energy consumption through the provision of microclimate, therefore, reducing the CO_2 emissions associated with the operation of cooling systems (McPherson and Simpson, 2003). They also intercept rainfall and reduce urban runoff (Ning *et al*., 2015), a phenomenon which is predicted to increase with climate change (Yan *et al.*, 2018). Planting trees in urban areas is therefore key in meeting the global sustainable development goals (Borelli and Conigliaro, 2018).

At the moment, urban trees are promoted as a nature-based solution for climate change and related environmental problems, however, their role in carbon storage at the global and local level has just begun to be studied (Weissert *et al*., 2014). Some important questions which research needs to answer on urban forests in its relation to climate change mitigation include how the present determinants of species choice in urban forests is likely to impact on carbon sequestration and storage in urban forests. Equally important is species differences in their ability to store carbon for longer periods in urban forest settings.

In terms of species choice, multipurpose trees are likely to be preferred in urban forests due to the varied and numerous benefits that planters are likely to derive from them. From the perspectives of carbon sequestration and storage, species characteristics such as fast growth, maximum attainable size, and life span will be crucial factors to be considered. Therefore, if species that combine these traits can be identified and promoted in urban forests it can enhance the role of urban forests in climate change mitigation via carbon storage. One species that appears as a possible candidate in meeting this description in the sahelian landscape is the neem tree.

Azadirachta indica (*A. indica*) A. Juss or neem tree belongs to the *Meliaceae* family. It is a fast growing species, which can attain a height of 6 m from seed planting in three years. It grows in a wide range of environmental conditions including high temperatures and low rainfall making it drought resistant (Dhar *et al*., 2011; Raj *et al.*, 2013). The neem tree is noted to grow on almost all types of soil (Hänke *et al.*, 2016) and is well adapted to stress conditions compared to other species (Raj *et al.*, 2013). Its productive lifespan can be up to 150 – 200 years, according to Kumaar and Navartnam (2013).

The neem tree is a multipurpose tree whose uses include restoration of degraded lands (Raj *et al.*, 2013), amelioration of saline soils (Narwal *et al*., 2003) and general soil amendment (Rafiu, 2012). It is widely used for land restoration and environmental protection in West Africa Sahel regions (Sené, 1993). It is commonly used as a shade tree in the tropics and its cool shade is noted to prevent the occurrence of several harmful diseases (Takase *et al.*, 2015). Neem tree is a good sinker of air pollutants (Dhadse *et al.*, 2011) and good accumulator and sequester of carbon in the built environment (Bohre *et al.*, 2016). It has a high rate of photosynthesis and releases more oxygen through the gas exchange than many other tree species (Raj *et al.*, 2013). The wood is a useful timber and fuelwood material in some of West Africa countries such as Ghana (Neal and Campbell, 2004; Mensah *et al*., 2017), Niger (Moussa *et al.*, 2018) and Nigeria (Jimoh *et al.*, 2017). The seeds are used for biodiesel production, (Dhar *et al*., 2011; Takase *et al.*, 2015). The neem tree is used for the treatment of many diseases (Hao *et al.*, 2014; Ravva and Korn, 2015; Patel *et al.*, 2016; Chandra *et al.*, 2017; Shareef *et al*., 2018) and almost every part of it is has a medicinal use in many countries (Anyaehie, 2009; Kumawat and Kumar, 2018). The leaves have been reported to be antimalarial, antifungal, antibacterial, antiviral, antiulcer and treat diseases such as general body ailments, dental pain, diabetes,malaria and as biopesticides (Anyaehie, 2009; Patel *et al.*, 2016; Chandra *et al.*, 2017; Soumaila *et al*., 2017; Ezzat *et al*., 2018; Shareef *et al*., 2018; Ibrahim *et al*., 2018). The leaves are also reported to reduce the AIDS virus load (Ezzat *et al*., 2018). The powdered leaves are used as a feed additive in poultry production (Ezzat *et al*., 2018; Kumawat and Kumar, 2018).

The neem tree was introduced to Niger in 1916 for afforestation purpose (Yacouba, 1999). It exists in the four agro-climatic zones of Niger (Saadou Mahamane, personal communication, 2018) namely Saharian with a mean annual rainfall of less than 150 mm; Sahelian (150-350 mm); Sudanian (600-800 mm) and Sudano-Sahelian (350-600 mm) (CNEDD, 2016). Neem is widely used for urban afforestation programmes in cities of Niger where they serve many purposes including shade provision, timber, and firewood production and as burial material (Moussa *et al.*, 2018).

Howerver, its role as a carbon storehouse in cities and other human settlements is not well captured in the scientific literature. Therefore, this study aimed to determine its role in climate change mitigation via the estimation of its carbon stocks in the cities of Niamey and Maradi across land use/land cover types. It was hypothesised that (i) land use/ land cover influences neem distribution and structural characteristics in urban forests; (ii) Niamey being a national capital with a higher elite population will have lower neem tree numbers in its urban forests and (iii) Neem stores more carbon than all other species in the cities' urban forests.

5.2. Materials and Methods

5.2.1. Data Collection

Urban forest data collection were described in the materials and methods section of **chapter 3.**

5.2.2. Data Analysis

The parameters of (Basal area, stem density and canopy cover) of neem trees and all other species were described in the materials and methods section of **Chapter 3**. Data on neem tree diameter were grouped in two DBH (5-40) cm and above 40 cm to determine the number of the stems in each diameter class per LULC in the two cities. Neem trees DBH data were grouped into two DBH (5-40) cm and above 40 cm to provide the number of stems in each diameter class LULC in two cities. The mean diameter and height were calculated across the LULC of urban forests. The equation 4.1 was used to estimate the AGB of neem trees and all other species AGB. The equation 4.2 was used to quantify the BGB. For the carbon content the **Chapter 4** approach was used to calculate the carbon stock of neem trees and all others species.

5.2.2.1. Statistical Analysis

Prior to statistical analysis, the Ryan-Joiner test and Levene' test were used to check the normality and homogeneity of the data. An ANOVA was used to examine the effect of land use/ land cover types on the structural characteristics (diameter, height, basal area, density and tree cover) of neem trees at alpha 0.05. Pearson Chi-Square (X^2) was used to test the association between LULC types and the relative representation (proportion) of neem tree stems in their urban forests. A two-sample t-test was used to test the difference between the two urban forest's mean carbon stocks. Descriptive statistics were used to summarise the proportion of neem trees and all other species per the LULC. Microsoft Excel was used for the statistical analysis.

5.3. Results

5.3.1. Structural characteristics of neem trees in Niamey and Maradi

The study recorded 78 species in Niamey and 90 in Maradi (excluding neem). In Niamey, the mean tree density (number of stems/ha) was 43.4 for neem and 55 for all other species combined. In Maradi, there were 85 trees/ha for neem and 92 trees/ha for all other species. Forty-four percent of trees sampled from urban forests across the different LULC types were neem in Niamey whilst in Maradi, neem trees formed 48% of the tree population (Table 5.1).

In terms of proportional representation of neem trees in the urban forests of the two cities (Table 5.1), neem trees represented 44 and 48% of stem stems recoded in Niamey and Maradi respectively. There were no significant differences in the proportion of neem trees across the LULC types in both cities ($X^2 = 3.02$, df = 2, $p = 0.08$). The mean stem density of neem tree was 43.4 ± 8.87 stems/ha in Niamey and 85.10 ± 15.7 stems/ha in Maradi. However, mean stem density of neem trees ($p < 0.05$) in each city and between the cities across the LULC. The mean basal area of neem tree was 4.85 ± 0.87 m^2/ha for Niamey and 7.25 ± 1.34 m^2/ha for Maradi. Again, there were no significant ($p > 0.05$) differences in the mean basal area in each city and between the two cities across the LULC (Table 5.2). The mean canopy cover of neem tree was 23.90 ± 4.81% in Niamey and 36.66 ± 5.81% in Maradi. In addition, canopy cover of neem trees varied significantly ($p < 0.05$) in each city and between the cities across the LULC.

At the city level in Niamey, the highest neem tree density was observed in urban forests along roads (80 stems/ha) followed by residential areas (68 stem/ha) while the lowest density was observed in peri-urban forests (16 stems/ha). There was a significant association between LULC types and the relative proportional representation of neem tree stems in their urban forests ($X^2 = 35.28$, df = 6, $p < 0.001$). In terms of basal area, neem tree populations in urban forests in schools had a mean of 9.39 m^2/ha followed by those along roads with 6.13 m^2/ha.

Table 5.1: Proportion of neem trees and all others species across the LULCs

Cities	LULC	Proportion of neem (%)	All other species (%)
Niamey	Administrative areas	4	10
Maradi		6	8
Niamey	Schools	6	4
Maradi		8	1
Niamey	Residential areas	10	8
Maradi		9	11
Niamey	Roads	12	14
Maradi		13	7
Niamey	Forested areas	6	9
Maradi		5	9
Niamey	Commercial areas	4	4
Maradi		5	9
Niamey	Peri-urban forests	2	6
Maradi		3	7
Niamey	Total	44	56
Maradi		48	52

The highest neem tree canopy cover was observed in urban forests along roads (44.51%) followed by residential areas (36.33%). The lowest neem tree basal area and canopy cover were observed in peri-urban areas (Table 5.2). In Maradi, the highest neem trees density was observed along roads (155 stems/ha) followed by residential areas (117 stems/ha) whilst the lowest density was observed in peri-urban forests (31 stems/ha

(Table 5.2). Here too there was a significant association between LULC types and the representation of neem tree stems in their urban forests (X^2 = 130.38, df = 6, $p < 0.001$). Basal area of urban forests in commercial areas and along roads had a mean of 13.22 m^2/ha followed by administrative area (7.94 m^2/ha) and the lowest was observed in the peri-urban forest (1.46 m^2/ha). The highest neem tree canopy cover was observed along roads (61.32%) followed by schools (39.3%). The lowest neem tree crown cover was observed in the peri-urban forests (9.34%) (Table 5.2). Table 5.2 presents also mean and standard errors of neem trees (DBH, AGB and H) in the various LULC types in Niamey and Maradi. There were significant differences in the mean DBH and H across the LULC types in both cities ($p < 0.05$), (Table 5.2).

The 5-40 cm diameter class represented 70% of the total neem tree stems recorded in Niamey. Nevertheless, the diameter class above 40 cm represented 70% of the total neem tree AGB. In Maradi, 91% of stems were in the 5-40 cm diameter class and had about 71% of the total AGB.

Table 5.2: Structural parameters of neem trees and all other species recorded in the urban forests. Mean ± standard error

Cities	LULC	Density (No. Stems/ha)		Basal Area (m^2/ha)		Tree canopy (%)		Mean DHB (cm)		Mean Height (m)		Number of the species
		Neem	All other species	Neem	All Other Species	Neem	All Other Species	Neem	All Other Species	Neem	All Other Species	
Niamey	Administrative areas	27	66	3.86	5.85	18.72	25.93	35.64± 2.20	26.52 ± 1.28	9.7 ± 0.57	8.12 ± 0.27	41
Maradi		69	96	7.94	7.28	30.88	28.07	35.81 ± 0.87	28.33 ± 0.96	8.4 ± 0.17	7.52 ± 0.22	51
Niamey	Schools	44	30	9.39	3.02	23.38	12.73	39.13 ± 1.53	24.55 ± 1.67	9.17 ± 0.12	7.41 ± 0.27	35
Maradi		100	16	7.61	1.70	39.3	10.18	28.0 ± 0.50	32.60 ± 1.76	7.90 ± 0.10	7.74 ± 0.33	24
Niamey	Residential areas	68	58	4.27	5.93	36.33	25.12	26.56 ± 1.90	25.47 ± 1.70	9.42 ± 0.30	7.22 ± 0.30	45
Maradi		117	131	7.22	5.62	38.35	19.35	26.55 ± 0.68	21.46 ± 1.07	7.24 ± 0.13	6.50 ± 0.26	55
Niamey	Roads	80	100	6.13	11.93	44.51	17.51	30.57 ± 1.29	41.11 ± 1.96	10.40 ± 0.25	9.46 ± 0.32	28
Maradi		155	85	13.22	7.12	61.32	26.96	31.34 ± 0.70	35.10 ± 2.63	8.44 ± 0.15	8.41 ± 0.42	30
Niamey	Forested areas	44	61	4.52	3.73	18.1	5.0	33.07 ± 0.91	27.02 ± 1.18	7.55 ± 0.18	6.12 ± 0.18	37
Maradi		65	111	5.06	7.26	36.15	12.38	30.08 ± 0.87	23.97 ± 0.99	8.41 ± 0.21	5.67 ± 0.18	43
Niamey	Commercial areas	25	27	3.15	3.40	20.02	20.48	37.87 ± 2.56	34.88 ± 3.07	10.31 ± 0.36	10.12 ±0.63	12
Maradi		59	117	13.22	11.06	43.26	44.62	34.01 ± 1.76	25.47 ± 1.40	8.68 ± 0.29	9.44 ± 0.52	28
Niamey	Peri-urban forests	16	44	2.61	5.38	6.10	11.7	40.67 ± 6.23	29.44 ± 1.84	6.90 ± 0.35	6.17 ± 0.35	23
Maradi		31	85	1.46	3.21	9.34	6.03	23.13 ± 2.15	36.71 ± 2.50	7.26 ± 0.50	7.70 ± 0.42	15
Niamey	P-values	0.00	0.00	0.49	0.28	0.00	0.00	0.00	0.00	0.00	0.00	-
Maradi		0.00	0.00	0.06	0.15	0.00	0.00	0.00	0.00	0.00	0.00	-

5. 3.2 Biomass and carbon stocks of neem trees compared with those of all others species

Table 5.3 presents the mean aboveground biomass and carbon stock of neem trees and all other species recorded in Niamey and Maradi. The mean carbon stock of neem tree was 26.66 ± 7.64 t/ha in the urban forests of Niamey and 34.66 ± 10 t/ha in urban forests of Maradi. There was also no significant difference in the neem trees mean carbon stock between the two urban forests (T-Value = -0.63, p = 0.54, df = 11). While the mean carbon stock of all other species combined was 22.82 ± 3.95 t/ha in the urban forests of Niamey and 22.49 ± 2.21t/ha in the urban forests in Maradi. There was significant difference in mean carbon stock for neem (26.66 ± 7.64 t/ha) and that of all other species combined (22.82 ± 3.95 t/ha) in Niamey (F-stats = 31.30, p < 0.00, df = 1). Similar observation was made in Maradi, where the mean carbon stock of neem trees carbon stock (34.66 ± 10 t/ha**)** was significantly higher than the mean of all other species (22.49 ± 2.21) (F-stats = 26.35, p = 0.00 df = 1). Neem trees constituted 54% and 61% of carbon stocks in urban forests of Niamey and Maradi respectively. The difference was not statistically significant i.e. higher carbon stocks were not associated with neem trees in urban forests of Maradi compared with those in Niamey (X^2 = 0.5115, p = 0.47).

In Niamey, commercial areas had the highest neem trees carbon stock (67.05.12 ± 27.49 t/ha), which was followed by roads (31.72 ± 6.79 t/ha) (Table 5.3). The reverse trend was observed in Maradi where the highest carbon stock was observed in urban forests along roads 78.02 ± 25.7 t/ha followed by those in commercial areas 64.93 ± 25.5 t/ha. The lowest mean carbon stock was observed in the peri-urban forests in the two cities (Table 5.3). In both cities differences in the level of carbon stocks in neem trees in the sampled urban forests were significant across the different LULC types in Niamey (F-stats = 8.70, p = 0.01, df = 6) in Maradi (F-stats = 9.04, p = 0.01, df = 6).

Table 5.3: Mean (± standard error) of AGB and carbon stocks of neem trees and all other species and their contribution to their carbon stock per land use and land cover types (LULCs) in Niamey and Maradi cities

		Mean AGB (t/ha)		Mean carbon stock (t/ha)		Contributions to the carbon (%)	
Cities	**LULC**	**Neem**	**All other species**	**Neem**	**All other species**	**Neem trees**	**All other species**
Niamey	Administrative areas	23.93 ± 6.17	49.31 ± 6.61	14.04 ± 2.71	28.74 ± 3.85	4	8
Maradi		47.43 ± 11.25	36.78 ± 4.71	27.86 ± 6.61	21.43 ± 2.74	6	5
Niamey	Schools	42.40 ± 18.60	24.67 ± 5.88	24.93 ± 10.94	14.38 ± 3.43	7	4
Maradi		54.76 ± 10.45	37.76 ± 4.80	32.17 ± 6.14	22.01 ± 2.80	8	5
Niamey	Residential areas	50.80 ± 17	26.89 ± 4.34	29.87 ± 9.97	15.67 ± 2.53	8	4
Maradi		30.25 ± 6.55	39.35 ± 5.79	17.77 ± 3.85	22.88 ± 3.37	4	5
Niamey	Roads	54.00 ± 11.60	30.08 ± 3.27	31.72 ± 6.79	17.67 ± 1.92	9	5
Maradi		132.82 ± 43.77	54.34 ± 2.77	78.02 ± 25.7	31.67 ± 1.62	19	7
Niamey	Forested areas	22.78 ± 5.13	6.16 ± 1.53	13.38 ± 3.02	43.77 ± 5.25	3	12
Maradi		28.89 ± 10.60	20.81 ± 2.50	16.97 ± 6.23	12.25 ± 1.47	4	3
Niamey	Commercial areas	114.10 ± 54	97. 30 ± 62.80	67.05 ± 27.49	22.52 ± 5.26	19	6
Maradi		110.5 ± 43.5	44.83 ± 6.01	64.93 ± 25.5	26.12 ± 3.50	16	6
Niamey	Peri-urban forests	9.54 ± 3.41	29.21 ± 6.88	5.6 ± 1.12	17.02 ± 4.01	1	4
Maradi		8.30 ± 5.60	36.13 ± 6.65	4.87 ± 1.40	21.05 ± 3.87	1	5
Niamey	Overall	45.37 ± 12.64	37.70 ± 11.0	26.66 ± 7.64	22.82 ± 3.95	54	46
Maradi		59.00 ± 17.29	38.60 ± 3.82	34.66 ± 10	22.49 ± 2.21	61	39
Niamey	P-values	-	-	0.01	0.00		
Maradi		-	-	0.01	0.00		

5.4 Discussion

The study shows a widespread planting of neem in urban forests in the two cities relative to other species. Many factors may account for this but the diversity of ecosystem services provided by the neem trees as reported elsewhere (Raj *et al.*, 2013; Ezzat *et al*., 2018; Shareef *et al*., 2018) seems to connect well with the socio-economic and environmental needs of the people of the two cities leading to its widespread planting. Other factors that could account for the abundance of the species include seed availability, fast growth and adaptability to harsh environmental conditions as observed by (Bohre *et al.*, 2016) that neem trees perform better in the anthropogenic environment. The massive use of neem trees in the two cities for urban greening programs during colonial and post-colonial administration such as Operation Green Sahel and National Tree Day for fighting desertification may all contribute to the widespread abundance of the species.

Land use/ land cover was found to influence the density of neem trees within the urban forests of the two cities. The variation in neem density across the land use/land cover types may be a reflection of the species preferences of tree planters in the various LULC types. For instance, where private individuals are in charge of tree planting such as in residential areas they are probably more likely to plant more neem trees than other species because of its multiple uses. On the other hand, in situations where the choice of species is made by public officers, e.g. administrative areas, the desire to plant neem because of its multiple uses may be low. This may explain why for example the percentage of neem trees in urban forests in residential areas was 54 in Niamey and 47.2 in Maradi whilst for administrative areas corresponding figures were 29% and 42%. Urban forests along roads were found to be associated with high neem tree density although city authorities rather than individuals are likely to be in charge of tree planting here. This observation is an indication of the worth of neem trees as avenue trees in cities.

Neem is an evergreen species and a has a wide crown (Raj *et al.*, 2015) thus possessing two important characteristics of species suitability for shade trees. Hungerford and Moussa (2017) reported that city authorities protect neem trees along roads in Niger to enhance its role. It is also important to note that the high neem tree density along roads may be an asset to mitigate urban air pollution, as neem was found to be the most tolerant species and suitable as a sink for air pollution in Nagpur City (Dhadse *et al.*, 2011).

The results showed no significant differences in relative abundance of neem trees between Niamey and Maradi. This was despite the differences in the political/administrative status of the cities as well as the socio-economic status of their populations. For instance, Maradi is dominated with the indigenous people, which may use neem trees for other services such as wood products and medicine while Niamey has more elites, who may prefer other species for different services other than neem. The study showed that neem tree is also present in the essentially semi-natural peri-urban forests which confirmed the findings that reported the presence of neem trees in agroforestry parklands in Maradi region in Niger (Moussa *et al.*, 2016). This may be the beginning of the invasion of agroforestry parklands by neem trees in Niger a phenomenon which has been observed in forest fragments of Southern Togo (Radji *et al.*, 2010). This calls for the attention of conservationists working on invasive species in the country.

Knowing the stand carbon stocks of urban forest is important for urban land use planning that integrates climate change mitigation. The present study shows high values of neem tree carbon stocks; which vary in Niamey and Maradi with the LULC. Land use and land cover types were found to be a driver of carbon stocks variation elsewhere (Seidl *et al.*, 2012). The high levels in carbon stocks may be due to the structural characteristics of neem trees in the urban forests of the two cities. Jagodzinki *et al*. (2018) in their study reported that forest structure influenced carbon stocks density. Related to the structural characteristics is the age of the forest such that old forest with large trees stores high levels of carbon (Kohl *et al*., 2017). Some of the neem trees in the study areas were planted way back in the pre-independence era, i.e. before 1960, with some dating back as far as 1916 (Yacouba, 1999). It was observed that neem trees with diameter > 40 cm held the highest AGB even though they were few in terms of the number of stems. This agrees with results of (Nero and Callo-concha, 2018) who found that the trees with the large diameter dominated the carbon biomass reservoir in Kumasi. It also confirms the findings of Udayakumar *et al*. (2011) who reported that the vegetation biomass is influenced to a large extent by tree size. Since the present study demonstrates the importance of big diameter trees in biomass accumulation in both cities, the preservation of existing neem trees should be encouraged. In general, the mean carbon stock values reported for neem in this study are similar to those reported by Majumdar and Selvan (2018) for the same species in urban and peri-urban forests of Agartala, Tripura. The neem tree carbon stocks estimates provided in the study shows the important role of urban trees in climate change mitigation as pointed out by (Weissert *et al*., 2014; Chen, 2015).

The findings show that the amount of carbon stored in neem trees in the cities' urban forests is comparable to the carbon stored in all other species combined implying neem stores more carbon than any other species in the cities. This indicates how the use of particular tree species such as neem by the urban community could influence carbon storage. This makes neem trees superior to the other species in the two cities in terms of carbon storage. Conserving and expanding the population of neem trees in sahelian cities can, therefore, improve carbon stocks in cities and contribute to climate change mitigation. The results are similar to those of Kirby and Potvin (2007) who found out that the mango tree was the top-ranked species in an agroforestry system in terms of abundance and carbon stocks in the tierra colectiva of Ipetı´-Embera´ in eastern Panama Province, Panama. Similar studies demonstrating the superiority of individual species in carbon storage in various land uses are rare. For this reason, it is essential to build data on multipurpose trees and their effect on carbon stocks across different land uses. This can be used to promote carbon stocks enhancement especially in systems like urban forests and agroforestry where the use of multipurpose trees is most of the time a priority.

5.5 Conclusions

The study showed that neem trees in Niamey and Maradi store a considerable and variable amount of carbon across urban land use and land cover types. Neem tree species has a high structural value (Basal area, canopy cover and stem density) and stores more carbon than all other species in the cities' urban forests. The neem tree's carbon stocks in Niamey and Maradi should be taken into account during urban land use planning for carbon conservation and carbon stocks enhancement, which are key to atmospheric CO_2 reduction. The findings complement the international tree carbon dataset and reference level from Sahel city for climate change mitigation.

CHAPTER 6: GENERAL DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

6.1 General Discussion

Urban forests play many roles critical to the development of sustainable cities. Many studies have reported the role of urban forests in biodiversity conservation and climate change mitigation across the world (Konijnendijk *et al.*, 2004; Kühn, Brandl *et al*., 2004; Elmqvist *et al.*, 2013; Chen, 2015; Nero and Callo-concha, 2018). The present study adds more information to the wealth of knowledge available on this subject area by determining the differences in diversity and stand structure of urban forests in two important cities in the sahelian zone as well as across land use and land cover types in the cities. In addition, the study provided information on the carbon stocks of the urban forests and carbon emission factors in the two cities across the land use and land cover types.

The study revealed high woody species diversity in the two cities which confirmed the findings of Gillespie *et al*. (2017); Ortega-Álvarez *et al*. (2011) and Pickett *et al*. (2001) who reported that urban areas are home to woody species diversity. This emphasizes the relevance of cities in the conservation of woody species.

Biodiversity in urban forests has been identified as an important indicator of urban sustainability, as it contributes to urban people's well-being in many ways including food, medicine and shelter (Gaston *et al*., 2013; du Toit *et al.*, 2018). The present study showed that urban forests diversity and structure varied significantly across land use/land cover types in Niamey and Maradi. A notable observation was the fact that residential areas had higher species diversity and evenness than other LULC types with peri-urban forests recording the least in these indices. This confirms the observation of Hungerford and Moussa (2017) that the household is a driver of woody species diversity. Therefore, in developing sustainable cities the participation of individual households in tree planting becomes important due to the influence they exercise on species choice, and by extension, biodiversity. It can also be said from the results that the conversion of peri-urban forests into urban forests located in the other LULC types may result in improved species diversity in cities. This implies urban forests can be used to mitigate some of the losses associated with urban expansion.

Urbanization is one of the causes of urban heat island. Several studies (Akbari, 2002; Mcpherson *et al.*, 2005; Bowler *et al.*, 2010) have demonstrated that urban forests mitigate urban heat island and provide microclimate to urban biodiversity. In addition to that, urbanized areas go with more use of vehicles, which may lead to CO_2 release and air pollution. But urban forests are important to mitigate CO_2 and air pollution (Nowak and Crane, 2002; Nowak *et al.*, 2017) and provide more liveable urban areas which can enhance urban people's comfort (Lu, 2018) and reduce mental stresses (McMorris *et al.*, 2015).

Vegetation structure is critical to understanding the ecology of urban forests. Trees were the dominant growth form in Niamey and Maradi where most of the woody species are planted for shade and tree products (Illiassou *et al.*, 2016). The high number of trees and shrubs found in the two cities may be attributed to the national urban afforestation projects such as the public urban green spaces, private plantations and urban tree plantations and during National Arbour days that began in 1974 (Hungerford and Moussa, 2017). The high number of trees found in the urban forests have implications for climate change mitigation benefits. Stem density and basal area determined in this study were higher than values reported for parklands in Niger (Moussa *et al.*, 2016). This indicates the high tree density achieved by urban afforestation programs in Niger.

Fabaceae was the dominant family in both cities. The family *Fabaceae* is widespread in semi-arid areas on a wide range of soils and climate (Mudzengi *et al.*, 2014) and this may explain its abundance in the cities. The dominance of *Fabaceae* is a good proxy for overall angiosperm diversity in many habitats (Raes *et al*., 2013). Furthermore, on the list of *Fabaceae* of this study, there were some multipurpose species such as *Faidherbia albida, Tamarindus indica*, *Acacia senegal*, *Dialium guineense, Parkia biglobosa, and Acacia species*. This dominance could be due the socio-economic importance of those species in terms of food production, medicines and forage among others, and the introduction of exotic *Fabaceae* species used in urban greening in Niamey and Maradi such as *Senna siamea*, *Prosopis juliflora*, *Dalbergia sissoo, Delonix regia* etc. For instance, from the field discussion, a respondent said that the fruits of *Delonix regia* are used for firewood in Maradi city. Woody plants contribute significantly to atmospheric CO_2 uptake but their capacity to capture CO_2 may be constrained by nitrogen (Batterman *et al.*, 2013). This dominance is also important because *Fabaceae* affects carbon sequestration indirectly by providing nitrogen in the ecosystem which helps non-nitrogen fixing species to grow better and hence fix more carbon and in general food production. Trees species of *Fabaceae* are also found to be dominant in agroforestry systems in Niger (Moussa, 2013).

The present study revealed the predominance of exotic species in the two Sahelian cities of Niger which was consistent with previous studies on urban forests across the world (Akbar *et al*., 2014). This predominance represents a threat to the local woody flora as it leads to the biotic homogenisation of the urban and peri-urban forests (Mckinney, 2006). For instance, the neem tree was the dominant species in the two cities representing more than 40% of the total recorded species. This is against the general rule about tree species diversity in urban areas in some of the countries with good urban forestry planning to the effect that no tree species in urban areas should exceed more than 10% of the total woody flora (Akbar *et al*., 2014) in order to reduce various threats such as pest attack. From this viewpoint, the high percentage of neem trees in the two cities indicates high susceptibility to pests and diseases. There is therefore a need to regulate the use of exotic tree species and educate urban people about their advantages and disadvantages in urban areas. From the perspective of forest utilisation, the predominance of the exotic species may be an indication of the fact that they provide several services to the urbanites (Riley *et al*., 2018). Discouraging their use in future tree planting may therefore be challenging unless the alternative native species also have multiple uses. The exotics also play a role in the diversity of urban forests (Riley *et al*., 2018) despite their negative impact on conservation. In this study, the 60 exotic species encountered might have had significant impact on the biodiversity indices.

According to Davies *et al*. (2011) the high number of exotics in urban forests could probably be explained by the informal way through which urban afforestation programmes are undertaken. In the present study, the role of the informal mechanism in species choice can be seen as residential areas tended to be associated more with exotic species. However, it is also true that some formal tree planting programmes such as Operation Green Sahel and National Tree Day have promoted the use of exotic species particularly neem in urban forests (Ministère de l'Environnement du Niger, 2010) .

Many studies have reported that urban forests present an opportunity to attenuate climate change (Akbari, 2002; Nowak *et al.*, 2013b; Weissert *et al*., 2014). The present study also proved that Sahel cities in Niger have appreciable levels of carbon stocks in their urban forests. This highlights the role of Sahelian urban forests in promoting sustainable cities through the provision of many ecosystem services including carbon storage and therefore climate change mitigation. Urban forestry in Niger dates back to the colonial times when climate change was not yet an environmental issue hence the role of urban forests in climate change may be accidental rather than planned. Therefore, to make urban forests more effective in climate change mitigation, there should be proper integration of climate change and biodiversity enhancement objectives and strategies into urban forestry planning. For instance, the observation that 66.36% of urban forest carbon stock is held in trees with DBH > 40 cm should provide guidance as to what species to promote for enhanced carbon storage.

6.2. Conclusions

The study was carried out to address four specific research objectives with the aim of providing insight into the role of urban forests in biodiversity conservation and climate change mitigation through woody species assemblage and carbon stocking in two Sahel cities in Niger. These objectives have been achieved and the following conclusions drawn.

6.2.1 Conclusions for Objective One

The cities' urban forests are rich in woody species diversity; they had a total of 115 species belonging to 82 genera in 35 families on 50.95 ha of land. Nonetheless, the conservation value of the forest is of concern as more than half of the woody flora population is made up of individuals of exotic origin. There were more trees than shrubs and *Fabaceae* was the dominant family for both life forms. Maradi (the smaller city with 86 km^2) had better urban forests than Niamey in terms of species richness, evenness, tree density and canopy cover. The location of urban forests within the cities had influence on the species composition and basic stand structure of the forests with residential areas having higher species richness than other LULC types; suggesting residents of the two cities have influence on the urban forests. The results provide a baseline against which future assessments and monitoring can be done.

6.2.2 Conclusions for Objective Two

The study demonstrated that urban forests in Niamey and Maradi are carbon sinks. The Carbon stock varied significantly with urban land use and land cover types in the two cities. Urban forests store more carbon than peri-urban agroforestry systems around the cities. Exotic species contribution about 65% to the total carbon stocks in the two cities. Large woody species with DBH above 40 cm were the leading classes in terms of AGB. The conversion of the peri-urban agroforestry to urban forests results in carbon gain. This study showed that urban forests in Niamey and Maradi are carbon sinks, which should be integrated in the national biomass carbon inventory.

6.2.3 Conclusions for Objective Three

The study showed that neem tree is a leading species in terms of carbon stock across the LULC in the two cities. This highlights the role of multi-purpose tree species in urban forests carbon stocks, which can be an opportunity for long-term storage. This information is essential for sustainable carbon management of urban forests in Niger. The results of the study serves as a baseline of carbon storage for future monitoring. Further attention should be given to the other species also in terms of carbon storage because the high percentage of neem tree observed in the two cities may lead to susceptibility to pests and diseases. This can affect the carbon conservation. The study recommends that neem trees urban forests should be included in national carbon inventory.

6.3 Recommendations

6.3.1. Recommendations for further Research

- Carbon sequestration studies in urban ecosystems should be extended beyond that of urban forests to urban soils, waste and herbaceous vegetation.
- Ecosystem services provision of urban forest and herbaceous enclaves need in-depth studies to include habitat for animal biodiversity and their socio-economic and environmental impacts on existing populations.
- There is need to study the socio-economic drivers of urban forest development and degradation including the role of gender.

6.3.2 Recommendations for Policy

- The national biodiversity report of Niamey and Maradi should include their urban forest woody biodiversity.
- The urban forest carbon stocks of Niamey and Maradi should be taken into account in the country's climate change mitigation policy and greenhouse gases inventory report to the UNFCCC.
- Urban forests forming green belts in the cities should be sustainably managed and used for recreational purposes to generate income for urban forestry development.
- The preservation of existing neem trees and trees with large diameter (BDH > 40 cm) should be encouraged;
- The study recommends that role of urban trees, particularly neem in sequestering carbon should be included in national carbon inventory.

- The indigenous woody species particularly multipurpose species should be prioritized in urban forestry in the two cities especially in schools for young people's education for biodiversity and climate change education.
- The adapted and multipurpose exotic species should be used with caution in order to avoid invasion.

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APPENDICES

Appendix 1: Description of Urban forest types in Niamey and Maradi

a. Roadside *Khaya senegalensis* in Maradi b. Roadside *Khaya senegalensis* in Niamey

c. Green space in Niamey as source of dumping refuses d. Sékou Touré green space in Maradi

a. Peri-urban forests in Maradi f. Peri-urban forests in Niamey

g. School urban forests in Maradi h. School urban forests in Niamey

i. Commercial area urban forests j. Commercial area urban forests

k. *Acacia senegal* in residential area urban forests in Maradi

for arabic gum production.

l. A planted *Tamarindus indica* in residential area urban forests in Niamey for tamarin

production.

m. Administrative area urban forests in Maradi n. Administrative area urban forests in

Niamey.

Appendix 2: List of mean AGB per species all over the cities

Species	Maradi	Niamey
Acacia holosericea A. Cunn. ex G. Don	0.00012	0.0007
Acacia senegal (L.) Willd.	0.0079	0.0426
Adansonia digitata L.	0.2894	0.1609
Adenium obesum (Forssk.) Roem.	0.0074	
Albizia chevalieri Harms	0.0048	
Albizia lebbeck (L.) Benth.	0.5832	0.0697
Anacardium occidentale L.		0.0072
Annona muricata L.	0.0008	
Annona senegalensis Pers.	0.0032	0.0002
Annona squamosa L.	0.0313	0.0000
Anogeissus leiocarpus (DC.) Guill. & Perr.	0.0000	0.0032
Azadirachta indica A. Juss.	28.7274	19.0648
Balanites aegyptiaca (L.) Del.	1.3327	2.4758
Bambusa vulgaris Schrad. Ex J.C.Wendl.		0.0333
Bauhinia monandra Kurz	0.0003	
Bauhinia rufescens Lam.	0.1044	0.0043
Blighia sapida Koenig	0.0264	0.0178
Borassus aethiopum Mart.	0.1071	0.0959
Boscia angustifolia A. Rich.		0.0084
Boscia salicifolia Oliv.	0.0552	
Boswellia dalzielii Hutch.	0.0014	
Boswellia papyrifera (Del.) A. Rich.	0.0096	
Bougainvillea spectabilis Willd	0.0033	
Calliandra brevipes Benth.	0.0003	
Calotropis procera (Ait.) Ait. f.	0.0071	0.0129
Caesalpinia pulcherrima (L.) Sw.	0.0003	0.0002
Cassia sieberiana DC.		0.0037
Casuariana equisefolia Forst.		0.0107
Ceiba pentandra (L.) Gaertn.	0.5383	0.2279
Citrus grandis (L.) Osbeck	0.0384	0.0008
Citrus limon (L.) Burm. f.	0.1124	0.0067
Citrus reticulata Blanco	0.0092	

Citrus sinensis (L.) Osbeck	0.0162	
Cola cordifolia (Cav.) R. Br.		0.0020
Combretum glutinosum Perr. ex *DC.*	0.0063	0.2957
Combretum nigricans Lepr. ex Guill. et Perr.		0.0264
Commiphora africana (A. Rich.) Engl.	0.0041	
Dalbergia sissoo Roxb.	0.0454	0.1591
Daniellia oliveri (Rolfe) Hutch. & Dalz	0.0015	
Delonix regia (Boj.) Raf.	0.2848	0.0599
Dialium guineense Willd.		0.0650
Diospyros mespiliformis Hochst. ex A. Rich.	0.0765	0.0226
Duranta repens Linn.		0.0003
Eucalyptus camaldulensis Dehnh.	0.7946	0.8041
Euphorbia balsamifera Ait.	0.0086	0.0033
Euphorbia kamerunica Pax	0.0182	
Faidherbia albida (Del.) Chev.	2.6053	6.4268
Ficus benjamina L.		0.0635
Ficus elastica Roxb. ex Hornem.	0.0015	
Ficus platyphylla Del.	0.0533	0.0800
Ficus sycomorus ssp. gnaphalocarpa (Miq.) C.C. Berg	0.1997	0.0175
Ficus thonningii Blume	0.0500	0.0224
Gardenia erubescens Stapf & Hutch.	0.0002	
Gliricidia sepium (Jacq.) Walp.	0.0049	0.0120
Gmelina arborea Roxb.	0.3401	0.1724
Grewia bicolor Juss.	0.0000	0.0042
Guiera senegalensis J.F. Gmel.	0.0046	
Hura crepitans L.	0.0036	
Hyphaene thebaica (L.) Mart.	0.0831	0.1226
Jatropha curcas L.	0.0006	0.0001
Jatropha gossypiifolia L.	0.0001	
Khaya senegalensis (Desr.) A. Juss	2.0786	4.9302
Kigelia africana (Lam.) Benth.	0.1398	0.0702
Lannea microcarpa Engl. & K. Krause	0.0418	0.0321
Lawsonia inermis L.	0.0112	0.0007
Leucaena leucocephala (Lam.) de Wit	0.0684	0.0510

Maerua angolensis DC.		0.0081
Maerua crassifolia Forssk.	0.0405	0.0028
Mangifera indica L.	0.7400	0.9367
Melia azedarach L.		0.0117
Mitragyna inermis (Willd.) Kuntze	0.0078	
Moringa oleifera Lam.	0.0071	0.0032
Moringa stenopetala Baker f.	0.0424	0.0246
Neocarya macrophylla (Sabine) Prance	0.0060	
Newbouldia laevis (P. Beauv.) Seem.	0.0137	
Parkia biglobosa (Jacq.) R. Br. ex G. Don	0.0277	0.0295
Parkinsonia aculeata L.	0.0015	0.0009
Phoenix dactylifera L.	0.0560	
Phoenix reclinata Jacq.	0.0513	
Piliostigma reticulatum (DC.) Hochst.	0.1260	0.0284
Pithecellobium dulce (Roxb.) Benth.	0.0701	0.0037
Plumeria rubra L.	0.0131	0.0088
Polyalthia longifolia. Sonn	0.0199	0.0003
*Prosopis africana (*Guill. & Perr.) Taub.	0.7081	
Prosopis juliflora (Sw.) DC.	0.7420	0.3231
Psidium guajava L.	0.0156	0.0012
Punica granatum L.	0.0049	0.0011
Sclerocarya birrea (A. Rich.) Hochst.	0.2365	0.1153
Senna siamea (Lam.) Irwin & Barneby	0.5093	0.3633
Senna singueana (Del.) Lock	0.0356	
Sterculia setigera Del.	0.0002	
Syzygium guineense (Willd.) DC.	0.0285	0.0498
Syzygium malaccense (L.) Merr. & L.M.Perry		0.0035
Tamarindus indica L.	0.0966	0.0403
Tectona grandis L. f.		0.0012
Terminalia catappa L.	0.0910	0.0106
Terminalia mantaly H. Perrier	3.2394	1.9058
Thevetia neriifolia Juss.	0.0029	0.0000
Vachellia nilotica subsp. Nilotica	0.5138	0.1373
Vachellia seyal (Delile) P.J.H.Hurter	0.0048	0.1520

Vachellia sieberiana (DC.) Kyal. & Boatwr.		0.0003
Vachellia tortilis(Forssk.) Galasso & Banfi	0.2095	0.4736
Vitellaria paradoxa Gaertn. f.	0.0066	0.0058
Vitex doniana Sweet	0.0203	0.0849
Vitex simplicifolia Oliv.	0.0407	0.0004
Ziziphus mauritiana Lam.	0.1354	0.0517
Ziziphus mucronata Willd		0.0636
Ziziphus spina-christi (L.) Desf.	0.4683	

Appendix 3: Species inventoried in Niamey and Maradi.

No	Species	Families	Niamey Inner city forest	Maradi Inner city forest	Per-urban Niamey	Peri-urban Maradi	Total	Origin
1	*Acacia holosericea*. Cunn. ex G. Don	*Fabaceae*	3			3	6	Exotic
2	*Acacia senegal* (L.) Willd.	*Fabaceae*	68	5	13		86	Native
3	*Adansonia digitata* L.	*Bombacaceae*	15	26	1	3	45	Native
4	*Adenium obesum* (Forssk.) Roem.	*Apocynaceae*		6			6	Exotic
5	*Albizia chevalieri* Harms	*Fabaceae*		7			7	Native
6	*Albizia lebbeck* (L.) Benth.	*Fabaceae*	5	35			40	Exotic
7	*Anacardium occidentale* L.	*Anacardiaceae*	3				3	Exotic
8	*Annona muricata* L.	*Annonaceae*		1			1	Exotic
9	*Annona senegalensis* Pers.	*Annonaceae*	1	5	7	5	18	Native
10	*Annona squamosa* L.	*Annonaceae*		21			21	Exotic
11	*Anogeissus leiocarpus* (DC.) Guill. &Perr.	*Combretaceae*	1				1	Native
12	*Azadirachta indica* A. Juss.	*Meliaceae*	854	1364	12	23	2253	Exotic
13	*Balanites aegyptiaca* (L.) Del.	*Balanitaceae*	161	63	57	6	287	Native
14	*Bambusa vulgaris* Schrad. Ex J.C.Wendl.	*Poaceae*	1				1	Exotic
15	*Bauhinia monandra* Kurz	*Fabaceae*		1			1	Exotic
16	*Bauhinia rufescens* Lam.	*Fabaceae*	7	20			27	Native
17	*Blighia sapida* Koenig	*Sapindaceae*	2	17			19	Exotic
18	*Borassus aethiopum* Mart.	*Arecaceae*	3	3			6	Native
19	*Bombax costatum* Pellegr. & Vuillet	*Bombacaceae*				1	1	Native
20	*Boscia angustifolia* A. Rich.	*Capparaceae*	2				2	Native
21	*Boscia salicifolia* Oliv.	*Capparaceae*		2			2	Native
22	*Boswellia dalzielii* Hutch.	*Burseraceae*		2			2	Native
23	*Boswellia papyrifera* (Del.) A. Rich.	*Burseraceae*		3			3	Native
24	*Bougainvillea spectabilis* Willd	*Nyctaginaceae*		1			1	Exotic
25	*Caesalpinia pulcherrima* (L.) Sw.	*Fabaceae*	1	1			2	Exotic

26	*Calliandra brevipes* Benth.	*Fabaceae*		1			1	Exotic
27	*Calotropis procera* (Ait.) Ait. f.	*Asclepiadaceae*	5	10		2	17	Native
28	*Cassia sieberiana* DC.	*Fabaceae*	3				3	Native
29	*Casuariana equisefolia* Forst.	*Casuarianaceae*	9				9	Exotic
30	*Ceiba pentandra* (L.) Gaertn.	*Bombacaceae*	5	4			9	Native
31	*Citrus grandis* (L.) Osbeck	*Rutaceae*	2	3			5	Exotic
32	*Citrus limon* (L.) Burm. f.	*Rutaceae*	14	29			43	Exotic
33	*Citrus reticulata* Blanco	*Rutaceae*		3			3	Exotic
34	*Citrus sinensis* (L.) Osbeck	*Rutaceae*		4			4	Exotic
35	*Cola cordifolia* (Cav.) R. Br.	*Sterculiaceae*	1				1	Exotic
36	*Combretum glutinosum* Perr. ex DC.	*Combretaceae*	9	2	15	5	31	Native
37	*Combretum nigricans* Lepr. ex Guill. et Perr.	*Combretaceae*	1		3		4	Native
38	*Combretum aculeatum* Vent.	*Combretaceae*			2		2	Native
39	*Commiphora africana* (A. Rich.) Engl.	*Burseraceae*		1			1	Native
40	*Dalbergia sissoo* Roxb.	*Fabaceae*	12	3			15	Exotic
41	*Daniellia oliveri* (Rolfe) Hutch. & Dalz	*Fabaceae*		1			1	Native
42	*Delonix regia* (Boj.) Raf.	*Fabaceae*	4	14			18	Exotic
43	*Dialium guineense* Willd.	*Fabaceae*	2				2	Native
44	*Diospyros mespiliformis* Hochst. ex A. Rich.	*Ebenaceae*	7	13			20	Native
45	*Duranta repens* Linn.	*Verbenaceae*	1				1	Exotic
46	*Eucalyptus camaldulensis* Dehnh.	*Myrtaceae*	37	51	2		90	Exotic
47	*Euphorbia balsamifera* Ait.	*Euphorbiaceae*	3	1		3	7	Native
48	*Euphorbia kamerunica* Pax	*Euphorbiaceae*		1			1	Exotic
49	*Faidherbia albida* (Del.) Chev.	*Fabaceae*	79	35	27	26	167	Native
50	*Ficus benjamina* L.	*Moraceae*	6				6	Exotic
51	*Ficus elastica* Roxb. ex Hornem.	*Moraceae*		1			1	Exotic
52	*Ficus platyphylla* Del.	*Moraceae*	10	8			18	Native
53	*Ficus sycomorus* ssp. g*naphalocarpa* (Miq.) C.C. Berg	*Moraceae*	4	9			13	Native

54	*Ficus thonningii* Blume	*Moraceae*	1	4			5	Native
55	*Gardenia erubescens* Stapf & Hutch.	*Rubiaceae*		2			2	Native
56	*Gliricidia sepium* (Jacq.) Walp.	*Fabaceae*	2	3			5	Exotic
57	*Gmelina arborea* Roxb.	*Verbenaceae*	20	18	1		39	Exotic
58	*Grewia bicolor* Juss.	*Malvaceae*	2				2	Native
59	*Guiera senegalensis* J.F. Gmel.	*Combretaceae*		6	4	2	12	Native
60	*Stereospermum kunthianum* Cham.	*Bignoniaceae*				2	2	Native
61	*Hura crepitans* L.	*Euphorbiaceae*		2			2	Exotic
62	*Hyphaene thebaica* (L.) Mart.	*Arecaceae*	19	3	5	8	35	Native
63	*Jatropha curcas* L.	*Euphorbiaceae*	1	2			3	Exotic
64	*Jatropha gossypiifolia* L.	*Euphorbiaceae*		1			1	Exotic
65	*Khaya senegalensis* (Desr.) A. Juss	*Meliaceae*	74	14	1		89	Native
66	*Kigelia africana* (Lam.) Benth.	*Bignoniaceae*	7	8			15	Native
67	*Lannea microcarpa* Engl. & K. Krause	*Anacardiaceae*	5	8			13	Native
68	*Lawsonia inermis* L.	*Lythraceae*	4	5			9	Exotic
69	*Leucaena leucocephala* (Lam.) de Wit	*Fabaceae*	10	16			26	Exotic
70	*Maerua angolensis* DC.	*Capparaceae*	1				1	Native
71	*Maerua crassifolia* Forssk.	*Capparaceae*	4	3	1	3	11	Native
72	*Neocarya macrophylla* (Sabine) Prance	*Chrysobalanaceae*			22		22	Native
73	*Mangifera indica* L.	*Anacardiaceae*	73	61			134	Exotic
74	*Melia azedarach* L.	*Meliaceae*	2	1			3	Exotic
75	*Mitragyna inermis* (Willd.) Kuntze	*Rubiaceae*		1			1	Native
76	*Moringa oleifera* Lam.	*Moringaceae*	9	21			30	Exotic
77	*Moringa stenopetala* Baker f.	*Moringaceae*	4	14			18	Exotic
78	*Newbouldia laevis* (P. Beauv.) Seem.	*Bignoniaceae*		2			2	Exotic
79	*Parkia biglobosa* (Jacq.) R. Br. ex G. Don	*Fabaceae*	1	12			13	Native
80	*Parkinsonia aculeata* L.	*Fabaceae*	1	4			5	Exotic
81	*Phoenix dactylifera* L.	*Arecaceae*		5			5	Native
82	*Phoenix reclinata* Jacq.	*Arecaceae*		1			1	Native

83	*Piliostigma reticulatum* (DC.)Hochst.	*Fabaceae*	4	22	1	9	36	Native
84	*Pithecellobium dulce* (Roxb.) Benth.	*Fabaceae*	1	2			3	Exotic
85	*Plumeria rubra* L.	*Apocynaceae*	4	5			9	Exotic
86	*Polyalthia longifolia*. Sonn	*Annonaceae*	2	5			7	Exotic
87	*Prosopis africana* (Guill. &Perr.) Taub.	*Fabaceae*		22		8	30	Native
88	*Prosopis juliflora* (Sw.) DC.	*Fabaceae*	23	35	5		63	Exotic
89	*Psidium guajava* L.	*Myrtaceae*	6	8			14	Exotic
90	*Punica granatum* L.	*Punicaceae*	4	11			15	Exotic
91	*Sclerocarya birrea* (A. Rich.) Hochst.	*Anacardiaceae*	7	15		2	24	Native
92	*Senna siamea* (Lam.) Irwin & Barneby	*Fabaceae*	45	24	1		70	Exotic
93	*Senna singueana* (Del.) Lock	*Fabaceae*		2			2	Native
94	*Sesbania sesban* (L.) Merrill	*Fabaceae*	1				1	Native
95	*Sterculia setigera* Del.	*Sterculiaceae*		1		4	5	Native
96	*Syzygium guineense* (Willd.) DC.	*Myrtaceae*	7	9			16	Exotic
97	*Syzygium malaccense* (L.) Merr. & L.M.Perry	*Myrtaceae*	1				1	Exotic
98	*Tamarindus indica* L.	*Fabaceae*	4	13	1		18	Native
99	*Tapinanthus dodoneifolius* (DC.)	*Loranthaceae*			2		2	Native
100	*Tectona grandis* L. f.	*Verbenaceae*	1				1	Exotic
101	*Terminalia catappa* L.	*Combretaceae*	8	23			31	Exotic
102	*Terminalia mantaly* H. Perrier	*Combretaceae*	107	104	1		212	Exotic
103	*Thevetia neriifolia* Juss.	*Apocynaceae*	2	7			9	Exotic
104	*Vachellia nilotica* subsp. *nilotica*	*Fabaceae*	11	66	7	4	88	Native
105	*Vachellia seyal* (Delile) P.J.H.Hurter	*Fabaceae*	50	11		5	66	Native
106	*Vachellia sieberiana* (DC.) Kyal. & Boatwr.	*Fabaceae*	1				1	Native
107	*Vachellia tortilis* (Forssk.) Galasso & Banfi	*Fabaceae*	1		5		6	Native
108	*Vitellaria paradoxa* Gaertn. f.	*Sapotaceae*	1	1			2	Native
109	*Vitex doniana* Sweet	*Verbenaceae*	19	5			24	Native
110	*Vitex simplicifolia* Oliv.	*Verbenaceae*	1	14			15	Native

111	*Vitex trifolia* L.	*Verbenaceae*	2				2	Exotic
112	*Volkameria inermis* L.	*Lamiaceae*	1				1	Exotic
113	*Ziziphus mauritiana* Lam.	*Rhamnaceae*	33	14	6	2	55	Native
114	Ziziphus mucronata Willd	*Rhamnaceae*	7				7	Native
115	*Ziziphus spina-christi* (L.) Desf.	*Rhamnaceae*		10		3	13	Native
	Total		1935	2423	202	129	4689	

The values indicate the number of individuals per species