TREE SPECIES DIVERSITY AND QUANTIFICATION OF ABOVE GROUND CARBON STORAGE OF ROOFTOP GARDEN IN DHAKA CITY

MD. TANVIR ZUBAYER

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE

SHER-E-BANGLA AGRICULTURAL UNIVERSITY

DHAKA-1207

JUNE, 2020

TREE SPECIES DIVERSITY AND QUANTIFICATION OF ABOVE GROUND CARBON STORAGE OF ROOFTOP GARDEN IN DHAKA CITY

BY

MD. TANVIR ZUBAYER

REGISTRATION NO. 13-05533

A Thesis
Submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka
in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE
IN
AGROFORESTRY & ENVIRONMENTAL SCIENCE

SEMESTER: JANUARY-JUNE, 2020

APPROVED BY:

Dr. Md. Forhad Hossain **Professor** **Supervisor**	**Md. Shariful Islam** **Assistant Professor** **Co-supervisor**

Dr. Jubayer-Al-Mahmud
Chairman
Examination Committee

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

*This is to certify that the thesis entitled "**TREE SPECIES DIVERSITY AND QUANTIFICATION OF ABOVE GROUND CARBON STORAGE OF ROOFTOP GARDEN AT DHAKA CITY**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **Master of Science in Agroforestry and Environmental Science**, embodies the result of a piece of bona fide research work carried out by **Md. Tanvir Zubayer**, Registration number: **13-05533** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has duly been acknowledged.

Dated: June, 2020

Place: Dhaka, Bangladesh

Dr. Md. Forhad Hossain
Professor
Supervisor

DEDICATED

TO

MY BELOVED PARENTS

ACKNOWLEDGEMENTS

First of all, I express my best gratitude to Almighty Allah for His never-ending blessing to complete this work successfully. It is a great pleasure to express profound thankfulness to my respected parents, who entitled much hardship inspiring for prosecuting my studies, thereby receiving proper education.

I would like to express my earnest respect, sincere appreciation and enormous indebtedness to my reverend Supervisor ***Prof. Dr. Md. Forhad Hossain****, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, for his scholastic supervision, helpful commentary and unvarying inspiration throughout the research work, and preparation of the thesis.*

I wish to express my gratitude and best regards to my respected Co-Supervisor, ***Md. Shariful Islam****, Assistant Professor, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, for his continuous direction, constructive criticism, encouragement and valuable suggestions in carrying out the research work and preparation of this thesis.*

I am also highly grateful to my honorable Chairman, ***Dr. Jubayer-Al-Mahmud****, Associate Professor, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, for his valuable teaching, direct and indirect advice, and encouragement and co-operation during the study period.*

I feel to express my heartfelt thanks to all the teachers of the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University Dhaka-1207, for their valuable suggestions and encouragement during the period of the study.

I would like to thank Zannatul Sifat Rumky, Washim Hossain, Md. Muktar Ahmed, Mahmudul Hassan Munna, Saiful Islam, Zahid Khan, Tofayel Ahmed linkon and Nahidul Islam who have helped me so much throughout the research work and preparation of the thesis.

I also wish to extend sincere gratitude to the Ministry of Science and Technology, Government of the People's Republic of Bangladesh for providing me financial support to conduct the research.

I found no word to thank my mother Tahmina Khatun, father Md. Moniruzzaman, Sister Misha Nushrat for their indefinable love and continuous support, their sacrifice never ending affection, immense strength and untiring efforts for bringing my dream to proper shape. They are my constant source of inspiration, zeal and enthusiasm in the critical moment of my studies.

June, 2020 ***The Author***
SAU, Dhaka

TREE SPECIES DIVERSITY AND QUANTIFICATION OF ABOVE GROUND CARBON STORAGE OF ROOFTOP GARDEN IN DHAKA CITY

ABSTRACT

In the current context of increasing urbanization and a related increase in greenhouse gas emissions, rooftop gardens are alternatives means in mitigating climate by its potential Carbon (C) sink. This work was aimed at estimating the aboveground carbon stock and tree diversity in the areas of DAE projected four metropolitans viz. Mirpur, Mohammadpur, Gulshan and Tejgaon of Dhaka city. The data of 63 rooftop gardens were analyzed; a total of 883 trees were sampled and 32 different tree species under 21 families were identified and recorded on the basis of tree diversity and Carbon stock. It was found that large rooftop gardens had 31 different types of species where mean number of trees per hectare was 586.97, medium rooftop gardens had 29 different types of species where mean number of trees per hectare was 616.86 and small rooftop gardens had 16 different types of tree species where mean number of trees per hectare was 701.45. The Shannon Wiener index was used to assess the tree diversity per rooftop garden and it ranged from 1.45 to 3.79 with a mean value of 2.74. The carbon estimations were done using allometric equations for small sized trees with diameter at breast height (DBH) as predictor variable for biomass. Size of the tree, diameter at breast height (DBH) and tree species diversity data were analyzed. As the few samples of the monitored population was smaller than 1.3 m and destructive measurements was not possible, root collar diameter (RCD) was recorded and corrected to be used in the allometric model. Among the rooftop garden categories large area gardens had the highest carbon stock 3.071 Mg ha^{-1} (ranges from 1.65 Mg ha^{-1} to 4.66 Mg ha^{-1}) and lowest carbon stock 1.867 Mg ha^{-1} was found in small rooftop gardens (ranges from 1.18 Mg ha^{-1} to 2.83 Mg ha^{-1}). Among the five major dominating species the highest amount of carbon was stored by Mango (20.37 Mg) followed by Guava (16.84 Mg), Jujube (13.84 Mg), Sapota (12.34 Mg) and Carambola (11.32 Mg). The results of the study show that rooftop farming of Dhaka city has a diverse tree species that could contribute significantly by reducing carbon in the atmosphere.

LIST OF CONTENTS

LIST OF CONTENTS (Contd.)

LIST OF CONTENTS (Contd.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Contd.)

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATION AND ACRONYMS

AGC	:	Above-ground carbon
AGB	:	Above-ground biomass
C	:	Carbon
CO_2	:	Carbon dioxide
DBH	:	Stem diameter at breast height (over bark)
GBH	:	Girth breast height
UHIE	:	Urban heat island effect
e.g.	:	For example
viz.	:	Namely/ as follows
DAE	:	Department of Agricultural Extension
GHG	:	Greenhouse gas
ha	:	Hectare
IPCC	:	Intergovernmental Panel on Climate Change
Mg	:	Mega gram = 10^6 gram
A/R	:	Aforestation and Reforestation
et al.	:	And others
^0C	:	Degree Celsius
ha^{-1}	:	Per Hectare
cm	:	Centimeter
m^2	:	Square meter
%	:	Percent
t	:	Ton
AGC	:	Above ground carbon
BGC	:	Below ground carbon
UNFCCC	:	United Nations Framework Convention on Climate Change
FAO	:	Food and agriculture organization
REDD+	:	Reducing Emissions from Deforestation and Forest Degradation
SOC	:	Soil organic carbon
AR5	:	5^{th} assessment report
spp	:	Species
AH	:	Ad hoc
SRP	:	Stratified random plot
SWI	:	Shannon–Wiener diversity index
POM	:	Point of measurement
CF	:	Carbon foot print
CDM	:	Clean development mechanism

CHAPTER I

INTRODUCTION

Dhaka, the capital of Bangladesh is the home of 18 million people and has ranked as the densest city in the world with 47,400 people per square mile (Amin, 2019). Such rapid urbanization imposes excessive development pressure as any land is lucrative for physical development and construction due to heavy demand for it. As a result, Dhaka has lost its wetland areas significantly and this city occupies only 1% of its total land for parks and open spaces whereas in many modern metropolises this percentage is almost 20%-30% (RAJUK, 2015). Due to migration from rural area to urban area populations in the city is increasing rapidly thus the numbers of low-income consumers are also increasing in cities. Urban agriculture (UA) generate employment and economic facilities through its backward and forward linkages. It contributes to food security by increasing the supply of food and by enhancing the quality of perishable foods reaching urban consumers (Islam, 2004). The part of urban agriculture rooftop garden can supplement the diets of the community as it supplies with fresh produce and provide a tangible benefits tie to food production. It also provide city-dwellers with a source of fresh produce, improved diet and important household budgetary savings (Hamm and Bellows, 2003).

In Dhaka the land has been converting to built-up area indiscriminately and thus agricultural land has been decreased at an alarming rate (Islam and Ahmed, 2011). A minimum 25% of forest cover is suggested for a healthy living (Mowla, 1984) where in old Dhaka (old part of the city) only 5% and new Dhaka (new part of the city) 12% of land is green and open (Mowla, 2011). For per capita GHG emissions, Bangladesh ranks 152 out of 188 countries and contributes less than 0.36% of global emissions (WRI, 2017). Although making only a small contribution to global emissions, it is highly vulnerable to climate change. Bangladesh ranked sixth on Global Climate Risk Index 2017 (Kreft *et al.*, 2017) of the countries most affected by climate change since 1995. The level of warming in 2017 was 0.15°C–0.35°C higher than average warming over the 30-year period 1988–2017 (IPCC, 2018). If this current rate continue to increase, atmospheric CO_2 will be doubled by 2050 that will lead to global temperature rise up to 2-4^{0}C (IPCC, 2013). Dhaka is suffering from Urban Heat Island Effect (UHIE) along with other megacities of the world. UHIE is mainly generated when urban green space is replaced by thermal materials that store solar energy which lead to the increase of surrounding air temperature once it is re-emitted (Maheng *et al.*, 2019). From 2002 to 2014 the built-up area of the city increased from 74.12 to 135.36 square kilometers. By these 12 years, the average yearly temperature has increased by 5^{0}C and this study suggested to focus on urban greening to curb the heating effect (Parvin and Adubu, 2017). Most of the observed increase in global surface average temperatures is due to the observed increase in the amount of greenhouse gases in our atmosphere, especially carbon dioxide. Worldwide concern about global climate change has created increasing interest in trees to help reduce the level of atmospheric CO_2 (Dwyer *et al.*, 1992). To adjust with the increasing carbon dioxide emission problem green roof will be a potential solution to Dhaka city. According to the urban town planner and chief revenue officer of Dhaka city Corporation, within last eight years (2006-2015), the number of buildings in Dhaka city has increased from 326,000 to 400,000. The Department of Agricultural Extension (DAE) aimed in 2015 to promote urban agriculture/rooftop garden for increasing the production of fresh-nutritious vegetables and fruits and also creating a positive impact on environment. It is to be notified that bringing the building roofs of Dhaka metropolitan areas under rooftop gardening would increase the production and consumption of fresh fruits and vegetables and to reduce CO_2 concentration in air for urban dwellers. Therefore, climate change and its impacts must be studied holistically and thoroughly which needs integration of climate, plant ecosystem and soil sciences.

Although the potential of green roofs to improve air quality and aid in carbon sequestration has been confirmed, the experimental data are still insufficient. Additionally, detail information on the effects of factors such as plant carbon content, carbon stock potential and plant species diversity is not available. This study focused on assessing the amount of above biomass carbon and the pattern of tree diversity on rooftop garden in Dhaka city.

Objectives

1. To assess the tree species diversity of rooftop garden in Dhaka city;
2. To estimate the above ground carbon (AGC) storage on rooftop garden in Dhaka city; and
3. To pursue the relationship within biomass carbon, tree species diversity, DBH, basal area and stem density in rooftop garden.

1.1 Limitations of the study

Considering money, times, labor and other available resources to the researcher and to make the study meaningful and manageable from the practical point of view, the following limitations are listed below:

1. The study was directed only in four metropolitan areas under Dhaka city.
2. Characteristics of the garden owners were many and varied but only seven characteristics were selected for investigation in this study.

CHAPTER II

REVIEW OF LITERATURE

2.1 General Concept of Rooftop Garden

Rooftop gardens, as a specific urban gardening niche set within a broader system of city gardens, enjoy their own set of distinctive benefits. Roof top gardening is generally defined as an art and science of growing plants on the fallow spaces within, surrounding or adjacent to the residence, most frequently referred to as a garden. Other conservative areas of roof gardening include atrium, balcony and window boxes. Plants are grown for a variety of utilitarian and non-utilitarian purposes (Sajjaduzzaman *et al.*, 2005). The planners have recognized the values and importance of greening its immediate surroundings for aesthetic, economic and protection purposes (Brown *et al.*, 2004).

While Germany established its first green roofs a century ago and green roofs became common practice in many German and Swiss cities in the 1970s (Brenneisen, 2006; Köhler and Poll, 2010; Thuring and Dunnett, 2014), scientific interest rose especially in the twenty first century, and since, many benefits were attributed to them. Green roofs contribute to urban vegetation without competing for public space, since they occupy the building's "fifth facades", which represent about one quarter of the urban space (Luo *et al.*, 2015).

Islam (2001) has reported that about 60 varieties are produced in Bangladesh. Not all types can be produced on the rooftop. The types and mix are chosen in the city depending upon individual household food preferences, availability of seeds types that can be grown on the rooftop, climate and availability of soils.

Rooftop garden is a powerful tool in protecting the adverse impacts of land utilization and the loss of open space. The vegetated space may be below, at or above grade; located on a podium deck, a 'sky garden' on an intermediate floor level, or at the very top level of the building; but in all cases the plants are not planted in the ground (Hossain, 2009).

2.2 Species Diversity

Magurran (1988) defined species diversity as the number of species and abundance of each species that live in a particular location.

Human disturbance on natural ecosystems is the major threat to local biodiversity. A pool of species will eventually go locally extinct unless its habitat is repaired or restored (Dobson *et al.*, 1997).

Studies that take into account the ability of plants to uptake and manage resources have strongly highlighted the importance of functional groups and functional diversity (Lacroix and Abbadie, 1998). A function group is defined as a set of species (taxa) with similar impacts on ecosystem process (Hobbs *et al.*, 1993).

They are characterized by a set of common biological attributes that relate with their behavior. Related studies that link biodiversity and ecosystem function have been recognized as a way to improve our knowledge on the causal connections between biological variability and ecosystems (Lacroix and Abbadie, 1998).

Studies that take into account the ability of plants to uptake and manage resources have strongly highlighted the importance of functional groups and functional diversity. A function group is defined as a set of species (taxa) with similar impacts on ecosystem process (Lacroix and Abbadie, 1998). Even though attempts to study the impacts of roof garden on environment have received attention (Sanchez, 1995), our knowledge on the causal mechanisms and approaches to evaluate the influence are poorly documented.

2.3 Benefits of Rooftop Gardening

Among green roofs' potential benefits, thermal insulation and regulation of the building has been the most studied, representing about 15 % of the articles on green roofs (Li and Yeung, 2014).

Green roof impact on water runoff has also be extensively researched, and although delay and reduction in rain water is commonly recognized, the quality of runoff water is however largely discussed and results are contrasting (Rowe, 2011).

Green roofs can also compensate habitat for various species, from invertebrates to birds, including endangered species (Molineux *et al.*, 2009).

Plants also find substitute niches in green roofs, as shown on the old and famous Wollishofen building in Zürich, built in 1914 for building and water cooling purpose but revealed to be a well-functioning near-natural habitat, hosting nowadays up to 175 recorded plants species (Brenneisen, 2006).

Green roofs also act as pollution purification and removal, notably for O_3, NO_2, PM_{10}[1] and SO_2 (Yang *et al.*, 2008).

The plants absorb air toxins from ambient air and decrease indirectly the chemical formation of pollutants by reducing surrounding temperature that tend to be 5.6 °C warmer than neighboring countryside, becoming potentially hardly bearable in the summer for its inhabitants (Rowe, 2011). Moreover, green roofs' esthetic was related positively to peoples' health and wellness (White and Gatersleben, 2011).

Others green roofs' benefits, as enhancement of roof membrane longevity, possibility of urban agriculture, and noise reduction, are currently being studied (Sutton, 2015; Whittinghill and Rowe, 2012).

Sajjaduzzaman (2005) reported that the major purpose of roof gardening are passing leisure time, creating aesthetic values, contributing in environmental amelioration and financial gain being a very minor concern in Dhaka Metropolitan city of Bangladesh.

On the other hand, Rumana Rashid *et al.* (2010) described the economic and social benefit of roof top gardening including fresh food supply for urban residents, converts the hard surface into soft green surface, energy saving, etc.).

Rashid and Ahmed (2009) stated that rooftop gardens support the social life, as a space to be comfortable outdoor environment with family and friends. It also develops a sense of self identity and independence, where one can primarily achieve self and emotion regulation viewing different flower indifferent seasons.

Rooftop Gardens could provide more than 12,000 t $year^{-1}$ vegetables to Bologna (Itali), satisfying 77 % of the urban inhabitants requirements (Orsini *et al.*, 2014). Beyond the benefits associated with food production and the natural environment, community gardening is claimed to improve human well-being (Okvat and Zautra, 2011).

Meneewan (2005) showed that rooftops not only divert up to 100% of stormwater and increase downstream erosion, but also account for up to 60% of building cooling load, contributing a significant source of building energy consumption.

The development of multifunctional urban green structures can be an important contributor to sustainable urban development in terms of improving the quality of life and environment for current urban populations (Konijnendijk *et al.*, 2004).

Mechelen (2014) mentioned that green roofs have a great importance for ecological life quality in cities. They do this in several ways. For instance, evapotranspiration, together with water storage in the substrate, leads to more effective storm water management. Roof farms can also absorb carbon emissions and noise (Hui, 2011).

The psychological benefits of green roofs are manifold (Gillis and Gatersleben, 2015), including a ‘warm glow’ feeling that one is contributing to improving the environment of the community they live in. However, it is difficult to measure this increased utility in dollar terms. The fact that a person opts to build a green roof and is aware of the maintenance costs suggests that the personal, intrinsic benefits are at least equal to the maintenance cost. These benefits are captured, at least to some extent, in the increased value of a residential property that includes a green roof. Two hedonic pricing studies, one in Toronto and one in Quebec City, suggest that a green roof adds between 6 and 15 % to the life time value of a residential property (Peck *et al.,* 1999). For the purpose here we assume a very conservative property appreciation due to green roof technology of 3 percent.

All vegetation will sequester carbon. Semi intensive green roofs provide an opportunity to plant and grow both grass, sedums, perennials and small shrubs. Focusing on plant growth in Ontario, with its harsh winters and sporadic rainfall through the fall, summer and spring, sedums are used for the initial carbon sequestering calculations. Sedums are selected because they are perennial, provide a range of species and not difficult to maintain (Carter and Butler, 2008). The coverage and hardiness of sedums makes them ideal for owners of gardens who look for low maintenance costs, especially on top of a garage roof.

Science for Environment Policy (2015) reported that rooftop gardeners grow lettuce, black cabbage, chicory, tomato, aborigine, chili pepper, melon and watermelon, either in plastic pipes, recycled pallets filled with compost or on polystyrene panels floating in tanks, also made from recycled pallets in Bologna, Italy. If all suitable flat roof space is used for urban agriculture, an estimated 624 tons of CO_2 would be captured each year.

2.4 Climate change, Carbon dioxide and Trees

The increasing concentration of CO_2 and other GHG, such as methane, in the atmosphere has likely contributed to the observed 0.6° C increase in global temperatures over the past one hundred years (Clark and York, 2005).

IPCC (2013) 5th Assessment Report (AR5) issued in 2013–2014 confirmed the 4th Assessment Report ′s assertion that global warming of our climate system is unequivocal and is associated with the observed increase in anthropogenic greenhouse gas concentrations and it is necessary to keep the temperature rise less than 2° C relative to preindustrial levels and that CO_2 emissions should be reduced globally by 41–72% by 2050 and by 78–118% by 2100 with respect to 2010 levels.

Dwyer *et al.* (1992) investigated that worldwide concern about global climate change has created increasing interest in trees to help reduce the level of atmospheric.

It is demonstrated by increasing world average ambient and ocean temperatures, changes in precipitation, widespread melting of glaciers, and mounting ocean levels (Manrique *et al.*, 2011).

According to the Intergovernmental Panel on Climate Change (IPCC, 2013) the period from 1995 until 2006 ranked among the twelve warmest years in the instrumental record of global surface temperature (since 1850). An increase in global temperature of 1.5–6.0° C is expected (Clark and York, 2005).

Nowak and Crane (2002) reported that urban trees in the Coterminous USA, store 700 million tons of carbon with a gross carbon sequestration rate of 22.8 million t C/yr. Nowak (1994) indicated that 600 trees in the tropics would fill one acre, which could sequester up to 15 tons of CO_2 annually, other statistics include 40 trees will sequester one ton of CO_2 each year; and that one million trees covering 1,667 acres could capture 25,000 tons of CO_2 annually.

Nowak and Crane (2002) reported that urban forests, due to their relatively low tree cover, typically store less C per hectare in trees (25.1 t C/ha) than forest stands (53.5 t C/ha). However, on a per unit tree cover basis, C storage by urban trees and gross sequestration may be greater than in forest stands annually.

In recent years, the estimation of biomass components has become important for environmental projects, since biomass can be related to carbon stocks and to carbon fluxes when biomass is sequentially measured over time (Návar, 2009).

The main source of anthropogenic emissions affecting global climate change is the use of fossil fuels. The second largest contribution to this change is deforestation and forest degradation, contributing to around 18% of total global GHG emissions (Manrique *et al.*, 2011).

Global carbon cycling consists in the exchange of carbon fluxes between the three main active pools: atmosphere, land and oceans (Falkowski, 2000). It has been reported that the terrestrial biosphere and marine environments are currently absorbing about half of the CO_2 that is emitted by fossil-fuel combustion and terrestrial processes (mainly deforestation). This carbon uptake is therefore limiting the extent of atmospheric and climatic change (Schimel *et al.*, 2001).

Plant tissue, deposited as detritus, is the primary source of soil organic carbon (SOC) in all terrestrial ecosystems. A typical green young plant contains 42% of carbon weight (Brady and Weil, 2008).

De Gier (2003) and Ketterings *et al.* (2001) were conducted studies to develop biomass equation that relates dry biomass of trees to its biophysical variables (e.g. diameter-at-breast height (dbh), tree height) and basal area (Murali *et al.*, 2005).

Plants fix atmospheric C, under CO_2 form through photosynthesis. Grasses can function either with C3 or C4 photosynthesis system, while succulent typically use CAM photosynthesis. C4-species and CAM-species resist more to water deficiency and high temperatures; therefore they are usually located in warmer and dryer climate (Sala, 2001).

2.5 Potentiality of Rooftop Garden

Smit *et al.* (2001) noted that rapid urbanization and urban growth is placing massive demand on urban food supply systems. Moreover, many cities in the world are facing problems like rapid decrease in green space and increase in heat island effects. Urban agriculture or roof farming is promoted as a potential solution to these problems.

Yang *et al.* (2008) used a dry deposition model to estimate the effects of green roofs on air pollutant reductions. The results indicated that 85 kg of air pollutants could be removed annually per hectare of green roof.

If rooftop farming is implemented across public housing estates, the share would increase to 35.5% and Singapore's carbon footprint would decrease by 9052 tons of emissions annually (Astee and Kishnani, 2010). Yang *et al.* (2005) researched the carbon storage ability of urban trees in Beijing, China.

Getter *et al.* (2009) measured the carbon storage potential of 12 green roofs and concluded that the above and below ground systems could store an average of 375 g/m^2 of carbon.

Nowak *et al.* (2002) reported that management practices had a large impact on the ability of urban forests and trees to sequester carbon and that more intensive management with powered machinery and tools reduced the net amount of carbon sequestered. The same would be the case in green roof.

Li *et al.* (2010) found that the respiration and photosynthesis of plants affected the ambient CO_2 concentration and that the CO_2 absorption rate of green roofs is higher than is the emission rate. Therefore, green roofs could contribute to reducing CO_2.

As indicated in the review paper of Li *et al.* (2014) green roofs could sequester carbon in the plants and the soils by photosynthesis and by reducing the ambient CO_2 concentrations. Whittinghill *et al.* (2014) also quantified the carbon sequestration ability of green roofs.

Nowak *et al.* (2005) mention that aspects such as different climatic conditions and different plants and substrates would also affect the potential for carbon storage and sequestration. Moreover, the intensive management of urban forests or green roofs could result in carbon emissions larger than the amount of carbon sequestrated. Careful consideration should therefore be given to this aspect.

Designers have been looking into ways to bring sustainable elements into urban and suburban areas. The green roof is one of the design solutions currently being implemented for that purpose. Some of that scientific research focuses on how a wide spread application of green roofs might be a viable design solution as a method to mediate global warming (NAS, 2008).

In recent years, some people in Taiwan are trying to develop effective growing methods for promoting rooftop farming (Hui, 2011). Many researches that demonstrate that there are many aspects of outdoor environments and green spaces that are attractive to people, regardless of age (Ward Thompson, 2007).

2.6 Importance of Small Sized Trees

Small trees constitute an important component of tropical landscapes and constitute a major global carbon sink. However, these areas are dominated by fewer species and the largest proportion of stand basal area is constituted by smaller-sized trees (Usuga *et al.,* 2010 and van Breugel *et al.*, 2011).

Frequently these young trees and small stems are not considered for carbon estimation because of the time required for adequate measurement and the lack of local robust models for carbon estimation (Baraloto *et al.,* 2011). Nevertheless of these limitations, they highlight the importance of smaller stems to carbon stocks, stating that AGB of stems with DBH between 2.5 and 10 cm varied by a factor of more than five, accounting for < 1% in some French Guianan forests to more than 25% of total AGB in a Peruvian white sand forest. This result contrasts with reports that small trees (< 10cm DBH) account for only 3% of aboveground biomass in French Guiana. Baraloto (2011) shows that small trees should be also take into consideration in biomass estimations.

2.7 Challenges and Incentives to Rooftop Farming

Though there are numerous benefits of rooftop farming, rooftop gardeners are facing several challenges, too. It is important to look at the structural composition of the building and retrofit them accordingly or design of new building should consider it from the very beginning (Hui, 2011).

Keeping the soils healthy and productive may also be challenging as rooftop structural soils are different from ground-bed soils (Green, 2011).

High winds and high temperatures are often a problem; windbreaks and heat-tolerant crops have to be deployed in the rooftop environment. Pesticide use in densely populated areas can be a problem and many rooftop gardeners go with organic farming for this reason (Tiller, 2008).

Many of the city residents do not have training in agriculture. Starting gardening without proper training may lead to frustrating outcomes, which might result in unwillingness of the people in initiating new projects (Islam, 2004).

CHAPTER III

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

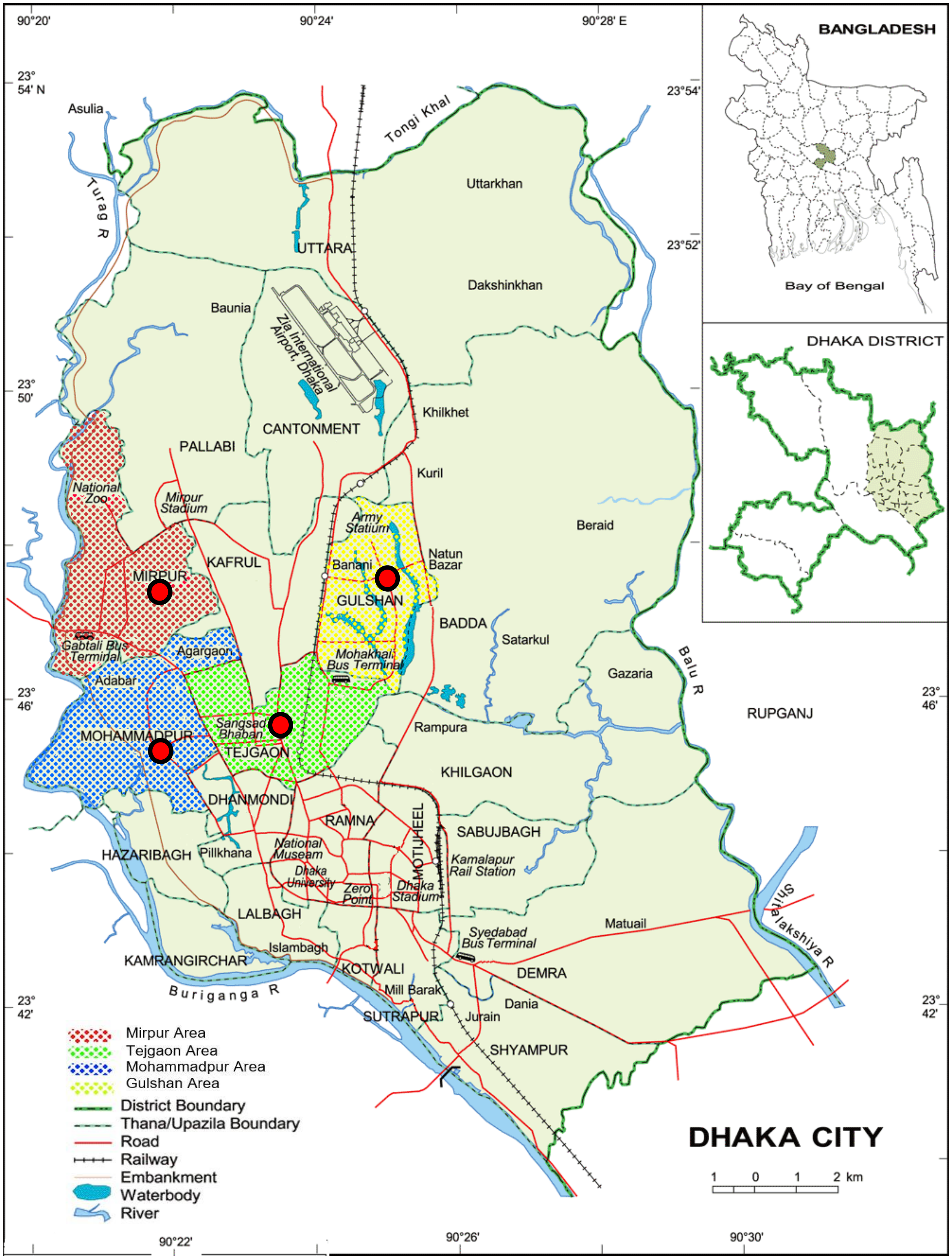
Dhaka city is located in the central part of Bangladesh. The total area of the city is 1528 square kilometers (589.96 square miles) located in between 23°42′ North latitude and 90°22′ East longitude on the eastern banks of the Buriganga River. The core city covers about 127 km^2 of land area (DNCC, 2017). The study was guided within the DAE projected four metropolitan areas of Dhaka city. The selected metropolitan areas for the study were Mirpur metropolitan area, Mohammadpur metropolitan area, Gulshan metropolitan area and Tejgoan metropolitan area. Mirpur metropolitan area covers 58.66 km^2 and located between 23º46´ and 23º48´ North latitudes and between 90º20´ and 90º22´ East longitudes. Mohammadpur area has 11.65 km^2 and it is located between 23.7542° North latitudes and 90.3625° East longitudes. Gulshan area covers 53.59 km^2 and located between 23.7917° North latitudes and 90.4167° East longitudes and Tejgoan area covers 2.74 km^2 and it is located between 23°45.5′ North latitudes and 90°23.5′ East longitudes.

3.1.2 Climate of the Study Area

Dhaka has a tropical wet and dry climate. It has three distinct seasons. The winter comes in the month of November to February and it is dry with temperature 10° to 20°C. The pre-monsoon season in the month of March to May has some rain and hot with temperature reaching up to 40°C and the monsoon is very wet with temperatures around 30°C in June to October. In Dhaka city the average annual rainfall is 1854 millimeter of which about 80% falls during the month of June to October (monsoon season) and the average annual temperature is 12.7 (Minimum) to 33.7 (Maximum) in centigrade (BBS, 2014).

3.1.3 Demographical View of the Location

Rooftop farming is growing popularly in Dhaka city because the land area for farming is shrinking day by day with construction of more and more new buildings, offices and industries. The total area of the city is 1528 square kilometers and the city has around 18.2 million people. Dhaka megacity has shown a population annual growth rate of about 3.48% and also one of most densely populated cities of the world having a density of 11,910 persons per km^2. The literacy rate is 74.6% (BBS, 2012). The number of household in the Dhaka city is 4,550,000 with the average size of household is 4.6 person/family (UN, 2016). The population of Mohammadpur is 3,55,843 (male 1,96,321 and female 1,59,522) and the total households is 81,754. In Mirpur the poplation is 5,00,373 (male 2,69,051 and female 2,31,322) with a total of 1,17,450 households. The Gulshan area has a population of 2,53,050 (male 1,40,322 and female 1,12,728) and total households is 59,149 and Tejgaon has a population of 1,48,255 where male 84,633 and female 63,622 with a total households is 29,622 (BBS, 2014). According to the DAE a total 400,000 rooftop gardens are in the Dhaka city. Around 3000 rooftop gardens are seen by Gulshan office, 2000 have been spotted by Tejgaon office, 4000 in Mirpur and 2500 in the Mohammadpur neighborhoods.



● Selected Metropolitan office

Plate 1. Location of the study area.

3.2 Sampling Procedure

Sampling, there are no strict rules to follow, and the researcher must rely on logic and judgment. The population is defined in keeping with the objectives of the study (David and Walonick, 2010). The study was guided within the DAE projected four metropolitan areas of Dhaka city. DAE divided Dhaka city in six metropolitan areas. The metropolitan areas are Uttora, Kamrangichor, Mirpur, Mohammadpur, Gulshan and Tejgaon. Out of six metropolitan areas of Dhaka city four metropolitan areas such as Mirpur, Mohammadpur, Gulshan and Tejgaon were selected purposively for this study. Stratified random sampling was used for selecting the sample. Sample was drawn from each metro area randomly. The sub areas of Mirpur metro are Pallabi, Shewrapara, Taltola and Mirpur were selected. The sub area of Mohammadpur metro are Shekhertek, Dhanmondi, Lalmatia and Mohammadpur housing society area were selected. In Gulshan metro Gulshan-1 and Niketan were selected. The sub area of Tejgaon metro Nakhalpara, Monipuripara, Indira road and Tejkunipara area were randomly selected. There is no safe general rule as to how large sample size must be for use of the normal approximation in computing confidence limit. Sample size, $n \geq 25$ which says 95% confidence probability (Fisher, 1958) was used and an optimum number of samples were chosen for each location of this study. Proportionate random sampling technique was used for selecting sample size in each location. For Mirpur 43-80%, Mohammadpur 38-75%, Gulshan 35-40% and for Tejgaon 42-78% households of the sampling frame were taken as sample. The proportionate sampling was done considering the minimum percentage of 35 in each location. Out of 112, a total of 63 (56.25%) sample households were selected for the study. Individual households represented the sampling units. The distribution of samples according to selected locations are presented in Table 1.

Table 1. Distribution of samples according to selected location.

Metropolitan areas	Sub-areas	No. of rooftop gardens selected for data collection	Percent (%)	Total no. of Rooftop gardens
Mirpur	Mirpur	5 (7)	71	18 (64.3%)
	Pallabi	4 (7)	64	
	Shewrapara	6 (7)	80	
	Taltola	3 (7)	43	
Mohammadpur	Shekhertek	3 (7)	38	17 (60.7%)
	Dhanmondi	5 (7)	70	
	Mohammadpur housing society	6 (7)	75	
	Lalmatia	3 (7)	44	
Gulshan	Gulshan-1	6 (14)	40	11 (39.3%)
	Niketan	5 (14)	35	
Tejgaon	Nakhalpara	4 (7)	58	17 (60.7%)
	Monipuripara	6 (7)	78	
	Tejkunipara	4 (7)	60	
	Indira road	3 (7)	42	
Total		**63 (112)**	**56.25**	**63**

3.2.1 Roof Garden Properties Data

A questionnaire survey was conducted in 63 roofs in the selected metro areas. Field data collection was made by physical measurement directly from the study sites. Data were sought on rooftop gardening like rooftop size, species composition in the study area. Demographic and socio economic data were also collected from the respondents. All qualitative and quantitative data were collected in local terms and units and then converted into standard unit. Interviews were performed during daytime, with an average duration of about 30 minutes. Respondents were free to express their own view at each step of the interview.

Plate 2. Rooftop gardens of the study area.

Plate 3. Interviewing with the garden owners.

3.2.2 Rooftop Garden Plot Survey

All tree species with a diameter at breast height (DBH) of ≥ 1 cm were identified and recorded according to species by their local name and scientific name for determining plant species diversity. In general the majority plant species in rooftop garden are smaller than the normal expectation. Because of destructive method was not possible it was very difficult to quantify carbon stock in shrub and herb species. The area of the rooftop garden was categorized (sq. ft.) into three groups for better comparison. Among them 1200 to 1700 sq. ft. was small area, 1701 to 2100 sq. ft. was medium area and above 2100 sq. ft. was large area. The diameter was measured in cm at 1.3 m (DBH) height using a measuring tape when the tree was tall enough. When deformities or buttress roots were present at this height, the point of measurement (POM) was altered and recorded (Phillips *et al.*, 2009). To define POM a pole with 1.3 m marked was used to push firmly into the litter layer over the soil next to the tree (Phillips *et al.*, 2009). In rooftop garden few trees were found small. In this case trees smaller than 1.3 m, the diameter was measured at the collar (RCD) in cm at the soil surface after removing coarse debris as recommended by Blujdea *et al.* (2012). In case of multiple stems, all stems greater than 1 cm of diameter at 1.3 m of height were measured and recorded. The girth breast height (GBH) of each single tree was converted to tree diameter by dividing the girth with π (3.1416). Lower amount of trees were found deformed (fluted, trees with surface irregularities, leaning, re-sprouts trees) as rooftop gardening is mostly intensive.

3.3 Estimation of Biodiversity

The biodiversity which is indicated as tree diversity was estimated by the Shannon-Wiener diversity Index (SWI). Each rooftop garden was considered as sample plot. For this study Shannon-Wiener diversity index (SWI) was used due to its suitability for evaluating diversity of tree species. The Shannon–Wiener diversity index indicates the highest diversity when all species are abundant equally to the proportion of species abundance in the population and the lowest when the sample contained one species that means 0 diversity. The proportion of species (i) related to the total number of species (Pi) was enumerated and multiplied by the natural logarithm of the same proportion ($Ln\ Pi$). The resulting product was summed through species and lastly multiplied by -1.

$$H = -\sum_{i=1}^{n} Pi\ Ln\ Pi$$

Where,

H = Shannon index

n = No. of species

Σ= Summation.

Pi = Proportion of total sample represented by species i. Total no. of individual species i, divided by total no. of plant species found in a sample community.

The total number of plant species of a rooftop garden was divided by the total area of that garden to measure the species per unit area (species density).

3.4 Allometric Equation for Above Ground Biomass Estimation

3.4.1 Tree biomass

For selecting appropriate allometric models in this study, three criteria were considered. First, as in this work the majority of the inventoried trees were smaller than 1.3 m height; models that include tree height as parameter were excluded considering the results of Peichl and Arain (2007), who stated that biomass of all above and belowground tree components are highly correlated to DBH, mentioning that the addition of tree height or age did not improve the equation fit within any of the small stands tested on their work, also mentioned by Pajtík *et al.,* 2008.

Secondly, previously published pan-tropical models as Chave's and Brown's were excluded considering the nature of the study area (altitudinal gradient). This criterion was based on the conclusion of Alvarez *et al.* (2012) about the useless of the Chave's forest type classification for differentiating variation in tree form among forest types along the altitudinal gradient in Colombia causing variation in the resulting AGB and introducing bias. Moreover Preece *et al.* (2012) conclude that in relatively young forest stands, such as the plantings investigated here, models that exclude stems <10 cm DBH are not appropriate for carbon accounting as is the case of Brown's model which was based only on stems ≥10 cm DBH.

Finally, equations using wood density as a parameter were excluded considering that small trees have higher wood density than older trees and that wood density slowly decreases, as the trees grow older and eventually increases again in older stands as the annual rate of growth abates (Pajtík *et al.* 2008). Considering all these factors the allometric equation developed by Sierra *et al.* (2007) was selected for AGB estimation in wide geographical area including small diameter (DBH).

3.4.2 Above Ground Biomas

Diameter measurements were used to parameterize allometric relation because of a destructive sampling was not possible the best AGB estimation. Since most allometric relationships for estimating AGB use DBH, we need to quantify the errors from using RCD (Root collar diameter) measurements. A relation between DBH and RCD was established for small trees by Peñafiel (2014) which allowed recording both measurements with the purpose of via this relation predict a DBH based on RCD for the rest (trees smaller than 1.3m). Afterwards, the predicted DBH or the measured DBH were used as independent variable for predicting AGB from the published equation. The AGB estimation from tree to area level involved three steps according to Van Breugel *et al.* (2011).

(1) The estimation of individual tree biomass,

(2) The summation of individual tree AGB to estimate roof AGB and

(3) The calculation of an across-roof average to yield a area-level estimation.

To measure the above ground biomass, following equations were used:

DBH = 0.46 ± 0.14 RCD (Peñafiel, 2014)

Where: DBH = Diameter at breast height, RCD = Root collar diameter, 0.46 and 0.14 are correction factors.

AGB = 1.087 ×exp (-2.232 + 2.422 × *ln* (DBH)) (Sierra *et al.*, 2007)

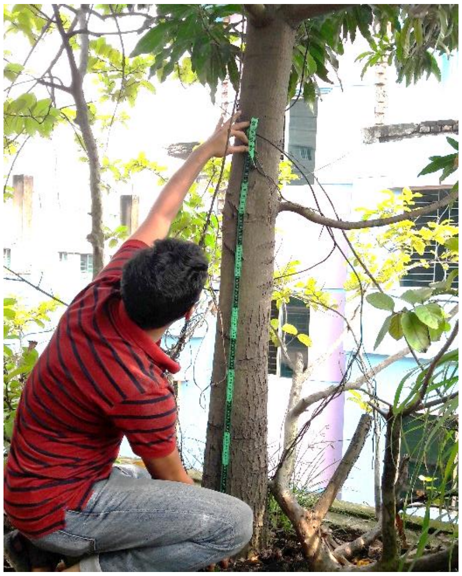
Where: AGB = Above Ground Biomass, *ln* = Natural logarithm, -2.232 and 2.422 are constant.

3.4.3 Aboveground Carbon (AGC) Estimation

After estimating the biomass from allometric relationship, it was multiplied by wood carbon content (50%). It was assumed that Carbon concentration was 50% of the dry weight of AGB (Losi *et al.*, 2003; Manrique *et al.*, 2011; Preece *et al.*, 2012).

Carbon (Mg) = Biomass estimated by allometric equation × Wood carbon content

% = Biomass estimated by allometric equation × 0.5



(1)

(2)

(3)

Plate 4. Measuring (1) tallness at breast height, (2) DBH (cm) and (3) RCD (cm).

3.5 Data Processing

Data collected from questionnaire survey were analyzed by SPSS-20 software and other field data were processed and analyzed using MS excel 2013 software. Above ground Carbon pools were computed using international standard common tree allometries. Regression analyses were used to test the relationship among different variables.

CHAPTER IV

RESULTS AND DISCUSSION

This study seeks to establish the baseline estimation of carbon aboveground storage in the rooftop garden in different locations at Dhaka city. These results are the first estimation of aboveground biomass on roof farming at Dhaka city since the farming is increasing day by day. The results are very important because it provides with a general overview of the success of the roof farming. In addition, this data will be used as the baseline data for future monitoring. Furthermore, the results contribute to the research of biomass estimation in small size plantation on rooftop at Dhaka city. A limitation of this study is that the data analysis reflects only one point in time (first estimation). The results are further discussed in the following sections.

4.1 Measurement of Tree Diversity

Tree species diversity is an important part of forest ecosystem as quantitative inventories have been concentrated on tree species than the other life forms. Assessment of tree diversity, above ground biomass and carbon stock was done by non-destructive methods.

Table 2. Tree diversity at various Rooftop garden in Dhaka city.

Rooftop garden categories	Mean number of tree species per Hectare	Species recorded in rooftop gardens		Shannon Wiener index (SWI)	
		Total	Mean	Mean ± SE	Range
Small area (n=25)	403	16	12.44	2.31 ± 0.07	1.45-3.13
Medium area (n=17)	376	29	9.21	2.78 ± 0.08	2.22-3.28
Large area (n=21)	348	31	13.45	3.26 ± 0.06	2.68-3.79

SE ± standard error

Tree diversity was presented in table 2 and the Shannon-Winner diversity index showed a range between 1.45 to 3.79 for diversity value within the rooftop gardens. This diversity index revealed that large area (n=21) had the highest mean value of 3.26 ± 0.06 and small area (n=25) had the lowest mean value of 2.31±0.07 where medium area (n=17) had moderate mean value of tree diversity of 2.78±0.08. The result can be compared as: large>medium>small. It was found that large rooftop garden had 31 different types of species where mean number of tree species per hectare was 348 trees ha^{-1}, medium rooftop garden had 29 different types of species where mean number of trees per hectare was 376 trees ha^{-1} and small rooftop garden had 16 different types of tree species where mean number of tree was 403 trees ha^{-1}. The study found that the variation was due to species composition and richness, soil characteristics, climate, topography and size of the rooftop gardens.

A similar study was conducted by Hossain (2014) and concluded that the area of the rooftop garden had a positive significant relationship with their plant species diversity. It could be concluded that the large the roof top garden area, the more was plant species diversity.

Table 3. Shannon-Wiener diversity index in the study area.

Metro Areas	Grand total tree Species	Relative abundance (Pi)	LN (Pi)	Pi*LN(Pi)
Mirpur	230	0.26	-1.35	-0.35
Mohammadpur	316	0.36	-1.02	-0.37
Gulshan	143	0.16	-1.83	-0.29
Tejgaon	194	0.22	-1.51	-0.33
Total	**883**	**1**	**ΣPiLn(Pi)**	-1.34
			H'= -ΣPiln(Pi)	1.34
			e H'	**3.82**

The S-W index is usually expressed as eH'. The Shannon diversity index ranges typically from 1.5 to 3.5 and rarely reaches 4.5 (Gaines *et al.*, 1999), though values beyond these limits may be encountered. The result showed that Shannon-Wiener diversity index was very high in the rooftop gardens of the study area which was 3.82. A similar study was conducted by Hossain (2014). In her study she revealed that the roof top garden of Dhaka city possess a high plant species diversity where Shannon-Wiener diversity index were 3.84. Our result was just similar to her study.

4.1.1 Distribution of Diversity in Different Metro Areas

The graph showed us about the diversity level among different metro areas. From this graph we found the highest tree diversity value in Mohammadpur metro that was 3.12 and lowest value in Tejgan 2.86 followed by Mirpur 3.01 and Gulshan 2.89.

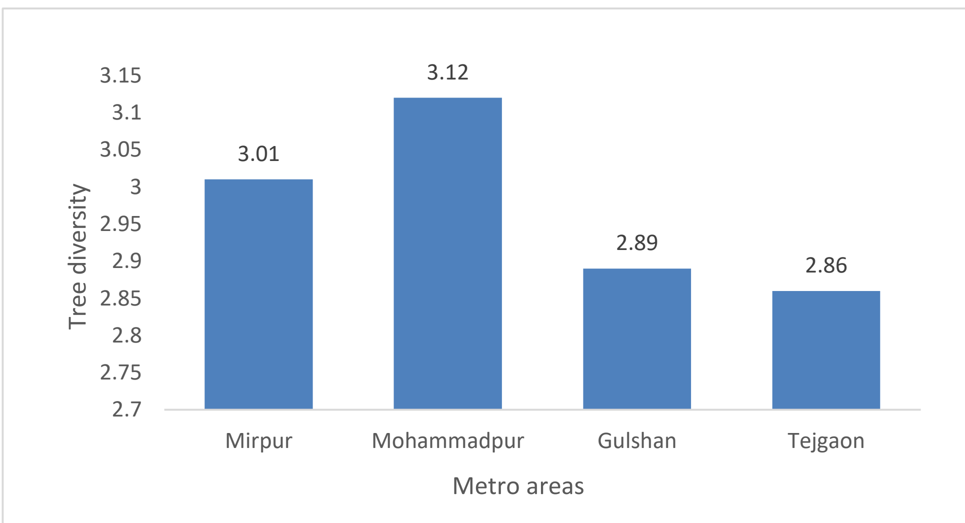


Figure 1. Tree diversity in four metro areas of study site.

In the previous study of Hossain (2014) it was found the highest diversity in Mirpur area, lowest diversity in the Mohammadpur area and moderate in Kamrangichor and Gulshan area. The variation between the results was due to the different location (sub-area) of the rooftop gardens. It may vary because rooftop garden becomes more popular day after day and people have a tendency to grow fresh fruits and vegetables in their open space (rooftop garden) for proper nutrition of their family (Uddin *et al.*, 2016).

4.2 Inventoried tree species in the study site

In total 883 trees were inventoried in this study. It focused on 32 tree species under 21 families with their local name, family, botanical name, their total number and percentage (%) of occurrence are shown in Table 4. Mango was the most predominant tree species with 10.31% (no. 91) followed by Jujubee 8.83% (no. 78), Guava 8.04% (no. 71), Sapota 6.80% (no. 60) and Lemon 6.57% (no. 58) (Table 4.4).

Table 4. Inventoried tree species in 63 Rooftop gardens at Dhaka City

Sl no.	Species	Family	Scientific Name	Total	%
1	Mango	Anacardiaceae	*Mangifera indica*	91	10.31
2	Jujubee	Rhamnaceae	*Zizyphus mauritiana*	78	8.83
3	Guava	Moraceae	*Psidium guajava*	71	8.04
4	Sapota	Sapotaceae	*Achros sapota*	60	6.80
5	Lemon	Rutaceae	*Citrus aurantifolia*	58	6.57
6	Karambola	Averrhoaceae	*Averrhoa carambola*	54	6.12
7	Amloki	Euphorbiaceae	*Phyllanthus embelica*	52	5.89
8	Karanda	Apocynaceae	*Carissa carandas*	47	5.32
9	Billimbi	Averrhoaceae	*Averrhoa bilimbi*	41	4.64
10	Orange	Rutaceae	*Citrus reticulata*	41	4.64
11	Malta	Rutaceae	*Citrus sinensis*	33	3.74
12	Wood Apple	Rutaceae	*Feronia limonia*	29	3.28
13	Custard apple	Annonaceae	*Annona reticulata*	28	3.17
14	Pummelo	Rutaceae	*Citrus grandis*	25	2.83
15	Hog-plum	Anacardiaceae	*Spondias pinnata*	24	2.72
16	Wax apple	Myrtle family	*Syzygium samarangense*	21	2.38
17	Gooseberry	Euphorbiaceae	*phyllanthus acidus*	20	2.27
18	Jalpai	Elaeocarpaceae	*Elaeocarpus floribundus*	16	1.81

Sl no.	Species	Family	Scientific Name	Total	%
19	Neem	Meliaceae	*Azadirachta indica*	15	1.70
20	Chondro mollika	Oleaceae	*Jasminum angustifolium*	12	1.36
21	Drum stick	Moringaceae	*Moringa oleifera*	12	1.36
22	Rambutan	Sapindaceae	*Nephelium lappaceum*	10	1.13
23	Bakul	Sapotaceae	*Mimosops elengi*	10	1.13
24	Jhau	Caesalpinae	*Casuarina equisetifolia*	8	0.91
25	Kababchini	Piperaceae	*Piper cubeba*	8	0.91
26	Musanda	Apocynaceae	*Musanda sp.*	5	0.57
27	Sarifa	Sapotaceae	*Chrysophyllum cainito*	5	0.57
28	Henna	Lythraceae	*Lawsonia inermis*	3	0.34
29	Golapjam	Myrtaceae	*Syzygium jambos*	2	0.23
30	Christmass tree	Araucariaceae	*Araucaria excelsa*	2	0.23
31	Tejpata	Lauraceae	*Cinnamomum tamala*	1	0.11
32	Long pepper	Piperaceae	*Piper longum*	1	0.11

Uddin *et al.* (2016) reported that the highest 75% respondents grew mango followed by lemon (72.8%), Guava (72.8%), Hog-plum (26.5%), Jujubee (24.5%), Wax apple (13%), Malta (12.8%) and Sapota (10.5%) in Dhaka city areas. Another study was conducted by Hossain (2014) reported that Mango, Guava, Sapota, karambola, Lemon, Amloki were the most dominant fruit species and Among 20 flower species, beli, petunia, dianthas, jasmine and chondro mollika were ranked in top position found on rooftop garden at Dhaka city. From these review the resulted species found in this study had similar dominating species that were shown in Figure 2.

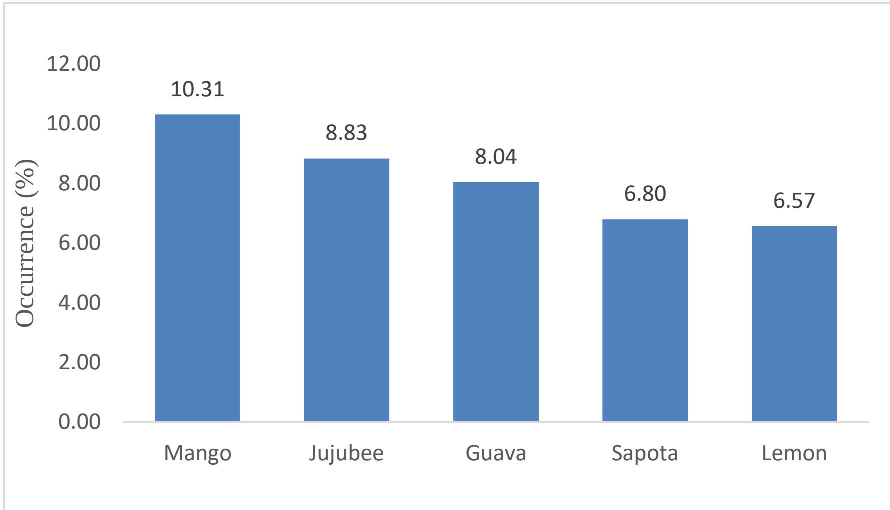


Figure 2. Occurrence of major tree species (%) of various rooftop gardens in Dhaka city.

4.3 Stand Density in Rooftop Gardens

The results of density of planted trees are showed a range of tree density value from 419.37 to 839.36. Among the three category of rooftop gardens, small area (1200-1700 ft^2) had the highest tree density mean value of 701.45±22.2 ranges from 481.21 to 839.36 and large area (> 2100 ft^2) had the lowest tree density mean value of 586.97±16.1 ranges from 419.37 to 743.03 where medium area (1701-2100 ft^2) had moderate tree density mean value of 616.86±26.6 ranges from 435.44 to 820.10. This result can be arranged in an order of small > medium> large in case of density value ha^{-1}. The variable number of trees found (Table 5) at each rooftop garden category could be attributed to various factors such as farmer willingness, climatic, anthropogenic, site conditions and type of planted species.

Table 5. Stand density of the rooftop gardens.

Rooftop Garden Categories	Higher Stand Density Value (ha^{-1})	Lower Stand Density Value (ha^{-1})	Mean ± SE
Small Area	839.36	481.21	701.45± 22.2
Medium Area	820.10	435.44	616.86± 26.6
Large Area	743.03	419.37	586.97± 16.1

4.4 Distribution of Basal Area (m^2 ha^{-1}) and Mean DBH (cm) of Different Rooftop Gardens

Basal area and DBH data were an important factor to be used as an AGB indicator. For the study mean basal area (ha^{-1}) and mean DBH (cm) were calculated from 63 rooftop gardens. From the Table 6 we found that large rooftop gardens had the highest basal area (3.43 m^2 ha^{-1}) followed by medium (2.89 m^2 ha^{-1}) and small gardens (1.89 m^2 ha^{-1}). In case of mean DBH large rooftop gardens had the highest value of 5.61 cm and small gardens had the lowest value of 4.38 cm where medium gardens had moderate mean DBH of 4.99 cm. These variations was found due to various age cycle of the species, types of the species, size of the rooftop gardens, soil and climate.

Table 6. Average basal area (m^2 ha^{-1}) and mean DBH (cm) of various rooftop gardens.

Parameters	Rooftop Garden Categories		
	Small Area	Medium Area	Large Area
Basal Area (m^2/ha)	1.89 (0.06)	2.89 (0.18)	3.43 (0.16)
Mean DBH (cm)	4.38 (0.14)	4.99 (0.25)	5.61 (0.24)

* Parenthesis are the standard errors.

4.5 Above Ground Carbon (AGC) Estimation

Above ground carbon (AGC) estimations demonstrate a clear relation with rooftop garden category. The distribution of aboveground carbon in the monitored trees is depicted in Table 7. Among the 63 rooftop gardens average AGC ranged from 1.18 Mg C ha^{-1} to 4.66 Mg C ha^{-1}. The highest amount of AGC reported in large area (3.071 ± 0.17 Mg/ha) with a number of 21 rooftop gardens and lowest in small area (11.867 ± 0.09 Mg/ha) with a number of 25 rooftop gardens. Moderate AGC was reported in medium area (2.678 ± 0.16 Mg/ha) with a number of 17 rooftop gardens. AGC estimations demonstrate that higher the garden area higher the AGC. This result happened because large area had the highest basal area (m^2 ha^{-1}) and the highest mean DBH (cm) as basal area and DBH are the main indicators of above ground carbon estimation. The table show the average values obtained from the Sierra model. The individual rooftop garden contribution of the monitored trees is given in the appendix VI.

Table 7. Above ground carbon (AGC) estimation at various rooftop gardens in Dhaka city.

Rooftop garden category	Number of Rooftop garden	Above ground carbon (Mg/ha)		Mean ± SE
		Highest	Lowest	
Small Area	25	2.83	1.18	1.867 ± 0.09
Medium Area	17	3.73	1.53	2.678 ± 0.16
Large Area	21	4.66	1.65	3.071 ± 0.17

Establishing a comparison of this study with previous ones resulted difficult because according to our knowledge there was no similar studies; at least not for rooftop gardens at Dhaka city. However, considering the above ground carbon content on rooftop garden in urban area it may be compared. A research conducted by Whittinghill *et al.* (2013) found that Landscape systems including green roofs containing more woody plants and shrub had carbon content ranges from 62.91 to 78.75 kg C m^{-2} was higher carbon content than other landscape systems. When we converting the carbon content to Mg per ha we obtained 7.04 Mg/ha. This considerably similar to our study. One of the key study in this research field was done by Getter *et al.* (2009). In a first study, they mapped aboveground biomass (AGB) of 12 extensive green roofs in Michigan. The sampled AGB averaged 162 g C per square meter. They conducted a second study and analyzed the Carbon content of 20 sedum-vegetated plots installed on the university roof over two growing seasons. At the end of the experiment they found 168 g C m^{-2} in AGB. Murtala *et al.* (2019) conducted a research at sokoto metropolis in north-western Nigeria and found the highest carbon density of 7.4 Mg ha^{-1} to 96.5 Mg ha^{-1}. Similar study was conducted by Islam M. S. (2013) at Sher-e-Bangla Agricultural University, Dhaka reported above ground carbon storage ranges from 15.74 Mg ha^{-1} to 385.86 Mg ha^{-1}. The both results were higher than the estimation of this study. The reason behind the results was that the both studies had high DBH > 5 cm (large tree). Other study of Liu and Li (2012), where mean carbon stock of 33.22t ha^{-1}, 30.25t ha^{-1} and 43.70t ha^{-1} were observed in Shenyang, Hangzhou, and Beijing cities, respectively. The relatively low tree carbon stock recorded in this study may be attributable to the number of trees with small trunk diameters. Most of the stems have a trunk diameter between 3 cm and 6 cm.

4.6 Tree Species and its Aboveground Carbon Stock

This study showed about the major carbon absorbed species in Dhaka city. It was found that the main contributors for carbon storage was *Mangifera indica* (20.37 Mg). However, there are other minor contributors which account smaller amounts of carbon, namely *Psidium guajava* (16.84 Mg), *Zizyphus mauritiana* (13.84 Mg), *Achros sapota* (12.34 Mg) and *Averrhoa carambola* (11.32 Mg) (Figure 3) and the number of the species was found 91, 71, 78, 60 and 54, respectively.

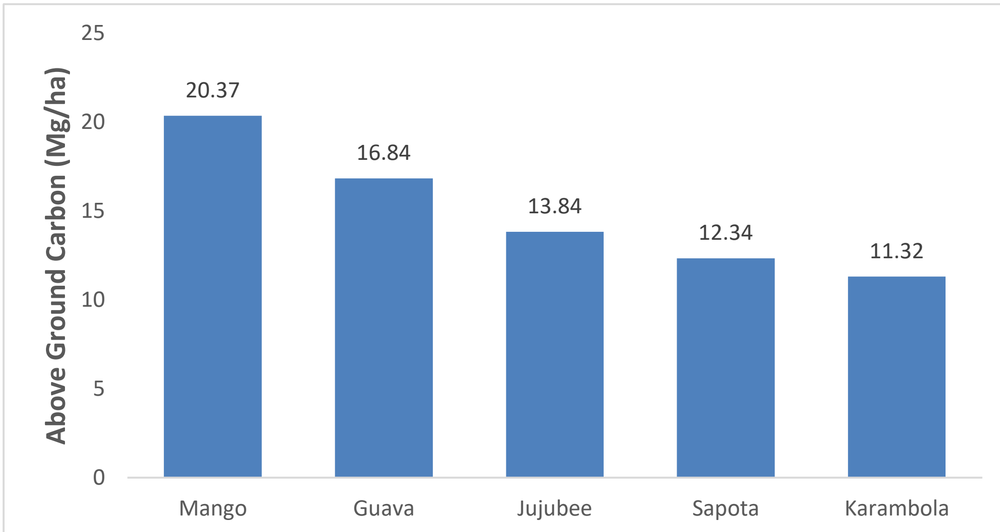


Figure 3. Major tree species and their carbon content.

Islam (2013) found that 10 species were considered as the most significant in terms of percent carbon contribution in homegarden. It was found that *Mangifera indica* covered 34.35%, *Artocarpus heterophyllus* (16.91%), *Salmalia malabarica* (22.69%), *Moringa oleifera* (3.25%), *Garuga pinnata* (2.08%), *Psidium guajava* (0.85%), *Syzygium samarangense* (1.48%), *Annona reticulate* (0.88%) , *Citrus grandis* (0.45%) and *Zizyphus jujuba* (1.01%) in residential area of Sher-e-Bangla Agricultural University, Dhaka.

4.6.1 The Relationship between Mean DBH (cm) and Tree Above Ground Carbon (Mg ha^{-1})

Relationship between mean DBH (cm) and tree above ground carbon were depicted in Figure 4. A linear relationship between mean DBH and carbon stock was estimated as; $y = 0.5527x - 0.2516$ where $R^2 = 0.5047$ (positive), which indicated that the relation was moderate and significant (5% level of significance) between mean DBH (cm) and carbon storage. The equation also stated that higher the mean DBH (cm) higher the carbon stock at the rate of 0.5527 Mg ha^{-1} per unit change of mean DBH (cm).

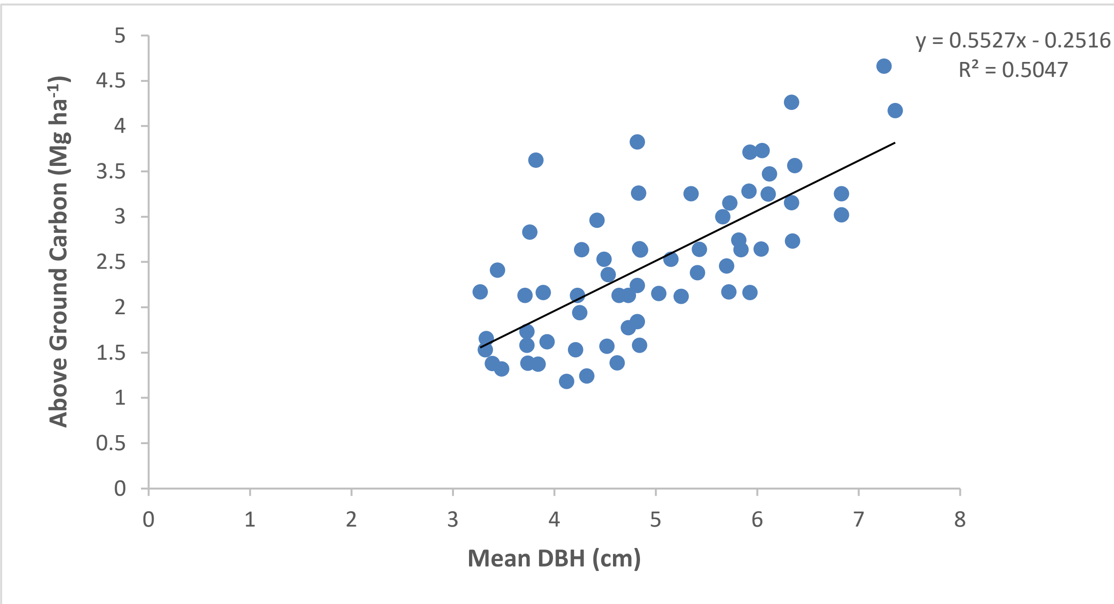


Figure 4. Relationship between mean DBH (cm) and tree above ground carbon (Mg ha^{-1}).

In some literature of van Breugel *et al.* (2011) and Malhi *et al.* (2006), DBH is considered the most important parameter for biomass estimations using allometric equation. Kenzo *et al.* (2009) and Sierra *et al.* (2007) stated that the relation between DBH and above ground carbon positively correlated with each other as DBH is the main predictor of above ground biomass estimation.

4.6.2 Relation between Basal Area and Above Ground Carbon

Basal area data was evaluated to be used as an AGB indicator. The latter was necessary because no destructive AGB estimations were performed in this study, so it was not possible to verify if the estimations obtained using allometric model from the literature described properly the situation of the study area. When whole data set is considered it is possible to identify a direct relation between basal area and AGC as depicted in Figure 5, The relationship between mean basal area and carbon stock were estimated and indicated a linear equation as: $y = 0.8731x + 0.1534$ where $R^2 = 0.9025$ (positive). This figure also indicates that basal area of tree species are significantly correlated with carbon stock as basal area increase AGC estimation also increases.

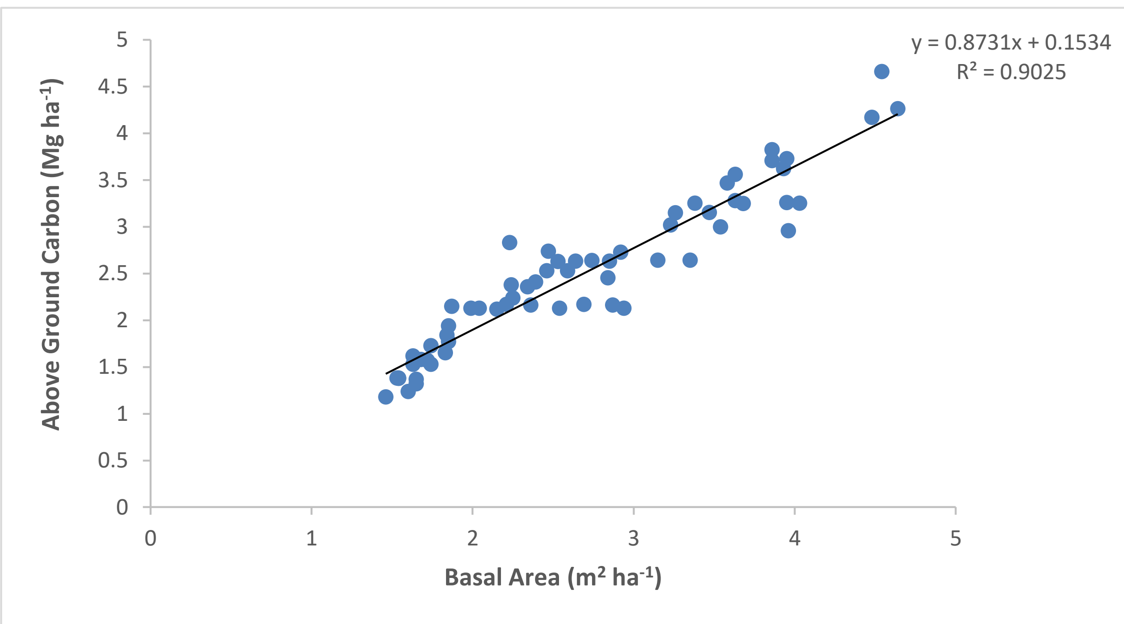


Figure 5. The relationship between basal area (m^2 ha^{-1}) and tree carbon stock (Mg ha^{-1}).

This is supported by studies that demonstrated strong relationships between AGB and both basal area throughout several studies. Baraloto *et al.* (2011); Chave *et al.* (2004) and Chiba (1998) stated that the relationship between aboveground biomass and basal area is likely to be associated with tree architectural development because the lower part of the tree trunk contains the growth process of the tree since initiation and obviously because DBH is used as the main predictor for AGB estimations.

4.6.3 Relationship between Stand Density (trees ha^{-1}) and Above Ground Carbon (Mg ha^{-1}) at Various Rooftop Gardens

From the study it was revealed that there was a negative relation between stem density (tree ha^{-1}) and above ground carbon storage (Mg ha^{-1}). The relationship was y = -0.003x + 4.3594 that was not significant. The value of R^2 is 0.1572 (Figure 6).

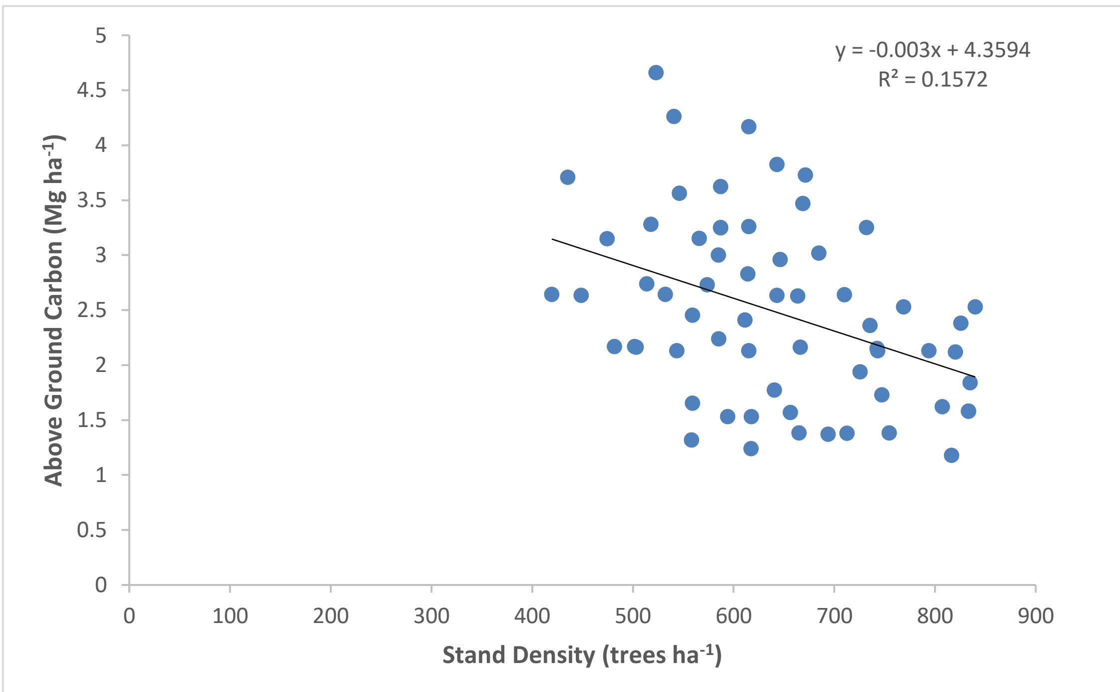


Figure 6. Relationship between stand density (trees ha^{-1}) and above ground carbon (Mg ha^{-1}).

Slik (2010) stated that the above ground biomass was only correlated with basal area, but not with stem density. Sundarapandian *et al.* (2013) observed from a study that tree density had a negative relationship with tree carbon content. Clark (2000) carried out a research in an old growth forest of Costa Rica, Central America, found two plots with a stem density 462 to 504 per ha where the above ground biomass was 139 to 138 Mg/ha, respectively. Another study of Roshetko *et al.* (2007)

showed that tree density is important to store carbon as it directly related to the carbon sequestration. So literary it can be concluded that the relation between stand density and carbon content either positive or negative. In this study a negative relation was obtained.

4.6.4 Relationship between Tree diversity and above ground carbon storage ($Mg\ ha^{-1}$) at various rooftop gardens

The relationship between tree diversity and above ground carbon stocks of rooftop gardens showed in Figure 7. The figure indicates a linear equation as: y = 0.7166x + 0.4801 (R^2 = 0.2434), where R^2 value was positive and significant. The equation stated that carbon stock increased at a rate of 0.7166 $Mg\ ha^{-1}$ per unit change in tree diversity.

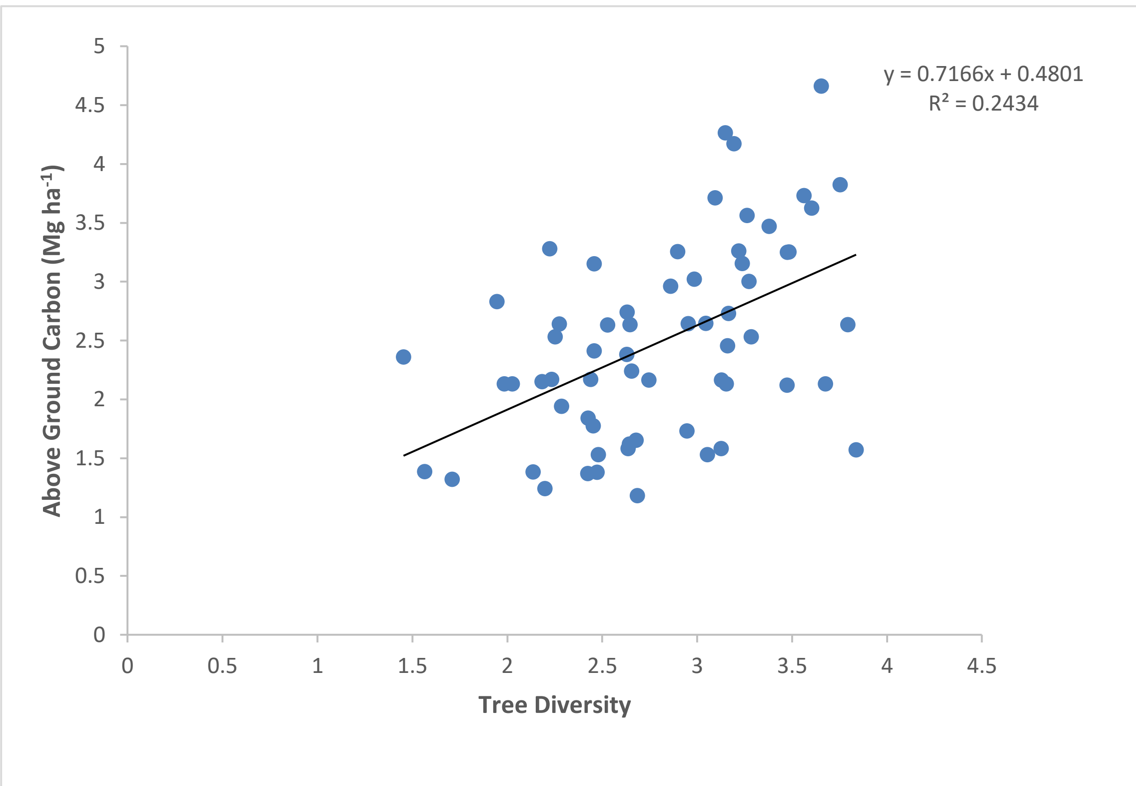


Figure 7. The relationship between tree diversity and above ground carbon storage ($Mg\ ha^{-1}$).

Day *et al.* (2013) conducted a research and found that the relationship between tree species diversity and tree carbon stock was significant but weakly correlated with each other in central African rainforest. Jaman (2014) found a positive relation between above ground carbon storage of homegardens in Rangpur district. Iqbal (2015) conducted a silimar research and found a positive relation between above ground carbon storage in north-western char island homegardens. Pushpakumara *et al.* (2012) and Kumar (2011) found a negative relationship between tree diversity and above ground carbon stock.

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

SUMMARY

A total of 63 rooftop gardens were selected from DAE projected four metropolitan areas such as Mirpur, Mohammadpur, Gulshan and Tejgaon at Dhaka city and data were collected on the basis of tree diversity and total carbon stock. Shannon-Winner diversity index was used to measure tree diversity. Allometric equation developed by Sierra *et al.* (2007) was used and predicted DBH for smaller tree species below 1.3m was measured by Peñafiel (2014) correlation equation to calculate carbon stock. A well-structured interview schedule was developed based on objectives of the study for collecting information with containing direct and simple questions in open form and close form keeping in view the dependent and independent variables. The researcher himself collected data through personal contact. The dependent variable of this study was the plant diversity and quantification of above ground carbon storage. Various statistical measures such as percentage distribution, average, and standard deviation were used in describing data. The major findings of the study are summarized below.

In a total of 63 rooftop gardens of 32 different species under 21 families were found which a good indicator of biodiversity. The results of the study found that the most dominating species was Mango with a number of 91 and Tejpata and Long pepper was the least dominating species with a number of 1. There were five major species found in the rooftop gardens namely, Mango which is 10.31% of total number of species followed by Jujube (8.83%), Guava (8.04%), Sapota (6.80%) and Lemon (6.57%).

Among the three rooftop garden categories the highest species diversity mean value was found in large rooftop gardens and that was 3.26 (range from 2.68 to 3.79) with the highest species number (31 nos.) and the lowest mean diversity value was observed in small rooftop gardens that was 2.31 (range from 1.45 to 3.13) with lowest number of species (16 nos.) where the medium rooftop garden had a moderate diversity value of 2.78 (range from 2.22 to 3.28) with a moderate number of tree species (29 nos.). Mean number of tree species per hectare in large rooftop garden was 348 trees ha^{-1}, in medium rooftop garden it was 376 trees ha^{-1} and in small rooftop garden that was 403 trees ha^{-1}. The highest tree diversity value was found in Mohammadpur metro and that was 3.12 and the lowest value in Tejgaon 2.86 followed by Mirpur 3.01 and Gulshan 2.89.

In the three category of rooftop gardens, small area (1200-1700 ft^2) had the highest tree density mean value of 701.45±22.2 ranges from 481.21 to 839.36 and large area (> 2100 ft^2) had the lowest tree density mean value of 586.97±16.1 ranges from 419.37 to 743.03 where medium area (1701-2100 ft^2) had moderate tree density mean value of 616.86±26.6 ranges from 435.44 to 820.10.

The large rooftop gardens had the highest basal area (3.43 m^2 ha^{-1}) followed by medium (2.89 m^2 ha^{-1}) and small gardens (1.89 m^2 ha^{-1}). But in DBH large rooftop gardens had the highest mean value of 5.61 cm and small gardens had the lowest mean value of 4.38 cm where medium gardens had moderate mean DBH of 4.99 cm.

The large rooftop gardens had the highest carbon stock 3.071 Mg ha^{-1} (range from 1.65 Mg ha^{-1} to 4.66 Mg ha^{-1}) and the lowest carbon stock 1.867 Mg ha^{-1} was found in small rooftop gardens (range from 1.18 Mg ha^{-1} to 2.83 Mg ha^{-1}) where moderate carbon stock 2.678 Mg ha^{-1} was found in medium rooftop garden (range from 1.53 Mg ha^{-1} to 3.73 Mg ha^{-1}). Among the five major dominating species the highest amount of carbon was stored by Mango (20.37 Mg) followed by guava (16.84 Mg), jujube (13.84 Mg), Sapota (12.34 Mg) and Carambola (11.32 Mg).

CONCLUSION

The study was conducted at four metropolitan areas in Dhaka city. At the same time this study showed some differences among the areas in terms of plant stand characteristics (stand density, basal area, mean DBH), tree species diversity, various degree of relationships of stand characteristics with carbon stock.

On the basis of the result of the study it can be stated as:

1. A huge variations in species occurrence and tree diversity were found in the study area. Among the rooftop garden categories large gardens had the highest value of tree diversity (SWI) followed by medium and small.
2. The highest amount of tree carbon (3.071 Mg ha^{-1}) was found in large rooftop gardens and the lowest tree carbon (1.867 Mg ha^{-1}) was found in small rooftop gardens where medium area gardens had a moderate value of tree carbon (2.678 Mg ha^{-1}).
3. In the study a positive relationship between tree diversity and tree carbon was found where tree carbon increased per unit change in tree diversity.

In the study, it is showed that rooftop garden can act as Carbon sinks. The result of carbon stock estimation can be directed to researchers and administrators to analyze carbon credit and considered as a baseline for future investigations on carbon sequestration potential of rooftop gardens of Dhaka city.

RECOMMENDATIONS

The finding of present study revealed that rooftop gardens should be established in a small area with diverse tree species so that it appropriates substantial amount of carbon. Rooftop garden should be promoted to store carbon and it could be contributed to the global climate change. Considering the findings of the study the following recommendations can be drawn:

1. As the results are the first estimation done on trees that are still small and young there is the possibility of a change of pattern between rooftop gardens in the future. For future monitoring, destructive measurements are recommended in order to develop a local allometric model which will provide more accurate estimations.
2. Other factors might have influenced the climate change adaptation to the production system, which need to be identified through further study.
3. Similar to the present study, more and large scale research should be conducted in other districts of Bangladesh including large number of rooftop gardens, all categories of plant like palm, herbs, shrubs and other plant species under a varied climatic conditions.

CHAPTER VI

REFERENCES

Alvarez, E. ; Duque, A.; Saldarriaga, J.; Cabrera, K.; Salas, G.; Valle, I. ; Lema, A.; Moreno, F.; Orrego, S. and Rodríguez, L. (2012). Tree above-ground biomass allometries for carbon stocks estimation in the natural forests of Colombia. *Forest Eco. Manag.* **267**: 297–308.

Amin, M. A. (2019) "Dhaka remains the world's most densely populated city", Dhaka Tribune. Sep. 2019, 55th ISOCARP World Planning, Jakarta-Bogor, Indonesia.

Awal, M.A., Ohta, T., Matsumoto J., *et al.* (2010). Comparing the carbon sequestration capacity of temperate deciduous forests between urban and rural landscapes in central Japan. *Urban For. Urban Gree.* **9**(3): 261–270.

Baraloto, C.; Rabaud, S.; Molto, Q.; Blanc, L. and Fortunel, C. (2011). Disentangling stand and environmental correlates of aboveground biomass in Amazonian forests. *Global Change Biol.* **17**(8): 2677–2688.

BBS (2012). Population and Housing Census 2011 (Community Series)—Dhaka, Gazipur, Narayanganj; Bangladesh Bureau of Statistics: Dhaka, Bangladesh.

Bigsby, H. (2009). Carbon banking: Creating flexibility for forest owners. *Forest Eco. Manag.* **257**(1): 378–383.

Blujdea, V.N.B.; Pilli, R.; Dutca, I.; Ciuvat, L. and Abrudan, I.V. (2012). Allometric biomass equations for young broadleaved trees in plantations in Romania. *Forest Eco. Manag.* **264:** 172–184.

Brennan, W.J.; Schultz, P. A.; Glackin, M.M. and Slimak, M.W. (2007). The First State of the Carbon Cycle Report North American Carbon Budget and Implications for the Global Carbon Cycle. Climate Change Science Program. Nov. 2007. U.S.

Brown, J. H.; Gillooly, J. F.; Allen, A.P. and Savage, V. M. (2004). Toward a Metabolic Theory of Ecology. *Ecol.* **85** (7): 1771-1789.

Brenneisen, S. (2006). Space for urban wildlife: designing green roofs as habitats in Switzerland. *Urban habitats*. **4**(1): 27-36.

Carter, T. and C. Butler. 2008. Ecological impacts of replacing traditional roofs with green roofs in two urban areas. *Cities Environ.* **1**(2): 17.

Chave, J.; Richard, C.; Aguilar, S.; Hernandez, A.; Lao, S. and Perez, R. (2004). Error propagation and scaling for tropical forest biomass estimates. Philosophical transactions of the Royal Society of London. Series B, *Biol. Sci.* **359**(1443): 409–20.

Chiba, Y. (1998). Architectural analysis of relationship between biomass and basal area based on pipe model theory. *Ecol. Model.* **108**(1-3): 219–225.

Clark, B. and York, R. (2005). Carbon metabolism: Global capitalism, climate change and the biospheric rift. *Theory Soc.* **34**(4): 391–428.

David, S. W. (2010). Statistics Calculator, StatPac Inc. (1996-2010). https://www.statpac.com/statistics-calculator/Statistics-CalculatorGuide.pdf

Day, M., Baldauf, C., Rutishauser, E. and Sunderland, T. C. H. (2013). Relationships between tree species diversity and above ground biomass in central African rainforests: implication for REDD. *Environ. Conserve*. **41**(1): 64-72.

De Gier, A. (2003). A new approach to woody biomass assessment in woodlands and shrublands. In: P. Roy (Ed), Geoinformatics for Tropical Ecosystems, India. p. 161-198.

DNCC (2017). Dhaka North City Corporation at a Glance; Dhaka North City Council: Dhaka, Bangladesh.

Dwyer, J. F.; McPherson, E. G.; Schroeder, H. W. And Rowan, A. R. (1992) Assessing the benefits and costs of the urban forest. *J. Arbor.* **18**: 227-234.

Falkowski, P. (2000). The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System. *Sci.* **290**(5490): 291–296.

Fisher, R. A. (1958). Statistical Methods for Research Workers (Thirteenth edition), Section 21. Oliver and Boyd, Edinburgh, U.K. p. 356.

Gaines, W. L.; Harrod, J. R. and Lehmkuhl, J. F. (1999). "Monitoring biodiversity: quantification and interpretation," General Technical Report PNW-GTR-443, USDA Forest Service, Pacific North-West Research Station.

Getter, K. L., Rowe, D. B., Robertson, G. P., Cregg, B. M., and Andresen, J. A. (2009).Carbon sequestration potential of extensive green roofs. *Environ. Sci. Tech.* **43**(19): 7564–7570.

Gillis, K. and Birgitta, G. (2015). A Review of Psychological Literature on the Health and Wellbeing Benefits of Biophilic Design, Buildings. **5**(3): 948-63.

Hamm, M.W. and Bellows, A.C. (2003). Community food security and nutrition educators. *J. Nutri. Edu. Behvr.* **35**: 37-43.

Hobbs, S.E., Jensen, D.B., and Chapin, F.S. (1993). Resource Supply and Disturbance as Controls Over Present and Future Plant Diversity. In: Schulze E.D. and Mooney H.A. (Eds), Biodiversity and Ecosystem Function. Springer-Verlag, Berlin. pp. 385–408.

Hossain, M. M. (2009). Effects of Green Roof Concept on Residential Apartment Buildings in the Context of Dhaka City, unpublished March term paper under the supervision of Prof. Dr. Qazi A. Mowla (the author of this paper) of Bangladesh University of Engineering and Technology, Dhaka**.**

Hossain, T. (2014). Plant species diversity of roof top garden in Dhaka city. M.S. thesis. Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh.

Hui, D.C. (2011). Green roof urban farming for buildings in high-density urban cities. The Hainan China World Green Roof Conference, March 18-21, Hainan, China. pp. 1–9.

IPCC, (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley]. Cambridge University Press, Cambridge, United Kingdom and New York, USA. p.1535.

IPCC (2018). *Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland. p. 32.

Islam, K. M. S. (2004). Rooftop Gardening as a Strategy of Urban Agriculture for Food Security: The Case of Dhaka City, Bangladesh. Department of Public

Administration, University of Dhaka, Bangladesh. Proc. IC on Urban Horticulture Eds: R. Junge-Berberovic *et al*. *Acta. Hort*. 643, ISHS.

Islam, M. S., and Ahmed, R. (2011). Land Use Change Prediction in Dhaka City Using GIS Aided. Retrieved August 28, 2015. **6**: 81-89.

Islam, M.S. (2013). Estimation of Biomass Carbon Stock at Three Plantation Sites in Sher-E-Bangla Agricultural University Campus. M.S. thesis. Department of agroforestry and environmental science, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh.

Jaman, M. A. (2014). Carbon stock quantification and tree diversity assesment of homegardens in Rangpur district. M.S. thesis. Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh.

Ketterings, Q. M., Coe, R., van Noordwijk, M., Ambagau Y. and Palm, C. A. (2001). Reducing uncertaintyin the use of allometric biomass equations forpredicting aboveground tree biomass in mixedsecondary forests. *Forest Eco. Manag*. **146**: 199-209.

Köhler, M. and Poll, P.H. (2010). Long-term performance of selected old Berlin greenroofs in comparison to younger extensive greenroofs in Berlin. *Ecol. Eng*. **36**: 722–729.

Konijnendijk, C.C. and Randrup, T.B. (2004). Urban Forestry. In: Burley, J., Evans, J., Younquist, J.A. (Eds.), Encyclopedia of Forest Sciences. *Elsevier Sci.* London. pp. 471-478.

Kreft, S.; Eckstein, D. and Melchior, I. (2017). Global Climate Risk Index 2017. Who suffers most from extreme weather events? Weather-related loss events in 2015 and 1995 to 2015. https://germanwatch.org/en/download/16411.pdf

Lacroix, G. and Abbadie, L. (1998). Linking Biodiversity and Ecosystem Function: An Introduction. *Acta. Oecol.* **19**: 189–193.

Li, J.F., Wai, O., Li, Y.S. (2010). Effect of green roof on ambient CO_2 concentration, *Building and Environ.* **45**: 2644-2651.

Li, W. and Yeung, K. (2014). A comprehensive study of green roof performance from environmental perspective. *Inter. J. Sustain. Built Environ.* **3**: 127–134.

Li, Y.L. and Babcock, R.W. (2014). Green roofs against pollution and climate change a review, Agronomy for sustainable development. **34**(4): 695-705.

Liu, C. and Li, X. (2012). Carbon storage and sequestration by urban forests in Shenyang, China. *Urban For. Urban Gree.* **11**(2): 121-128.

Losi, C.J.; Siccama, T.G.; Condit, R. and Morales, J. E. (2003). Analysis of alternative methods for estimating carbon stock in young tropical plantations. *Forest Eco. Manag.* **184** (1-3): 355–368.

Luo, H., Liu, X., Anderson, B., Zhang, K., Li, X., Huang, B., Li, M., Mo, Y., Fan, L. and Shen, Q. (2015). Carbon sequestration potential of green roofs using mixed-sewage-sludge substrate in Chengdu World Modern Garden City. *Ecol. Indic*. **49**: 247–259.

Magurran, A. E. (1988). Introduction: measurement of (biological) diversity. Sample chapter one in Ecological diversity and its measurement. Princeton University Press, Princeton.

Maheng, D.; Ducton, I.; Lauwaet, D.; Zevenbergen, C. and Pathirana, A. (2019). "The Sensitivity of Urban Heat Island to Urban Greenspace: A Model-Based Study of City of Colombo, Sri Lanka", MDPI.

Malhi, Y.; Wood, D.; BAKER, T. R.; Wright, J.; Phillips, O. L.; Cochrane, T.; Meir, P. *et al.* (2006). The regional variation of aboveground live biomass in old-growth Amazonian forests. *Global Change Bio.* **12**(7): 1107–1138.

Manrique, S.; Franco, J. and Núñez, V. (2011). Potential of native forests for the mitigation of greenhouse gases in Salta, Argentina. *Biom. Bioen.* **35**(5): 2184–2193.

Mechelen, C.V.; Dutoit, T. and Hermy, M. (2014). Mediterranean Open Habitat Vegetation Offers Great Potantial for Extensive Green Roof Design. *Landsc. Urban Plan.* **121**: 81–91.

Meneewan, S.; Hirunlabh, J.; Khedari, J.; Zeghmati, B.; Teekasap, S. (2005). Heat Gain Reduction by Means of Thermoelectric Roof Solar Collector. *Solar Energy*. **78**: 495–503.

Molineux, C., Fentiman, C. and Gange, A. (2009). Characterising alternative recycled waste materials for use as green roof growing media in the U.K. *Ecol. Eng*. **35**: 1507–1513.

Mowla, Q. A. (1984). 'Energy Conservation in Buildings and Settlements', unpublished research monograph, Department of Planning and Architecture, University of Roorkee, India.

Mowla, Q. A. (2011). 'Crisis in the Built Environment of Dhaka: An Overview', in the Proceedings of the Conference on Engineering Research, Innovation and Education, CERIE 2011, 11-13 January, Sylhet, Bangladesh.

Murali, K. S., Bhat, D. M. and N. H. (2005). Ravindranath, Biomass estimation equation for tropical deciduous and evergreen forests. *Inter. J. Agricul. Resour. Govern. Ecol.* **4**: 81–92.

Murtala, D.; Manaf, L.A.; Ramli, M.F.; Yacob, M.R. and Makmom, A.A. (2019). Quantifying the Aboveground Biomass and Carbon Storage of Urban Tree Species in Sokoto Metropolis, North-Western Nigeria. *J. Malaysian Inst. Planners.* **17** (2): 179 – 190.

NAS – United States National Academy of Sciences (2008). Understanding and responding to climate change. http://americasclimatechoices.org/climate_change_2008_final.pdf.

Návar, J. (2009). Allometric equations for tree species and carbon stocks for forests of northwestern Mexico. *Forest Eco. Manag.* **257** (2): 427-434.

Nowak, D. J. and Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. *Environ. Pollution*. **116**: 381-389.

Nowak, D. J., Stevens, J. C., Sisinni, S. M., & Luley, C. J. (2002). Effects of urban tree management and species selection on atmospheric carbon dioxide. *J. Arbor.* **28**(3): 113–122.

Okvat, H. A., & Zautra, A. J. (2011). Community gardening: A parsimonious path to individual, community, and environmental resilience. *American J. Community Psychol.* **47**: 374–387.

Orsini, F., Daniela, G., Livia, M., Chiara, P., Stefano, D., Solange, R., Giovanni, B. and Giorgio, G. (2014). Exploring the production capacity of rooftop gardens (RTGs) in urban agriculture: the potential impact on food and nutrition security, biodiversity and other ecosystem services in the city of Bologna. A Case Study. *Food Sec.* **6** (6): 781-792.

Pajtík, J., Konôpka, B. & Lukac, M. (2008). Biomass functions and expansion factors in young Norway spruce (Picea abies [L.] Karst) trees. *Forest Eco. Manag.* **256**(5): 1096–1103.

Parvin, N. S. and Abudu, D. (2017), “Estimating Urban Heat Island Intensity using Remote Sensing Technique”. *Inter. J. Scif. Eng. Res.* **8** (4): 289-298.

Peck, S. & Chris, C. (1999). Forging a new industry in canada: Status Report on Benefits, Barriers and Opportunities for Green Roof and Vertical Garden Technology Diffusion. Retrieved form. Environmental Adaptation Research Group, Canada.

Peichl, M. & Arain, M.A. (2007). Allometry and partitioning of above- and belowground tree biomass in an age-sequence of white pine forests. *Forest Eco. Manag.* **253**(1-3): 68–80.

Peñafiel, R. S. (2014). Aboveground carbon stock estimation of young reforested areas in Northern Ecuador. M.S. thesis, Ghent University, Belgium.

Phillips, O.; Baker, T.; Feldpausch, T. and Brienen, R. (2009). Field manual for plot establishment and remeasurement. Pp. 2-22.

Preece, N.D. *et al.* (2012). Comparing above-ground biomass among forest types in the Wet Tropics: Small stems and plantation types matter in carbon accounting. *Forest Eco. Manag.* **264**: 228–237.

RAJUK (2015) “Draft Dhaka Structure Plan 2016-2035”, RAJUK.

Rashid, R., Ahmed, M.H.B. and Khan, M.S. (2010). Green roof and its Impact on Urban Environmental sustainability: The Case in Bangladesh. *World J. Manag.* **2**: pp. 59-69.

Rowe, D. (2011). Green roofs as a means of pollution abatement. *Environ. Poll.* **159**: 2100–2110.

Sajjaduzzaman, M., Koike, M. and Muhammed, N. (2005). An Analytical Study on Cultural and Financial Aspects of Roof Gardening in Dhaka Metropolitan City of Bangladesh. *Inter. J. Agric. Bio.* **2** (7): 184–187.

Sanchez, P.A. (1995). Science in agroforestry. *Agrofor. Sys.* **30**: 5–55.

Schimel, D.S.; House, I.J.; Hibbard, K.A.; Bousquet, P. and Ciais, P. (2001). Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. *Nature*. **414**(6860): 169–72.

Science for Environment Policy (2015). March 26. Rooftop gardens could grow three quarters of city’s vegetables. Retrieved February 9, 2016, Sailor, D.J. 2008. A green roof model for building energy simulation programs, *Energ. Build.* **40**: 1466-1478.

Sierra, C. a.; Valle, J.I.D.; Orrego, S. and Moreno, F. (2007). Total carbon stocks in a tropical forest landscape of the Porce region, Colombia. *Forest Eco. Manag.* **243**(2-3): 299–309.

Smit, J., Nasr, J., and Ratta, A. (2001). Urban agriculture: Food, jobs and sustainable cities New York: The Urban Agriculture Network, Inc. Sprouting Good Urban Farming Sydney (2014). January 23. Retrieved February 8, 2016. Portable rooftop farm education center.

Sutton, R. (2015). Introduction to green roof ecosystems, in: Sutton, R. (Ed.), Green roof ecosystems. Springer International Publishing, *Cham.* pp. 1–25.

Thuring, C. and Dunnett, N. (2014). Vegetation composition of old extensive green roofs (from 1980s Germany). *Ecol. Pro.* **3** (4): 1-11.

Uddin, M. J., Khondaker, N.A., Das, A.K., Hossain, M. E., Chakma, A. S., Nabila, N.A., Saikat, M. I. and Chowdhury, A.A. (2016). Baseline Study on Roof Top Gardening in Dhaka and Chittagong City of Bangladesh. A final technical report under the project of "Enhancing Urban Horticulture Production to Improve Food and Nutrition Security" funded by Food and Agriculture Organization of the United Nations. FAO Representation in Bangladesh. Road#8, House#37, Dhanmondi R/A, Dhaka 1205, Bangladesh

UN (2016). The World's Cities in 2016.World Urbanization Prospects: Data Booklet (ST/ESA/SER.A/392); United Nations: New York, USA.

UNFCCC, (2007). Climate Change: Impact, Vulnerabilities and adaptation in developing countries, Climate change Secretariat (UNFCCC), Martin Luthar King- strasse, 8, 53175 Bonn, Germany.

United Nations (2014). World Urbanization Prospects: The 2014 Revision. Retrieved from esaun. http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf⟩.

United Nations (2014). World urbanization prospects: The 2014 revision. Department of Economic and Social Affairs, Population Division, New York.

Usuga, J.C.L.; Toro, J.A.R.; Alzate, M.V.R. and Tapias, A.J.L. (2010). Estimation of biomass and carbon stocks in plants, soil and forest floor in different tropical forests. *Forest Eco. Manag.* **260**(10): 1906–1913.

Van Breugel, M.; Ransijn, J. and Craven, D. (2011). Estimating carbon stock in secondary forests: Decisions and uncertainties associated with allometric biomass models. *Forest Eco. Manag.* **262**(8): 1648–1657.

Ward Thompson. C. (2007). “Playful nature: What makes the difference between some people going outside and others not? In: Ward Thompson, C. & Travlou, P. Open Space People Space (Ed.). London: Taylor and Francis.

White, E. and Gatersleben, B. (2011). Greenery on residential buildings: Does it affect preferences and perceptions of beauty? *J. Environ. Psychol*. **31**: 89–98.

Whittinghill, L. and Rowe, D. (2012). The role of green roof technology in urban agriculture. Renew. *Agric. Food Syst.* **27**: 314–322.

Whittinghilla, L. J.; Roweb, D. B.; Schutzkic, R. and Creggd B. M. (2013). Quantifying carbon sequestration of various green roof and ornamental landscape systems. *Landscape Urban Plan.* **123**: 41– 48.

WRI (2017) http://cait2.wri.org/

Yang, J., McBride, J., Zhou, J., *et al.* (2005). The urban forest in Beijing and its role in air pollution reduction. *Urban For. Urban Gree.* **3**: 65–78.

Yang, J., Yu, Q. and Gong, P. (2008). Quantifying air pollution removal by green roofs in Chicago. *Atmos. Environ.* **42**(31): 7266-7273.

Zhao M., Kong Z.H., Escobedo E.J. *et al.*, (2010). Impacts of urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China. *J. Environ. Manag.* **91**(4): 807-813.

APPENDICES

Appendix I: English version of the interview schedule

Department Of Agroforestry and Environmental Science

Sher-e-Bangla Agricultural University, Dhaka- 1207

On

"TREE SPECIES DIVERSITY AND QUANTIFICATION OF ABOVE GROUND CARBON STORAGE OF ROOFTOP GARDEN AT DHAKA CITY"

Serial No. ________

Name of the Survey Collector:__________________________________

Name of the respondent:____

Address: House no#________Road no#_______Flat No. (if any):________,

Ward no.:_______

Location:____

Please answer the following questions (Use √ mark in multiple choice questions and write in the blank space when necessary)

1. Age

How old are you? ________ years.

2. Education: (a) Illiterate (b) Primary (c) Secondary (d) Higher Secondary (e) Graduate (f) Post-graduate (g) PhD

3. Family Size (number of person/family):

Male_________Female_________Total____________

4. Main Occupation: (a) Govt. service (b) Private service (c) Business (d) Agriculture (e) Others:____

5. Give information about your annual income:

Sources of income	Amount of annual income (Taka)
1. Service holder	
2. Business	
3. Others	

6. Total space of roof top (In sq. feet):________________

7. What kind of tree species would you have in your roof garden?

SL. No.	Local Name	Plant Number	Habit	Scientific name
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				

Thank You So Much for Your Nice Cooperation

Signature:____________________ Date:_______________________

APPENDIX II: Number of trees per specie and per rooftop garden category. N/A= No information available, it means that the specie were not found at that category.

Sl no.	Tree Species	Rooftop garden categories		
		Small	Medium	Large
1	*Mangifera indica*	31	25	35
2	*Zizyphus mauritiana*	28	20	30
3	*Psidium guajava*	25	19	27
4	*Achros sapota*	24	15	21
5	*Citrus aurantifolia*	20	16	21
6	*Averrhoa carambola*	18	15	21
7	*Phyllanthus embelica*	14	17	21
8	*Carissa carandas*	11	16	20
9	*Averrhoa bilimbi*	7	14	20
10	*Citrus reticulata*	9	14	18
11	*Citrus sinensis*	N/A	13	20
12	*Feronia limonia*	N/A	10	19
13	*Annona reticulata*	5	9	14
14	*Citrus grandis*	1	9	15
15	*Spondias pinnata*	N/A	9	15
16	*Syzygium samarangense*	1	7	13
17	*phyllanthus acidus*	1	7	12
18	*Elaeocarpus floribundus*	N/A	6	11
19	*Azadirachta indica*	2	5	8
20	*Jasminum angustifolium*	N/A	3	9
21	*Moringa oleifera*	2	4	6
22	*Nephelium lappaceum*	N/A	2	8
23	*Mimosops elengi*	N/A	3	7
24	*Casuarina equisetifolia*	N/A	2	6
25	*Piper cubeba*	N/A	2	6
26	*Musanda sp.*	N/A	1	4
27	*Chrysophyllum cainito*	N/A	2	3
28	*Lawsonia inermis*	N/A	1	2
29	*Syzygium jambos*	N/A	N/A	2
30	*Araucaria excelsa*	N/A	N/A	2
31	*Cinnamomum tamala*	N/A	N/A	1
32	*Piper longum*	N/A	1	N/A

APPENDIX III: Number of trees per specie and per metro. N/A= No information available, it means that the specie were not found at that metro.

Sl no.	Tree Species	Metro area			
		Mirpur	Mohammadpur	Gulshan	Tejgaon
1	*Mangifera indica*	28	31	14	18
2	*Zizyphus mauritiana*	23	21	11	16
3	*Psidium guajava*	17	17	8	16
4	*Achros sapota*	15	15	10	14
5	*Citrus aurantifolia*	14	17	8	13
6	*Averrhoa carambola*	10	15	5	11
7	*Phyllanthus embelica*	7	12	8	6
8	*Carissa carandas*	4	5	3	4
9	*Averrhoa bilimbi*	18	19	11	16
10	*Citrus reticulata*	7	15	9	10
11	*Citrus sinensis*	8	10	3	7
12	*Feronia limonia*	10	15	8	14
13	*Annona reticulata*	3	5	2	N/A
14	*Citrus grandis*	9	8	2	5
15	*Spondias pinnata*	22	27	11	18
16	*Syzygium samarangense*	7	9	1	8
17	*phyllanthus acidus*	3	7	4	6
18	*Elaeocarpus floribundus*	10	13	3	3
19	*Azadirachta indica*	2	4	4	1
20	*Jasminum angustifolium*	1	2	N/A	2
21	*Moringa oleifera*	N/A	6	4	N/A
22	*Nephelium lappaceum*	4	7	N/A	1
23	*Mimosops elengi*	N/A	2	1	N/A
24	*Casuarina equisetifolia*	N/A	6	2	1
25	*Piper cubeba*	3	5	4	3
26	*Musanda sp.*	2	4	2	N/A
27	*Chrysophyllum cainito*	N/A	1	N/A	N/A
28	*Lawsonia inermis*	N/A	1	N/A	N/A
29	*Syzygium jambos*	3	17	5	1
30	*Araucaria excelsa*	N/A	N/A	N/A	N/A
31	*Cinnamomum tamala*	N/A	N/A	N/A	N/A
32	*Piper longum*	N/A	N/A	N/A	N/A

APPENDIX IV: Tree diversity in 63 rooftop gardens at Dhaka city.

R.T.G. no.	R.T.G Categories	Tree diversity	Mean	Standard deviation
1	Small Area	2.20	2.32	0.40
2	Small Area	1.71		
3	Small Area	2.69		
4	Small Area	2.18		
5	Small Area	1.95		
6	Small Area	3.13		
7	Small Area	2.42		
8	Small Area	2.25		
9	Small Area	2.14		
10	Small Area	1.45		
11	Small Area	2.03		
12	Small Area	2.64		
13	Small Area	2.64		
14	Small Area	2.45		
15	Small Area	2.23		
16	Small Area	2.29		
17	Small Area	2.43		
18	Small Area	2.47		
19	Small Area	2.63		
20	Small Area	2.48		
21	Small Area	1.56		
22	Small Area	2.63		
23	Small Area	1.98		
24	Small Area	2.95		
25	Small Area	2.46		
26	Medium Area	3.05	2.78	0.34
27	Medium Area	3.28		
28	Medium Area	2.47		
29	Medium Area	2.98		
30	Medium Area	2.52		
31	Medium Area	2.97		
32	Medium Area	2.45		
33	Medium Area	2.65		
34	Medium Area	3.09		
35	Medium Area	3.15		
36	Medium Area	2.86		
37	Medium Area	3.17		
38	Medium Area	2.22		
39	Medium Area	2.27		
40	Medium Area	3.15		
41	Medium Area	2.64		

R.T.G. no.	R.T.G Categories	Tree diversity	Mean	Standard deviation
42	Medium Area	2.43		
43	Medium Area	3.05		
44	Large Area	3.05	3.26	0.32
45	Large Area	3.48		
46	Large Area	3.19		
47	Large Area	2.95		
48	Large Area	3.26		
49	Large Area	3.75		
50	Large Area	3.27		
51	Large Area	3.16		
52	Large Area	3.79		
53	Large Area	3.24		
54	Large Area	3.22		
55	Large Area	3.13		
56	Large Area	2.90		
57	Large Area	3.15		
58	Large Area	3.65		
59	Large Area	3.16		
60	Large Area	3.68		
61	Large Area	3.48		
62	Large Area	2.75		
63	Large Area	2.68		

APPENDIX V: Stand density, Basal area and Mean DBH of 63 rooftop gardens at Dhaka city.

R.T.G. no.	R.T.G Categories	Stand Density (trees per ha)	Basal area ($m^2\ ha^{-1}$)	Mean DBH (cm)
1	Small Area	617.35	1.6	4.32
2	Small Area	558.13	1.65	3.48
3	Small Area	816.57	1.46	4.12
4	Small Area	742.34	1.87	5.03
5	Small Area	614.10	2.23	3.76
6	Small Area	833.34	1.64	4.84
7	Small Area	693.87	1.65	3.84
8	Small Area	839.89	2.46	5.15
9	Small Area	664.81	1.54	3.74
10	Small Area	735.41	2.34	4.53
11	Small Area	543.62	2.04	4.23
12	Small Area	833.34	1.68	3.73
13	Small Area	807.29	1.63	3.93
14	Small Area	640.43	1.85	4.73
15	Small Area	481.75	2.21	5.72
16	Small Area	725.74	1.85	4.25
17	Small Area	835.02	1.84	4.82
18	Small Area	712.46	1.54	3.39
19	Small Area	825.75	2.24	5.41
20	Small Area	594.21	1.74	4.21
21	Small Area	754.59	1.53	4.62
22	Small Area	513.65	2.47	5.82
23	Small Area	793.84	1.99	4.64
24	Small Area	747.35	1.74	3.73
25	Small Area	611.37	2.39	3.44
26	Medium Area	617.64	1.63	3.32
27	Medium Area	656.36	1.72	4.52
28	Medium Area	820.11	2.15	5.25
29	Medium Area	684.57	3.23	6.83
30	Medium Area	663.82	2.53	4.85
31	Medium Area	671.36	3.95	6.05
32	Medium Area	474.57	3.26	5.73
33	Medium Area	585.37	2.25	4.82
34	Medium Area	435.45	3.86	5.93
35	Medium Area	668.78	3.58	6.12
36	Medium Area	646.34	3.96	4.42
37	Medium Area	768.85	2.59	4.49
38	Medium Area	517.82	3.63	5.92
39	Medium Area	710.05	2.74	5.43
40	Medium Area	615.08	2.54	3.71

R.T.G. no.	**R.T.G Categories**	**Stand Density (trees per ha)**	**Basal area (m^2 ha^{-1})**	**Mean DBH (cm)**
41	Medium Area	448.74	2.85	4.27
42	Medium Area	501.73	2.69	3.27
43	Medium Area	587.12	3.93	3.82
44	Large Area	532.21	3.35	4.84
45	Large Area	587.12	3.38	5.35
46	Large Area	615.00	4.48	7.36
47	Large Area	419.37	3.15	6.04
48	Large Area	546.27	3.63	6.37
49	Large Area	643.04	3.86	4.82
50	Large Area	584.84	3.54	5.66
51	Large Area	573.86	2.92	6.35
52	Large Area	643.04	2.64	5.84
53	Large Area	565.74	3.47	6.34
54	Large Area	615.08	3.95	4.83
55	Large Area	503.25	2.36	3.89
56	Large Area	731.95	4.03	6.83
57	Large Area	540.74	4.64	6.34
58	Large Area	523.04	4.54	7.25
59	Large Area	559.16	2.84	5.7
60	Large Area	743.04	2.94	4.73
61	Large Area	587.12	3.68	6.11
62	Large Area	666.37	2.87	5.93
63	Large Area	559.16	1.83	3.33

APPENDIX VI: Above ground carbon (AGC) stock in 63 rooftop gardens at Dhaka city.

R.T.G. no.	R.T.G Categories	AGC (Mg/ha)	Mean	Standard deviation
1	Small Area	1.24	1.87	0.49
2	Small Area	1.32		
3	Small Area	1.18		
4	Small Area	2.15		
5	Small Area	2.83		
6	Small Area	1.58		
7	Small Area	1.37		
8	Small Area	2.53		
9	Small Area	1.38		
10	Small Area	2.36		
11	Small Area	2.13		
12	Small Area	1.58		
13	Small Area	1.62		
14	Small Area	1.77		
15	Small Area	2.17		
16	Small Area	1.94		
17	Small Area	1.84		
18	Small Area	1.38		
19	Small Area	2.38		
20	Small Area	1.53		
21	Small Area	1.38		
22	Small Area	2.74		
23	Small Area	2.13		
24	Small Area	1.73		
25	Small Area	2.41		
26	Medium Area	1.53	2.68	0.67
27	Medium Area	1.57		
28	Medium Area	2.12		
29	Medium Area	3.02		
30	Medium Area	2.63		
31	Medium Area	3.73		
32	Medium Area	3.15		
33	Medium Area	2.24		
34	Medium Area	3.71		
35	Medium Area	3.47		
36	Medium Area	2.96		
37	Medium Area	2.53		
38	Medium Area	3.28		
39	Medium Area	2.64		
40	Medium Area	2.13		

R.T.G. no.	R.T.G Categories	AGC (Mg/ha)	Mean	Standard deviation
41	Medium Area	2.63		
42	Medium Area	2.17		
43	Medium Area	3.62		
44	Large Area	2.64	3.07	0.77
45	Large Area	3.25		
46	Large Area	4.17		
47	Large Area	2.64		
48	Large Area	3.56		
49	Large Area	3.82		
50	Large Area	3.00		
51	Large Area	2.73		
52	Large Area	2.63		
53	Large Area	3.15		
54	Large Area	3.26		
55	Large Area	2.16		
56	Large Area	3.25		
57	Large Area	4.26		
58	Large Area	4.66		
59	Large Area	2.45		
60	Large Area	2.13		
61	Large Area	3.25		
62	Large Area	2.16		
63	Large Area	1.65		